United States
Environmental Protection
Agency

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

EPA-454/R-95-010
January 1994

Air

EPA

SURFACE COAL MINE EMISSION FACTOR FIELD STUDY

Office of Air Quality
Clean Air
OAQPS
Planning and Standards

EPA-454/R-95-010

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Emission Factor And Inventory Group
Emissions, Monitoring, And Analysis Division
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FOREWORD

Section 234 of the Clean Air Act was included in the Amendments signed into law on November 15,1990. A partial citation of this requirement is as follows:

> **"the Administrator shall analyze the accuracy of such model and emission factors and make revisions as may be necessary to eliminate any significant over-prediction of air quality effect of fugitive particulate emissions from such sources."**

The group responsible for emission factors (methods) and requirements of Section 234 is the Emissions, Monitoring and Analysis Division with the Office of Air Quality Planning and Standards. Upon passage this organization initiated steps to reexamine the available data base, evaluate the emission and dispersion (diffusion and deposition simulation) models most vulnerable to possible biases and tendencies to over-estimate emissions and their impacts upon air quality. This report and related reports described herein, focuses on the emission factors and estimation models. Separate reports focus on the dispersion modeling aspects of this effort.

Emission estimation for the simple processes is an approximate science, at best. There are frequently significant variabilities due to the complex nature of the processes modeled. Although emissions of "dust" from a mining operation might be viewed at first observation as basic and fundamental, this is in reality far from the case. To develop an emission estimation model, you must examine and analyze each physical force and phenomenon which affects emissions. In mining operations, these variables may include the physical characteristics of the soil and surfaces, meteorological conditions, size, weight, load, number of tires and speed of moving vehicles and so on. What at casual glance might appear to be a simple process, is in fact, very complex and sensitive to many uncertainties.

The first steps taken in preparation for responding to Section 234 were to review the existing emissions models and data bases, explore the availability of resources from private and government sources, determine the extent of a cooperative spirit within the affected industry toward needed studies, and design studies to address potential weaknesses in a prioritized manner. References 2 through 4 describe the steps and results of these review and design efforts. Also, several meetings were held with representatives of the Wyoming mining industry, the Wyoming State agency (Wyoming is the area most affected by Section 234) and the Environmental Protection Agency Regional Office. Both industry and State representation were very helpful and forthcoming with input, comments, and often with on-site support during the conduct of the efforts described in this report.

The net result of these efforts conducted on emission estimation modeling tend to be in general agreement with previous work, though resulting net emission estimates for a typical mine will tend to be a little lower. However, many uncertainties and questions remain. A fully implemented plan to study the variables to the full satisfaction of concerns would likely cost a minimum, of 5 to 10 times the resources that were available for the efforts reported here. Even with substantial additional funding, a high level of uncertainty would remain due to limitations of estimation technology and inherent variabilities in a physical process such as this.

Related to the numerical values of emission factors are assumptions that must be made to use them. These assumptions involve the intertwining of numerous technical, policy and regulatory issues. These studies have served to sensitize the regulators and regulated communities to these relationships and to ignite a renewed spirit of common sense implementation of these programs. Additional efforts are underway to further refine the emission factors presented here for incorporation into AP-42.

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ACKNOWLEDGEMENT

This test report was prepared by Midwest Research Institute (MRI) under contract No. 68-D2-0159. Midwest Research Institute acknowledges the Cordero Mining Co. for its cooperation in providing access to the study site.

Mr. Dennis Shipman was the U. S. EPA work assignment manager for the project.

SECTION 1

INTRODUCTION

This report describes a study of airborne particulate matter released from the activities conducted at open pit coal mines in the western United States. The study focuses on one facility in Wyoming and provides information to evaluate emission factors of relevance to new air quality programs nationwide. This program is a direct result of the Clean Air Act Amendments (CAAA) of 1990 which require examination of how the ambient air quality near mines is projected.

At present, ambient particulate matter (PM) impacts from surface coal mining operations are assessed in the following ways:

1. The mine's operating plan is reviewed to identify major PM emission sources, such as blasting, overburden removal, haul trucks, etc. The plan is also reviewed to determine source activity rates—such as tons of coal mined or tons of overburden removed per year—over the effective life of the mine.

2. An emission factor (mass emitted per unit source activity) is proposed for each major source. Factors for surface coal mines are usually selected from Section 8.24 of AP-42[1] or from a list used by a state agency, such as that prepared by the Wyoming Department of Environmental Quality (WDEQ).

3. Values from items 1 and 2 above are combined to estimate annual and worst-case-day PM emission rates from the mine.

4. Dispersion models (such as the Industrial Source Complex [ISC] model) are then used to simulate the atmospheric transport of the estimated emissions. Resulting ambient air concentration estimates are compared against National Ambient Air Quality Standards (NAAQSs) or Prevention of Significant Deterioration (PSD) increments.

The principal pollutant of interest is particulate matter (PM), with special emphasis placed on PM-10—particulate matter no greater than 10 μmA (microns in aerodynamic diameter). PM-10 is the basis for the current NAAQSs and thus represents the size range of the greatest regulatory interest. Nevertheless, formal

establishment of PM-10 as the standard basis is relatively recent, and almost all historical surface coal mine field measurements reflect a particulate size 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.

The field study described in this report was undertaken to address certain issues identified in the CAAA of 1990 relative to potential overestimation of the air quality impacts of western surface coal mining. Specifically, the principal objective of this study was to compare field measurements against available emission factors for surface coal mines and to revise the factors as necessary.

This report presents the results from one phase of a field program undertaken in response to Section 234 of the CAAA. As part of the overall planning process, however, several other studies have already been completed.

An initial study[2] thoroughly reviewed emission factors either currently used for or potentially applicable to inventorying particulate matter emissions at surface coal mines. A companion report[3] describing emission factors available for coal processing operations, was also prepared. For each anthropogenic emission source, an emission factor was suggested. Overall, the recommendations followed the guidelines presented in Section 8.24 of AP-42; the most notable exception applied to 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.

The report concluded that additional source testing was necessary to address major shortcoming in the data base:

- 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. 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 presents a limitation on the use of the surface coal mining factors in both eastern and western mines.

- Because most surface coal mining 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 based on size data presented for the generic emission factors presented in Section 11.2.

A second planning program[3] recommended an "integrated" approach to field measurements in response to Section 234. In general terms, the recommended approach combined extensive long-term air quality and meteorological monitoring with intensive short-term, source-directed testing. The long-term data collection is necessary to answer the following questions:

- Does the current emission factor/dispersion modeling methodology result in systematic overprediction of air concentrations?
- If so, what is the degree of overprediction?
- How well do dispersion model results match measurements in time and space?

No matter how sophisticated, long-term monitoring of ambient "far-field" concentrations alone cannot answer questions such as the following:

- What portion or portions of the methodology are most responsible for overprediction?
- Can the identified portions be modified so that systematic overprediction is effectively removed?
- What fraction of material emitted at the bottom of the pit eventually escapes?

To answer these types of questions, the plan recommended that the long-term ambient program be supplemented with the intensive short-term source/ambient monitoring. Quantitative examination of separate steps in the emission factor/ dispersion model methodology is necessary to answer the "how" and"why" questions. Furthermore, the particulate tracer studies would provide a quantitative basis for development of a pit retention algorithm.

As a practical matter, it became necessary to revise the integrated approach. Under the revised approach,[4] most source-directed measurements would be conducted first, with full-scale long-term ambient monitoring taking place in the year following.

This report describes the first phase of the field measurements, and the results obtained. Testing occurred during the fall of 1992 at the Cordero Mine in Wyoming's Powder River Basin. Also presented are details of the sampling methods, data analysis, and quality assurance procedures followed in the study. The report compares test results with the historical data base to assess how well currently available emission factors perform. In addition, results from special studies conducted to support the later full-scale ambient monitoring program are summarized.

SECTION 2

AIR SAMPLING METHODOLOGY

This study was primarily directed toward characterizing particulate emissions from "line" sources (e.g., haul roads, scrapers, etc.) at surface mining sites. The original review[2] of emission factors placed the highest priorities on obtaining new field data for haul truck traffic.

Six test sites were identified at the Cordero mine. Figure 1 presents a recent aerial photograph of the Cordero mine and indicates the location of the following test sites:

Site	Description
1	North-south portion of permanent coal haul road from north pit.
1B	Northwest-southeast portion of permanent haul road from north pit. At same grade as site 1 but approximately 800 ft from start of ramp down to coal load-out area.
2	Southwest-northeast portion of permanent coal haul road from south pit.
3	North-south portion of permanent coal haul road from south pit.
4	Overburden haul route at east end of north pit area.
5	North-south scraper route between topsoil removal and stockpile area at west end of north pit.

Testing did not occur at site 3, however, as the coincidence of westerly winds and haul road traffic from the south pit was infrequent while MRI crew members were on-site.

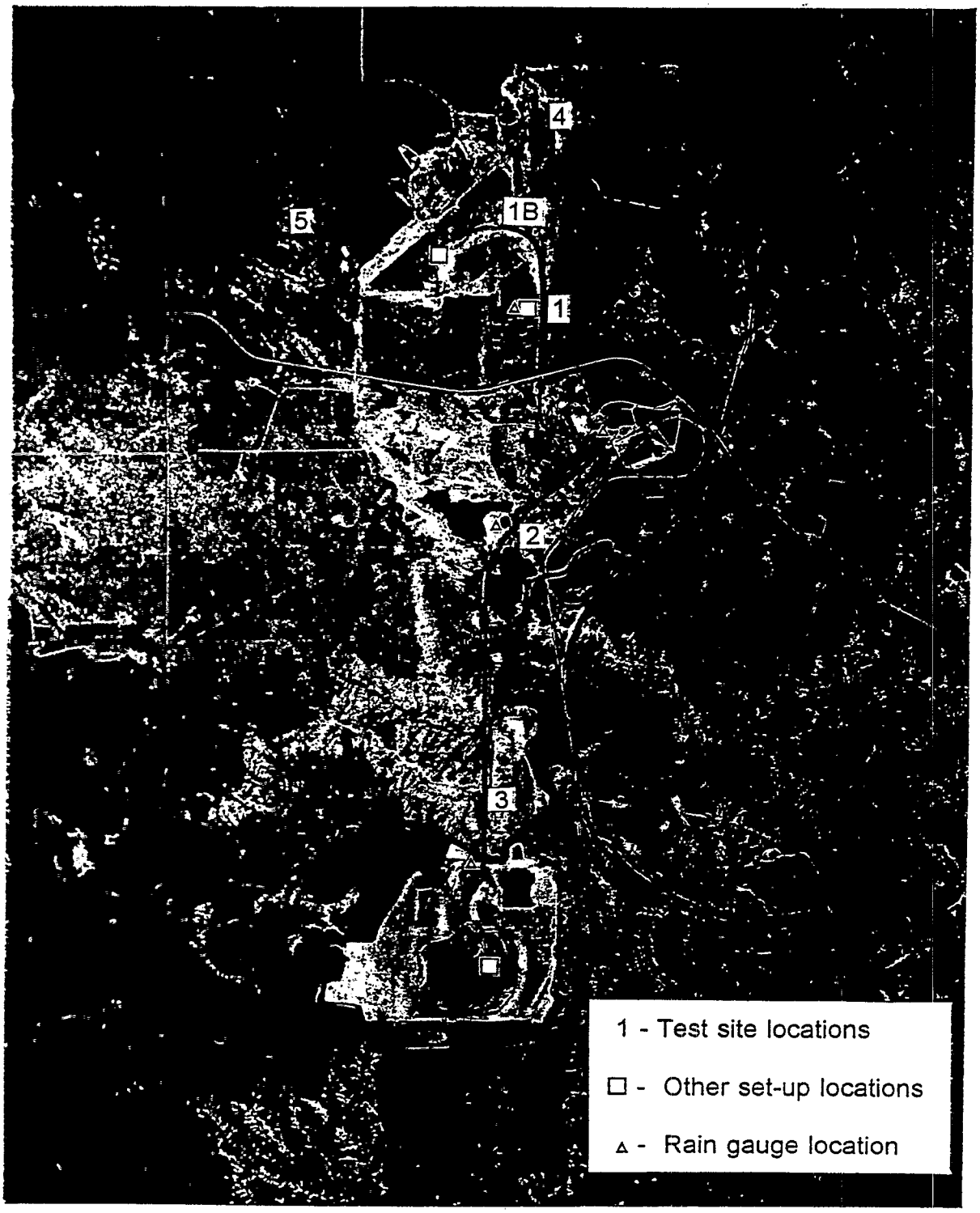


Figure 1. Location of test sites.

2.1 GENERAL AIR SAMPLING EQUIPMENT AND TECHNIQUES

The exposure profiling technique used for the tests in this study is based on the isokinetic profiling concept that is used in conventional source testing. The passage of airborne pollutant immediately downwind of the source was measured directly by means of simultaneous multipoint sampling over the effective cross section of the open dust source plume. This technique used 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.

The equipment deployment for a typical test is shown in Figure 2 and Table 1. (Slightly variant deployment schemes were used when testing took place in less accessible locations such as "Site 5" in Figure 1.) The primary air sampling device in this study was a high-volume (hi-vol) air sampler fitted with a cyclone preseparator (Figure 3). The cyclone exhibits an effective 50% cutoff diameter (D_{50}) of approximately 10 µmA when operated at a nominal flow rate of 40 acfm (68 m^3/h).[5]

Besides the samplers fitted with the cyclone preseparator to sample PM-10 emissions, two other types of samplers were used in the upwind (background) and downwind arrays. Standard hi-vols were placed at two heights near one of the downwind arrays to sample TSP emissions. Those measurements provide a valuable link to past surface coal mine emission factor studies, in that all of those studies focused on TSP as the basis of the former PM NAAQS. Volumetric flow controllers kept the flow rates of each cyclone and the 3-m hi-vol at a nominal value of 40 acfm; the flow rate of the 1-m hi-vol was maintained at 40 scfm by means of a variac. PM-10 reference method samplers (Wedding and Associates' PM-10 Critical Flow High-Volume Samplers) were also used, with one located alongside the upwind array and another next to a downwind array.

Throughout each test, wind speed was monitored at the downwind sampling site by directional warm-wire anemometers (Kurz Model 465) at up to three heights. (In a few cases, equipment malfunction required use of a backup wind speed system consisting of manual records of Biram vane anemometer readings.) Horizontal wind direction was monitored by a wind vane at a single height. Wind speed and direction were scanned using a Fluke HYDRA data logger, and 5-min averages were stored on a computer file. The vertical profile of horizontal wind speed was determined by fitting the measurements to a logarithmic profile.

Because of the importance of incoming solar radiation on the control performance of watering of unpaved travel surfaces, a mechanical pyranograph (Weathertronics Model 3010) was deployed in the immediate vicinity of watered travel surfaces. This device provided a continuous record of the intensity of direct and scattered solar radiation during the test period. Four rain gauges were also positioned throughout the mine; their locations are shown in Figure 1.

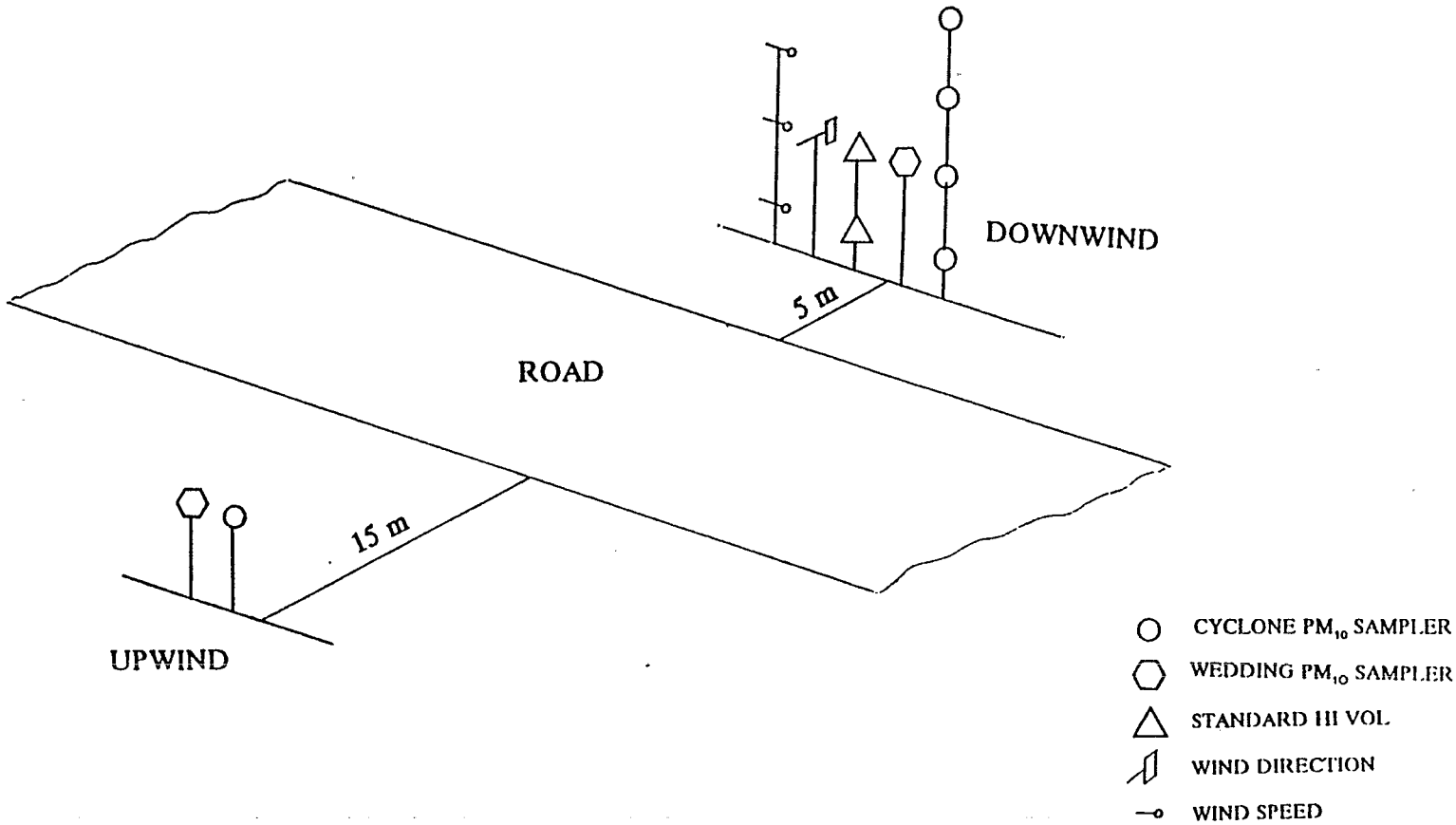


Figure 2. Upwind and downwind sampling arrays.

TABLE 1. SAMPLER DEPLOYMENT

Upwind/ downwind	No. of instruments	Measurement height(s) (m)	Type of sampler or instrument	Parameter measured
U	1	1.9	Cyclone	PM-10
U	1	1.9	Wedding PM-10 Sampler	PM-10
D (one to three arrays)	4 per array	1, 3, 5, 7	Cyclone	PM-10
D	2	1, 3	Hi-Vol	TSP
D	1	3	Wedding PM-10 Sampler	PM-10
D	1	3	Wind vane	Wind direction
D	3	1, 3, 5	Warm wire anemometer	Wind velocity

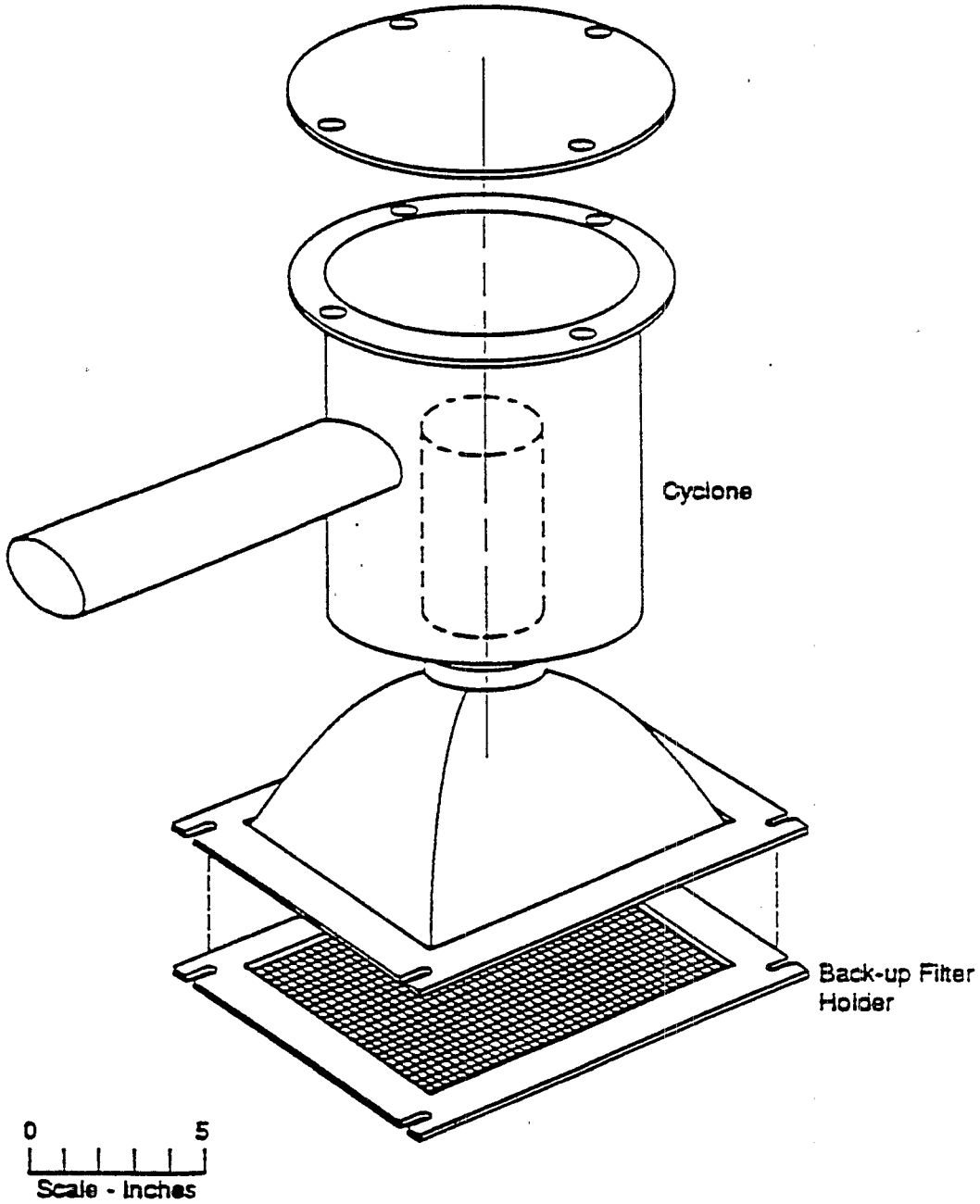


Figure 3. Cyclone preseparator.

In addition to the general emission testing program, a number of additional studies were conducted as part of the overall field sampling effort. One study, requested by the Source Receptor Branch (SRB) of the Office of Air Quality Planning and Standards (OAQPS), measured near-source particle size distributions. SRB requested that data be collected to support the development of a new deposition algorithm. The combination of a cyclone preseparator and a cascade impactor (C/CI) (Figure 4) provides a means to isokinetically collect and aerodynamically size total particulate (TP). Each sizing test deployed C/CI combinations at 1- and 3-m heights at a nominal distance of 5 m from the roadway; wind data were collected in the same manner as for emission tests.

The cyclone preseparators remove coarse particles which otherwise would tend to bounce off the glass fiber impaction substrates, causing fine particle measurement bias. To further reduce particle bounce problems, each substrate was sprayed with stopcock grease solution to provide a sticky impaction surface. Each impactor consisted of five impaction stages (cutoffs for 50% collection are 10.2, 4.2, 2.1, 1.4, and 0.73 μmA at 20 acfm, the flow rate used in this special phase of the program). Variacs were used to control the flow rates.

2.2 PARTICULATE SAMPLE HANDLING AND ANALYSIS

The sampling and analysis procedures followed in this field testing program were subject to certain QA guidelines. These guidelines will be discussed in conjunction with the activities to which they apply. These procedures met or exceeded the requirements specified in the reports entitled "Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II—Ambient Air Specific Methods" (EPA 600/4-77-027a) and "Ambient Monitoring Guidelines for Prevention of Significant Deterioration" (EPA 450/2-78-019).

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

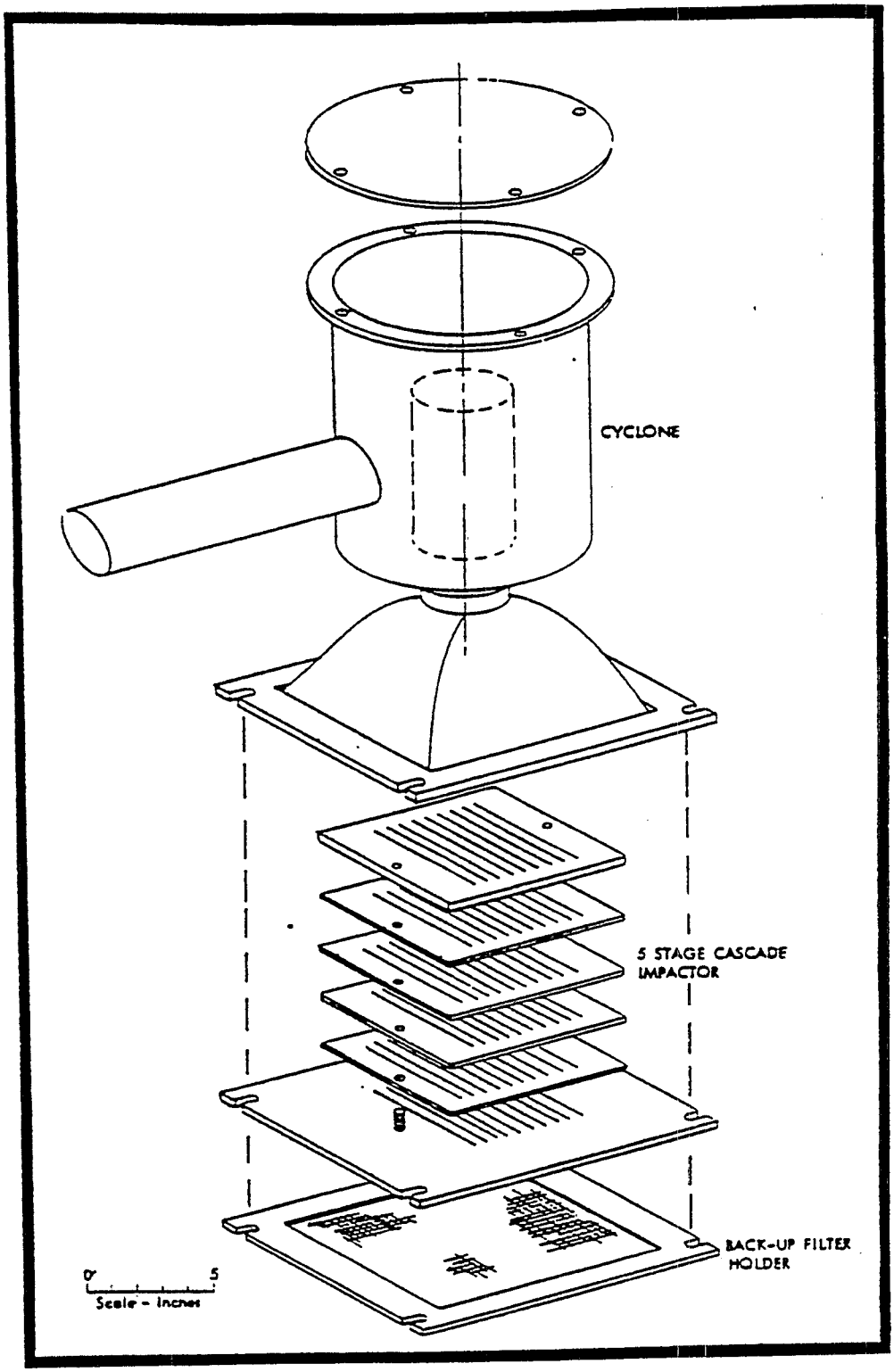


Figure 4. Cyclone preseparator/cascade impactor combination used during "sizing" tests.

2.2.1 Preparation of Sample Collection Media

Particulate samples were collected on Whatman Grade AH glass fiber filters, with the exception of the Wedding PM-10 samplers which require quartz filters. Prior to the initial weighing, the filters were equilibrated for 24 h at constant temperature and humidity in a special weighing room. During weighing, the balance was checked at frequent intervals with standard (Class S) weights to ensure accuracy. The filters remained in the same controlled environment for another 24 h, after which a second analyst reweighed them as a precision check. Ten percent of the filters used in the field served as blanks. The QA guidelines pertaining to preparation of sample collection media are presented in Table 2.

2.2.2 Pretest Procedures/Evaluation of Sampling Conditions

Weather forecasts, on-site meteorological measurements, and discussions with mine personnel formed the basis to select which, if any, emission sources and sites would be most acceptable for testing on any given day. Equipment was moved to the most promising site, and deployment was initiated.

Once the source testing equipment was set up, if meteorological conditions were favorable, filters were inserted and air sampling commenced. Information recorded on specially designed reporting forms included:

1. Air samplers—Start/stop times, wind speed profiles, sampler flow rates, and wind direction measured from a perpendicular to the roadway centerline (5-min average). See Table 3 for QA procedures.

2. Traffic data—Truck ID, speed measured by radar gun, travel direction, number of axles and tires, whether the truck is loaded or empty, and what material is being hauled.

3. General meteorology—Wind speed, wind direction, temperature, barometric pressure, and solar radiation.

Sampling time was long enough to provide sufficient particulate mass and to average over several cycles of the fluctuation in the emission rate (e.g., vehicle passes on the road). Occasionally sampling could be interrupted because of the occurrence of unacceptable meteorological conditions and then restarted when suitable conditions returned. Table 4 presents criteria used for suspending or terminating a source test.

TABLE 2. QUALITY ASSURANCE PROCEDURES FOR SAMPLING MEDIA

Activity	QA check/requirement
Preparation	Inspect and imprint glass fiber media with identification numbers.
Conditioning	Equilibrate media for 24 h in clean controlled room with relative humidity of 45% (variation of less than ±5% RH) and with temperature of 23°C (variation of less than ±1°C).
Weighing	Weigh hi-vol filters to nearest 0.1 mg.
Auditing of weights	Independently verify final weights of 10% of filters (at least four from each batch). Reweigh batch if weights of any hi-vol filters deviate by more than ±2.0 mg. For tare weights, conduct a 100% audit. Reweigh tare weight of any filters that deviate by more than ±1.0 mg. Follow same procedures for impactor substrates used for sizing tests. Audit limits for impactor substrates are 1.0 and 0.5 mg for final and tare weights, respectively.
Correction for handling effects	Weigh and handle at least one blank for each 1 to 10 filters of each type used to test.
Calibration of balance	Balance to be calibrated once per year by certified manufacturer's representative. Check prior to each use with laboratory Class S weights.

TABLE 3. QUALITY ASSURANCE PROCEDURES FOR SAMPLING EQUIPMENT

Activity	QA check/requirement[a]
Maintenance • All samplers	Check motors, gaskets, timers, and flow measuring devices at each plant prior to testing.
Operation • Timing	Start and stop all downwind samplers during time span not exceeding 1 min.
• Isokinetic sampling (cyclones)	Adjust sampling intake orientation whenever mean wind direction dictates. Change the cyclone intake nozzle whenever the mean wind speed approaching the sampler falls outside of the suggested bounds for that nozzle. This technique allocates no nozzle for wind speeds ranging from 0 to 10 mph, and unique nozzles for four wind speed ranges above 10 mph.
• Prevention of static mode deposition	Cover sampler inlets prior to and immediately after sampling.

[a] "Mean" denotes a 3- to 15-min average.

TABLE 4. CRITERIA FOR SUSPENDING OR TERMINATING A TEST

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

1. Rainfall ensues during equipment setup or when sampling is in progress.

2. Mean wind speed during sampling falls below 1.8 (4 mph) for more than 20% of the sampling time.

3. The angle between mean wind direction and the perpendicular to the path of the moving point source during sampling exceeds 45 degrees for two consecutive averaging periods.

4. Daylight or available artificial lighting is insufficient for safe equipment operation.

5. Wind speeds are high enough that safe equipment operation is not possible.

6. Source condition deviates from predetermined criteria (e.g., occurrence of truck spill, accidental water splashing prior to uncontrolled testing, or high winds result in high upwind concentrations that cannot be effectively distinguished from downwind concentrations).

[a] "Mean" denotes a 3- to 15-min average.

2.2.3 Sample Handling and Analysis

To prevent particulate losses, the exposed media were carefully transferred at the end of each run to protective containers for transportation. The interior surfaces of cyclone preseparators were washed with distilled water; particulate matter that collected on the interior surfaces of cyclone preseparators during sizing tests was rinsed into separate sample jars which were then capped and taped shut. In the field laboratory, exposed filters were placed in individual glassine envelopes and then into numbered file folders. When exposed filters and the associated blanks were returned to the MRI laboratory, they were equilibrated under the same conditions as the initial weighing. After reweighing, 10% were audited to check weighing accuracy.

To determine the sample weight of particulate collected on the interior surfaces of samplers, the entire wash solution was passed through a 47-mm (1.8-in) Buchner-type funnel holding a glass fiber filter under suction. This water was passed through the Buchner funnel ensuring collection of all suspended material on the 47-mm filter, which was then dried in an oven at 100°C for 24 h. After drying, the filters were conditioned at constant temperature and humidity for 24 h.

All wash filters were weighed with a 100% audit of tared and a 10% audit of exposed filters. Blank values were determined by washing "clean" (unexposed) cyclone preseparators in the field and following the above procedures.

2.3 EMISSION FACTOR CALCULATION PROCEDURES

To calculate emission rates from exposure profiling test data, 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. Exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement, or equivalently, the net particulate mass passing through a unit area normal to the mean wind direction during the test. The steps in the calculation procedure for line sources are described below.

2.3.1 Particulate Concentrations

The concentration of particulate matter measured by a sampler is given by:

$$C = 10^3 \frac{m}{Qt}$$

where:
- C = particulate concentration ($\mu g/m^3$)
- m = particulate sample weight (mg)
- Q = sampler flow rate (m^3/min)
- t = duration of sampling (min)

To be consistent with the NAAQSs, all concentrations and flow rates are expressed in standard conditions (25°C and 101 kPa or 77°F and 29.92 inHg).

The isokinetic flow ratio (IFR) is the ratio of a directional sampler's intake air speed to the mean wind speed approaching the sampler. It is given by:

$$IFR = \frac{Q}{aU}$$

where:
- Q = sampler flow rate (m^3/min)
- a = intake area of sampler (m^2)
- U = mean wind speed at height of sampler (m/min)

This ratio is of interest in the sampling of total particulate, since isokinetic sampling ensures that particles of all sizes are sampled without bias. Note, however, that because the primary interest in this program is directed to PM-10 emissions, sampling under moderately nonisokinetic conditions poses no difficulty. It is readily agreed that 10 µm (aerodynamic diameter) and smaller particles have weak inertial characteristics at normal wind speeds and therefore are relatively unaffected by anisokinesis.[6]

Exposure represents the net passage of mass through a unit area normal to the direction of plume transport (wind direction) and is calculated by:

$$E(h) = 10^{-7} \times CUt$$

where: $E(h)$ = particulate exposure (mg/cm^2) at height h (m)
C = net concentration ($\mu g/m^3$)
U = approaching wind speed (m/s)
t = duration of sampling (s)

Exposure values vary over the spatial extent of the plume. If exposure is integrated over the plume effective cross section, then the quantity obtained represents the total passage of airborne particulate matter due to the source.

For a line source, a one-dimensional integration is used:

$$A1 = \int_O^H E \, dh$$

where: $A1$ = integrated exposure ($m\text{-}mg/cm^2$)
E = particulate exposure (mg/cm^2)
h = vertical distance coordinate (m)
H = effective extent of plume above ground (m)

The effective height of the plume is found by linear extrapolation of the uppermost net concentrations to a value of zero.

Because exposures are measured at discrete heights of the plume, a numerical integration is necessary to determine A1. The 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). However, the maximum exposure usually occurs below a height of 1 m, so that there is a sharp decay in exposure near the ground. To account for this sharp decay, the value of exposure at the ground level is set equal to the value at a height of 1 m. The integration is then performed using Simpson's rule. Because Simpson's rule requires an odd number of equally spaced points, additional points are obtained (if needed) by linear extrapolation.

2.3.2 Particulate Emission Factors

The PM-10 emission factor for particulate generated by vehicular traffic on a straight road segment expressed in grams of emissions per vehicle-kilometer traveled (VKT) is given by:

where: e = particulate emission factor (g/VKT)
$A1$ = integrated exposure ($m\text{-}mg/cm^2$)

$$e = 10^4 \frac{A1}{N}$$

N = number of vehicle passes (dimensionless)

TSP emission factors e_{TSP} were found by scaling the PM-10 emission factor e by the geometric mean ratio of TSP to PM-10 exposure at the 1- and 3-m heights:

$$e_{TSP} = e \sqrt{\frac{E_{TSP}(1)}{E(1)} \frac{E_{TSP}(3)}{E(3)}}$$

where: e_{TSP} = TSP emission factor (g/VKT)
$E(h)$ = PM-10 exposure (mg/cm^2) at height h (m)
$E_{TSP}(h)$ = TSP exposure (mg/cm^2) at height h (m)

2.4 SOURCE MATERIAL SAMPLE COLLECTION AND ANALYSIS

A sample of loose aggregate was collected from the travel surface for each source emission test to characterize the emitting material. Each sample was analyzed for silt and moisture contents, as described below. Furthermore, for tests of emissions from watered surfaces, frequent grab samples were collected for moisture analysis.

The following describes the procedures used to collect unpaved road surface samples.

1. Ensure that the site offers an unobstructed view of traffic and that sampling personnel are visible to drivers. If the road is heavily traveled, use one person to "spot" traffic and ensure that the person collecting the surface sample (increment) gets safely out of the way.

2. Using string or other suitable markers, mark a 0.3-m (1-ft) width across the road. (WARNING: Do not mark the collection area with a chalk line or in any other method likely to introduce fine material into the sample.)

3. With a whisk broom and dustpan, remove the loose surface material from the hard road base. Do not abrade the base during sweeping. Sweeping should be performed slowly so that fine surface material is not injected into the air. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i.e., not from berms or any "mounds" along the road centerline).

4. Periodically deposit the swept material into a clean, labeled container of suitable size (such as a metal or plastic 19-L [5-gal] bucket) with a sealable polyethylene liner. Increments may be mixed within this container.

5. Record the required information on the sample collection sheet. Additional "grab" samples were collected during tests of watered surfaces to determine how moisture content varied during the test period. Samples were comprised of approximately 10 increments taken at randomly selected spots across the road.

Upon return to MRI's main laboratories, samples underwent moisture and silt content determination. Moisture content was determined by weight loss upon oven drying. Silt content refers to the fraction of material smaller than 200 mesh, as determined by mechanical dry sieving.

The following steps describe the moisture content determination procedure:

1. Preheat the oven to the desired temperature of approximately 80°C (180°F) or 110°C (230°F). Record oven temperature.

2. Record the make, capacity, and smallest division of the scale.

3. Weigh the empty laboratory sample containers which will be placed in the oven to determine their tare weight. Record the tare weight(s). Check zero before each weighing.

4. Weigh the laboratory sample(s) in the container(s). For materials with high moisture content, ensure that any standing moisture is included in the laboratory sample container. Record the combined weight(s). Check zero before each weighing.

5. Place sample in oven and dry overnight. Samples likely to contain significant amounts of coal were dried for only 1.5 h at 80°C. Samples unlikely to contain coal (e.g., overburden haul roads or scraper routes) were dried overnight (nominally 24 h) at 110°C.

6. Remove sample container from oven and (a) weigh immediately if uncovered, being careful of the hot container; or (b) place the tight-fitting lid on the container and let cool before weighing. Record the combined sample and container weight(s). Check zero reading on the balance before weighing.

7. Calculate the moisture as the initial weight of the sample and container minus the oven-dried weight of the sample and container divided by the

initial weight of the sample alone. Record the value. The 1.5-h samples may be redried at 110°C (230°F) overnight for comparison purposes.

8. Calculate the sample weight to be used in the silt analysis as the oven-dried weight of the sample and container minus the weight of the container. Record the value.

Silt analysis was then performed on the oven-dried sample using the following procedure:

1. Select the appropriate 20-cm (8-in) diameter, 5-cm (2-in) deep sieve sizes. Recommended U.S. Standard Series sizes are 3/8 in, No. 4, No. 40, No. 100, No. 140, No. 200, and a pan. Comparable Tyler Series sizes can also be utilized. The No. 20 and the No. 200 are mandatory. The others can be varied if the recommended sieves are not available or if buildup on one particulate sieve during sieving indicates that an intermediate sieve should be inserted.

2. Obtain a mechanical sieving device such as vibratory shaker or a Roto-Tap without the tapping function.

3. Clean the sieves with compressed air and/or a soft brush. Material lodged in the sieve openings or adhering to the sides of the sieve should be removed (if possible) without handling the screen roughly.

4. Obtain a scale (capacity of at least 1,600 g or 3.5 lb) and record make, capacity, smallest division, date of last calibration, and accuracy.

5. Weigh the sieves and pan to determine tare weights. Check the zero before every weighing. Record weights.

6. After nesting the sieves in decreasing order with pan at the bottom, dump dried laboratory sample (preferably immediately after moisture analysis) into the top sieve. The sample should weigh between ~ 400 and 1,600 g (0.9 to 3.5 lb). This amount will vary for finely textured materials; 100 to 300 g may be sufficient with 90% of the sample passing a No. 8 (2.36-mm) sieve. Brush fine material adhering to the sides of the container into the top sieve, and cover the top sieve with a special lid normally purchased with the pan.

7. Place nested sieves into the mechanical sieving device and sieve for 10 min. Remove pan containing minus No. 200 and weigh. Repeat the sieving in 10-min intervals until the difference between two successive pan sample weighings (where the tare weight of the pan has been subtracted) is less than 3.0%. Do not sieve longer than 40 min.

8. Weigh each sieve and its contents and record the weight. Check the zero reading on the balance before every weighing.

9. Collect the laboratory sample and place the sample in a separate container if further analysis is expected.

10. Calculate the percent of mass less than the 200 mesh screen (75 μm). This is the silt content.

2.5 CONTROL APPLICATION INTENSITY

To measure the application intensity of water for dust control, MRI placed tared sampling pans at various locations on the test road strips prior to application. Special attention was paid to the problem associated with the suppressant splashing off the bottom of the pan. To reduce this potential source of error, an absorbent material was used to line the bottom of the pan. Once the control agent was applied, the sample pans were reweighed.

The application intensity measured by each pan is given by:

$$a = \frac{m_f - m_t}{\rho A}$$

where:
- a = application intensity (volume/area)
- m_f = final weight of the pan and solution (mass)
- m_t = tare weight of the pan and absorbent material (mass)
- ρ = weight density of solution (mass/volume)
- A = area of the pan (area)

The individual application intensities obtained were examined to determine any significant spatial variations and to obtain an average value.

TEST RESULTS

SECTION 3

A total of 36 PM-10 emission tests, distributed over various sources and five test sites, was performed. In keeping with priorities established in the earlier emission factor review,[2] a majority of the field effort was devoted to emissions from haul truck traffic. For haul roads especially, testing spanned a large range of wind speeds. In addition, 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. The permanent north and south pit coal haul roads were well compacted and had been treated with surfactants for several years. These roads are further controlled by regular watering. TSP emission tests were run concurrently with 22 of the PM-10 tests. In addition, three PM-10 and three TSP light-duty captive traffic tests 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 were also conducted.

Table 5 presents the site parameters for these tests, including the date and location of the testing and general meteorology. Runs with an "X" suffix identify sizing tests conducted to provide the Source Receptor Branch (SRB) at EPA with additional information about the particle size distribution of haul road emissions. These tests are discussed as "Special Studies" in the next section.

Table 6 presents a summary of 1992 field testing at the Cordero mine.

Table 7 presents the concentration measurements collected during the field program. Table 8 lists, for each run, the individual PM-10 exposure values at each sampling location. TSP exposure values are also listed. These exposure values were integrated over the plume area in order to determine emission factors, which are given in Table 9. Table 9 also presents road surface and vehicle parameters.

Approximately one-half of all haul truck emission tests were controlled by use of water/surfactant. Appendix C contains relatively detailed time histories of the water application as well as surface moisture content. Table 10 compares results for different haul road test sites. As one can see by comparing the two sets of mean emission factors, water/surfactant afforded control efficiencies ranging from about 40% to 70% from PM-10 and from about 30% to 60% for TSP. These findings are in good agreement with the commonly applied control efficiency value of 50% for watering.

Section 5 of this report discusses further the emission factors developed during this study.

TABLE 5. EXPOSURE PROFILING TEST SITE PARAMETERS

Run	Control measure	Site[a]	Date	Test start	Sampling duration (min)	Vehicle passes	Ambient air temperature		Barometric pressure		Mean wind speed[b]	
							°C	°F	(inch Hg)	(mm Hg)	(m/s)	(mph)
BB2	None	1	09/09/92	1258	30	35	16	61	25.63	651.00	6.45	14.43
BB3	None	1	09/09/92	1303	25	35	16	61	25.63	651.00	6.45	14.43
BB6	None	1B	09/10/92	1310	55	40	23	74	25.75	654.05	4.33	9.68
BB7	None	1B	09/10/92	1310	66	45	23	74	25.75	654.05	4.29	9.60
BB8	None	1B	09/10/92	1513	29	18	26	79	25.75	654.05	3.88	8.68
BB10	None	1	09/12/92	1227	88	57	27	80	25.35	643.89	8.07	18.06
BB11	None	1	09/12/92	1226	89	57	27	80	25.35	643.89	8.05	18.02
BB12	None	1B	09/14/92	1347	58	50	23	73	25.50	647.70	6.39	14.29
BB13	None	1B	09/14/92	1345	60	50	23	73	25.50	647.70	6.37	14.26
BB14	None	1B	09/18/92	1152	80	44	15	59	25.68	652.27	4.42	9.88
BB15	None	1B	09/18/92	1338	64	41	17	62	25.60	650.24	5.09	11.39
BB16	None	1B	09/18/92	1514	63	51	17	62	25.60	650.24	4.47	10.01
BB29	None	4	10/05/92	1330	37	21	18	65	25.95	659.13	2.62	5.86
BB31	None	4	10/05/92	1457	37	22	18	65	25.95	659.13	2.32	5.18
BB33	None	2	10/10/92	1232	92	32	16	61	25.55	648.97	6.13	13.72
BB34	None	2	10/10/92	1422	72	36	17	63	25.50	647.70	5.47	12.24
BB36	None	4	10/12/92	1251	44	21	21	69	25.25	641.35	2.07	4.63
BB44	None	4	10/22/92	1248	105	200	21	69	25.50	647.70	4.03	9.01
BB46	None	5	10/24/92	1440	89	32	27	80	25.40	645.16	4.52	10.13
BB47	None	5	10/24/92	1653	44	14	27	80	25.40	645.16	2.37	5.31
BB45	None	1B	10/25/92	1305	75	322	12	53	25.40	645.16	4.43	9.93
BB48	None	1B	10/25/92	1451	50	381	12	53	25.40	645.16	3.45	7.71
BB17	Watering[c]	1B	09/21/92	1233	79	50	18	65	25.65	651.51	5.69	12.73
BB18	Watering[c]	1B	09/21/92	1335	93	71	18	65	25.65	651.51	4.44	9.92

TABLE 5 (Continued)

Run	Control measure	Site[a]	Date	Test start	Sampling duration (min)	Vehicle passes	Ambient air temperature °C	Ambient air temperature °F	Barometric pressure (inch Hg)	Barometric pressure (mm Hg)	Mean wind speed[b] (m/s)	Mean wind speed[b] (mph)
BB19	Watering[c]	1B	09/21/92	1418	67	47	18	65	25.65	651.51	3.64	8.15
BB20	Watering[c]	1B	09/21/92	1523	53	41	20	68	25.75	654.05	3.57	7.98
BB21	Watering[c]	1B	09/22/92	1119	82	32	26	78	25.70	652.78	3.63	8.11
BB22	Watering[c]	1B	09/22/92	1313	36	32	28	82	25.70	652.78	2.03	4.54
BB23	Watering[c]	1B	09/23/92	1120	52	33	31	87	25.60	650.24	3.38	7.55
BB25	Watering[c]	1B	09/28/92	1110	62	40	16	60	25.80	655.32	8.12	18.17
BB26	Watering[c]	1B	09/28/92	1253	79	63	19	66	25.80	655.32	6.04	13.51
BB27	Watering[c]	1B	09/28/92	1358	72	42	21	69	25.80	647.70	5.39	12.05
BB35	Watering[c]	2	10/10/92	1644	87	32	16	60	25.50	647.70	3.70	8.27
BB38	Watering[c]	1B	10/13/92	1319	50	43	12	53	25.10	637.54	10.15	22.71
BB39	Watering[c]	1B	10/13/92	1324	45	40	12	53	25.10	637.54	10.06	22.52
BB40	Watering[c]	4	10/14/92	1249	78	40	7	45	25.20	640.08	5.47	12.24
BB41	Watering[c]	4	10/14/92	1334	97	51	7	45	25.20	640.08	5.31	11.88
BB42	Watering[c]	4	10/14/92	1437	70	36	7	44	25.15	638.81	5.20	11.63
BB43	Watering[c]	2	10/19/92	1541	48	25	17	62	25.40	645.16	6.31	14.11
BB100X	None	1B	09/16/92	1204	97	55	20	68	25.65	651.51	1.96	4.24
BB102X	None	1B	09/17/92	1401	46	37					8.39	18.76
BB111X	Watering[c]	1	10/09/92	0923	147	101	8	46	25.50	647.70	8.28	18.51
BB112X	Watering[c]	1	10/09/92	1432	94	76	12	54	25.60	650.24	9.93	22.22
BB121X	None	4	10/20/92	1325	104	63					2.96	6.63

[a] Refer to Figure 1 for site locations
[b] At a height of 3m
[c] Permanent haul roads have been treated with surfactant for several years and are very well compacted with little loose surface material. Testing took place with supplemental watering of the surface.

TABLE 6. SUMMARY OF PHASE I TESTING AT CORDERO

	Coal haul roads			Overburden haul road	
Site ID[a]	1	1B	2	4	Total
PM-10 emission tests:					
Uncontrolled	4	8[b]	2[b]	3	17
Controlled		12	2	3	17
Total	4	20	4	6	34
TSP emission tests:					
Uncontrolled	2[b]	4[b]	2[b]	2	10
Controlled		8	2	2	12
Total	2	12	4	4	22
Emission tests of captive light-duty vehicles					
Uncontrolled		2[b,c]	1[b,c]		3[c]
Particle sizing tests:					
Uncontrolled		2		1	3
Controlled	2				2
Total	2	2		1	5

[a] Refer to Figure 1 for test site locations. Not included in the table are the two uncontrolled scraper tests (BB-46, -47) conducted at site 5.

[b] Permanent coal haul roads had been treated with surfactant for several years and were very well compacted with little loose surface material. "Controlled" and "uncontrolled" in the sense used here means that testing took place with or without supplemental watering of the surface.

[c] Each entry reflects one PM-10 and one TSP test.

[d] "Moisture tracking" refers to collection of grab samples from watered road every 10 to 30 min to better define average moisture contents for controlled roads.

TABLE 7. CONCENTRATION MEASUREMENTS

Run	Upwind PM_{10} Concentration ($\mu g/m^3$)		Downwind PM_{10} Concentration ($\mu g/m^3$)					Downwind TSP Concentration ($\mu g/m^3$)	
	1.9 m Cyclone	1.9 m Wedding	1 m Cyclone	3 m Cyclone	5 m Cyclone	7 m Cyclone	3 m Wedding	1 m	3 m
BB2	38.34	36.34	2447	1218	980.9	462.7	1354	17480	12720
BB3	38.34	36.34	3698	1906	1277	657.5			
BB6	14.96	9.86	858.7	477.3	429.2	223.8	473.5		2149
BB7	14.96	9.86	977.3	795.0	451.9	251.8			
BB8	14.96	9.86	1030	395.0	439.7	269.9	542.1	2372	2461
BB10	9.40	9.44	319.4	174.3	123.8	60.34	183.3	1528	1067
BB11	9.40	9.44	337.1	138.8	75.80	63.13			
BB12	7.45	17.27	199.9	239.2	117.2	38.45	199.2	1769	1074
BB13	7.45	17.27	161.2	171.9	76.81	62.20			
BB14	6.73	6.14	336.9	226.0	183.0	83.55	195.0[d]	884.9	973.6
BB15	6.73	6.14	608.5	358.4	312.3	127.7	195.0[d]	2138	1802
BB16	6.73	6.14	936.1	607.2	506.7	263.4			
BB17	79.54	53.59	209.3	203.2	148.4	146.5	197.7[b]	1072	836.4
BB18	79.54	53.59	608.4	559.5	403.6	310.1			
BB19	79.54	53.59	340.2	487.2	342.9	279.7	197.7[b]	1893	2020
BB20	79.54	53.59	749.8	510.8	304.0	301.4			
BB21	3.64	11.19	198.8	129.8	73.95	61.74	143.2[c]	829.2	832.9
BB22	3.64	11.19	350.4	418.3	265.9	246.9	143.2[c]	1274	1272
BB23	17.10	31.91	109.8	126.5	128.7	85.24	175.8	787.9	804.3
BB25	8.78	14.14	78.76	90.52	71.48	29.58	99.32[e]	723.6	600.9
BB26	8.78	14.14	368.1	406.9	117.9	53.22	99.32[e]	1515	1193
BB27	8.78	14.14	538	205.7	251.6	126.0			
BB29	2.87		3920	2275	1681	842.0			
BB31	2.87		1563	1905	1367	673.2		13280	9803
BB33	9.28	5.38	322.9	200.1	131.7	100.3	205.8[d]	2368	1804
BB34	9.28	5.38	1012	413.0	321.7	233.0	205.8[d]	3364	2661
BB35	9.28	5.38	658.7	453.0	254.1	171.3	191.5	2383	2039
BB36	19.11	17.81	1679	2304	2130	1165	522.3	11730	11490
BB38	262.6	194.6	453.6	502.5	383.2	331.9	197.7	1725	1074
BB39	262.6	194.6	488.5	401.7	284.6	249.9			
BB40	10.65	13.07	150.0	124.3	121.7	95.14	92.36	1988	1743
BB41	10.65	13.07	502.6	378.1	353.8	169.2			
BB42	10.65	13.07	673.0	539.3	513.2	414.6		4190	3513
BB43	6.65		38.05	36.65	47.59	34.86		440.8	336.6
BB44	14.96	12.98	241.5	63.61	24.67	57.12	56.92	923.7	328.5
BB46	9.45[f]		1564[g]	729.1	275.2[h]				
BB47	9.45[f]		1484[g]	939.2	568.9[h]				
BB45	3.94[i]		101.9	70.75	39.27	0		868.9	452.3
BB48	3.94[i]		400.9	258.3	47.16	11.81		1802	875.8

[b,c,d,e] 3 m Wedding operated during 2 runs with the same filter.
[f] 1.2 m height.
[g] 1.5 m height.
[h] 4.5 m height.

TABLE 8. PLUME SAMPLING DATA

Run	Sampling Height (m)	PM_{10} Sampling Rate (m^3/hr)	PM_{10} Sampling Rate (cfm)	IFR	Net PM_{10} Exposure (mg/cm^2)	TSP Sampling Rate (m^3/hr)	TSP Sampling Rate (cfm)	Net TSP Exposure (mg/cm^2)
BB2	1	61.86	36.41	1.04	2.376	67.96	40	17.20
	3	61.49	36.19	0.88	1.370	61.08	35.95	14.72
	5	61.28	36.07	0.82	1.170			
	7	61.42	36.15	0.78	0.5500			
BB3	1	61.55	36.23	1.03	3.007			
	3	62.08	36.54	0.88	1.807			
	5	61.74	36.34	0.83	1.282			
	7	62.08	36.54	0.79	0.6686			
BB6	1	60.86	35.82	1.48	1.058			
	3	61.27	36.06	1.31	0.6605	60.33	35.51	3.049
	5	61.15	35.99	1.24	0.6251			
	7	61.45	36.17	1.19	0.3263			
BB7	1	61.16	36.00	1.49	1.436			
	3	60.67	35.71	1.31	1.325			
	5	60.47	35.59	1.22	0.7845			
	7	60.67	35.71	1.19	0.4401			
BB8	1	60.55	35.64	1.83	0.5362	67.96	40	1.245
	3	60.81	35.79	1.45	0.2565	60.21	35.44	1.651
	5	60.74	35.75	1.31	0.3158			
	7	61.01	35.91	1.24	0.2010			
BB10	1	59.69	35.13	1.52	1.102	67.96	40	5.402
	3	60.08	35.36	1.27	0.7028	59.23	34.86	4.509
	5	59.79	35.19	1.18	0.6628			
	7	59.99	35.31	1.13	0.2448			
BB11	1	59.91	35.26	1.52	1.182			
	3	59.30	34.90	1.26	0.5567			
	5	59.23	34.86	1.18	0.3072			
	7	59.36	34.94	1.12	0.2600			
BB12	1	60.60	35.67	1.04	0.3608	67.96	40	2.573
	3	60.81	35.79	0.87	0.5153	59.80	35.20	2.484
	5	60.52	35.62	0.82	0.2620			
	7	60.72	35.74	0.78	0.07730			
BB13	1	60.25	35.46	1.02	0.2992			
	3	60.54	35.63	0.87	0.3776			
	5	60.01	35.32	0.82	0.1704			

TABLE 8 (Continued)

Run	Sampling Height (m)	PM_{10} Sampling Rate (m^3/hr)	PM_{10} Sampling Rate (cfm)	IFR	Net PM_{10} Exposure (mg/cm^2)	TSP Sampling Rate (m^3/hr)	TSP Sampling Rate (cfm)	Net TSP Exposure (mg/cm^2)
	7	59.63	35.10	0.77	0.1405			
BB14	1	62.13	36.57	1.14	0.5934	67.96	40	1.406
	3	62.40	36.73	0.97	0.4651	61.67	36.30	1.974
	5	62.13	36.57	0.90	0.4002			
	7	62.47	36.77	0.87	0.1820			
BB15	1	61.55	36.23	0.97	1.006	67.96	40	3.561
	3	62.01	36.50	0.83	0.6876	61.35	36.11	3.509
	5	61.86	36.41	0.78	0.6377			
	7	62.08	36.54	0.75	0.2629			
BB16	1	61.61	36.26	1.22	1.223			
	3	61.81	36.38	0.94	1.016			
	5	61.66	36.29	0.85	0.9330			
	7	61.86	36.41	0.81	0.5086			
B17	1	61.54	36.22	1.37	0.2544	67.96	40	1.871
	3	62.08	36.54	1.00	0.3337	61.13	35.98	1.964
	5	61.72	36.33	1.21	0.2095			
	7	62.00	36.49	1.13	0.2187			
BB18	1	61.78	36.36	1.40	0.9479			
	3	61.35	36.11	1.00	1.187			
	5	61.08	35.95	1.20	0.9049			
	7	61.28	36.07	1.12	0.6915			
BB19	1	61.35	36.11	1.65	0.2654	67.96	40	1.846
	3	61.59	36.25	1.16	0.5969	60.99	35.90	2.840
	5	61.52	36.21	1.36	0.4404			
	7	61.66	36.29	1.27	0.3622			
BB20	1	61.76	36.35	1.73	0.5238			
	3	61.18	36.01	1.18	0.4895			
	5	60.91	35.85	1.02	0.2919			
	7	61.25	36.05	0.95	0.3126			
BB21	1	60.76	35.76	1.39	0.2871	67.96	40	1.214
	3	61.21	36.03	1.55	0.2251	60.37	35.53	1.479
	5	60.94	35.87	1.43	0.1356			
	7	61.15	35.99	1.87	0.1175			
BB22	1	60.69	35.72	2.12	0.1473	67.96	40	0.5396
	3	60.20	35.43	2.47	0.1820	60.04	35.34	0.5564

TABLE 8 (Continued)

Run	Sampling Height (m)	PM_{10} Sampling Rate (m^3/hr)	PM_{10} Sampling Rate (cfm)	IFR	Net PM_{10} Exposure (mg/cm^2)	TSP Sampling Rate (m^3/hr)	TSP Sampling Rate (cfm)	Net TSP Exposure (mg/cm^2)
	5	59.92	35.27	2.42	0.1168			
	7	60.13	35.39	2.89	0.1094			
BB23	1	59.97	35.30	1.48	0.08037	67.96	40	0.6554
	3	60.30	35.49	1.23	0.1152	59.26	34.88	0.8132
	5	60.16	35.41	1.13	0.1273			
	7	60.37	35.53	1.08	0.08151			
BB25	1	62.17	36.59	1.18	0.1722	67.96	40	1.760
	3	62.64	36.87	0.97	0.2470	61.62	36.27	1.790
	5	62.40	36.73	0.89	0.2059			
	7	62.49	36.78	0.84	0.07189			
BB26	1	62.01	36.50	1.41	0.8478	67.96	40	3.554
	3	61.42	36.15	1.15	1.140	61.23	36.04	3.390
	5	61.23	36.04	1.18	0.3379			
	7	61.50	36.20	1.12	0.1445			
BB27	1	61.50	36.20	1.29	1.007			
	3	62.03	36.51	1.06	0.4583			
	5	61.62	36.27	0.97	0.6136			
	7	61.89	36.43	0.93	0.3114			
BB29	1	62.25	36.64	2.58	1.438			
	3	62.52	36.80	1.63	1.320			
	5	62.23	36.63	1.39	1.142			
	7	62.51	36.79	1.27	0.6257			
BB31	1	62.12	36.56	2.71	0.5439	67.96	40	4.630
	3	62.66	36.88	1.85	0.9776	61.71	36.32	5.039
	5	62.30	36.67	1.60	0.8058			
	7	62.64	36.87	1.49	0.4296			
BB33	1	61.72	36.33	1.03	0.7404	67.96	40	5.570
	3	61.15	35.99	1.25	0.6460	61.23	36.04	6.078
	5	60.96	35.88	1.09	0.4729			
	7	61.16	36.00	1.01	0.3803			
BB34	1	61.28	36.07	1.12	1.621	67.96	40	5.420
	3	60.84	35.81	1.23	0.9547	60.84	35.81	6.270
	5	60.64	35.69	1.07	0.8473			
	7	60.84	35.81	1.12	0.6578			
BB35	1	61.88	36.42	1.55	0.9321	67.96	40	3.408

TABLE 8 (Continued)

Run	Sampling Height (m)	PM_{10} Sampling Rate (m^3/hr)	PM_{10} Sampling Rate (cfm)	IFR	Net PM_{10} Exposure (mg/cm^2)	TSP Sampling Rate (m^3/hr)	TSP Sampling Rate (cfm)	Net TSP Exposure (mg/cm^2)
	3	61.37	36.12	1.36	0.8566	61.18	36.01	3.919
	5	61.10	35.96	1.27	0.5284			
	7	61.23	36.04	1.36	0.3743			
BB36	1	60.50	35.61	2.45	0.7418	67.96	40	5.233
	3	59.52	35.03	1.96	1.250	59.67	35.12	6.273
	5	59.72	35.15	1.82	1.252			
	7	59.92	35.27	1.96	0.7149			
BB38	1	60.99	35.90	1.12	0.4731	67.96	40	3.621
	3	61.38	36.13	1.04	0.7306	60.40	35.55	2.471
	5	61.25	36.05	0.95	0.3992			
	7	61.32	36.09	1.22	0.2415			
BB39	1	61.16	36.00	1.12	0.4966			
	3	60.60	35.67	1.02	0.3780			
	5	60.47	35.59	0.95	0.06511			
	7	60.60	35.67	1.21	(0)[a]			
BB40	1	62.08	36.54	1.25	0.3030	67.96	40	4.297
	3	61.64	36.28	1.42	0.2913	61.23	36.04	4.436
	5	61.05	35.93	1.31	0.3048			
	7	61.52	36.21	1.26	0.2417			
BB41	1	61.84	36.40	1.27	1.284			
	3	62.10	36.55	1.46	1.137			
	5	61.81	36.38	1.36	1.139			
	7	62.17	36.59	1.31	0.5495			
BB42	1	62.03	36.51	1.17	1.224	67.96	40	7.723
	3	61.52	36.21	1.09	1.154	61.18	36.01	7.649
	5	61.38	36.13	1.02	1.177			
	7	61.52	36.21	0.97	0.9870			
BB43	1	61.10	35.96	1.16	0.04402	67.96	40	0.6086
	3	60.03	35.33	1.19	0.05451	60.60	35.67	0.5995
	5	60.67	35.71	1.09	0.08226			
	7	61.32	36.09	1.04	0.06029			
BB44	1	60.82	35.80	1.42	0.4189	67.96	40	1.680
	3	59.82	35.21	1.02	0.1235	60.47	35.59	0.7959
	5	60.45	35.58	1.07	0.02775			
	7	61.11	35.97	1.18	0.1294			

TABLE 8 (Continued)

Run	Sampling Height (m)	PM_{10} Sampling Rate (m^3/hr)	PM_{10} Sampling Rate (cfm)	IFR	Net PM_{10} Exposure (mg/cm^2)	TSP Sampling Rate (m^3/hr)	TSP Sampling Rate (cfm)	Net TSP Exposure (mg/cm^2)
BB46	1.5	60.11	35.38	1.15	3.460			
	3.0	60.26	35.47	1.07	1.741			
	4.5	59.41	34.97	1.15	0.6744			
BB47	1.5	60.11	35.38	2.00	0.8510			
	3.0	58.56	34.47	1.85	0.5827			
	4.5	59.35	34.93	1.73	0.3685			
BB45	1	61.69	36.31	1.22	0.1530	67.96	40	1.352
	3	60.60	35.67	1.13	0.1334	61.05	35.93	0.8958
	5	61.32	36.09	1.16	0.07769			
	7	61.93	36.45	1.50	(0)[a]			
BB48	1	61.69	36.31	1.56	0.3212	67.96	40	1.455
	3	60.67	35.71	1.20	0.2631	61.13	35.98	0.9020
	5	61.32	36.09	1.10	0.04924			
	7	61.98	36.48	1.42	0.009500			
BB100X	1	29.63	17.44	1.42				
	3	29.63	17.44	1.28				
BB102X	1	33.98	20.00	1.20				
	3	33.98	20.00	0.94				
BB111X	1	30.73	18.09	0.66				
	3	30.73	18.09	0.71				
BB112X	1	30.38	17.88	0.98		67.96	40	
	3	30.38	17.88	0.70		62.06	36.53	
BB121X	1	33.98	20.00	1.05		67.96	40	
	3	33.98	20.00	0.92		67.96	40	

[a] Downwind concentration is less than upwind concentration.

TABLE 9. UNPAVED ROAD EMISSION FACTORS FOR OBSERVED TRAFFIC MIXES

				ALL TRAFFIC						
									Emission factor	
Run	Silt (%)	Moisture (%)	Surface silt loading (g/m^2)	Weight (English ton)	Weight (metric ton)	Wheels	Speed (mph)	Speed (km/h)	PM_{10} (g/VKT)	TSP (g/VKT)
BB-2	10.7	1.08	142	131	119	5.54	36.4	58.6	3040	26810
BB-3	10.7	1.08	142	131	119	5.54	36.4	58.6	3827	
BB-6	3.57	1.19	8.12	200	181	5.80	22.7	36.5	1316	
BB-7	3.57	1.19	8.12	200	181	5.73	22.4	36.0	1838	
BB-8	3.78	1.01	11.2	220	200	5.56	21.2	34.1	1472	5693
BB-10	3.08	1.17	16.2	160	145	5.47	27.5	44.2	920.9	5163
BB-11	3.08	1.17	16.2	160	145	5.47	27.5	44.2	807.1	
BB-12	2.24	1.09	3.09	155	141	5.80	22.6	36.4	506.6	3289
BB-13	2.24	1.09	3.09	155	141	5.80	22.6	36.4	420.7	
BB-14	3.32	1.77	7.81	92.0	83.4	5.18	22.9	36.8	738.7	2529
BB-15	2.05	1.39	3.48	183	167	5.66	21.3	34.3	1234	5247
BB-16	2.05	1.39	3.48	178	161	5.57	22.1	35.6	1464	
BB-17	2.08	1.80	3.24	169	153	5.48	24.6	39.6	461.2	3157
BB-18	1.34	1.29	1.65	184	167	5.97	23.0	37.0	1197	
BB-19	1.25	1.45	1.73	192	174	5.74	22.8	36.7	884.8	5088
BB-20	3.89	1.40	16.0	175	159	5.66	24.3	39.1	760.0	
BB-21	1.76	2.00	17.4	218	198	5.75	22.8	36.7	506.4	2670
BB-22	1.70	2.50	12.8	161	146	5.50	24.3	39.1	391.0	1308
BB-23	1.90	4.10	1.24	181	164	5.70	22.6	36.4	264.8	2048
BB-25	3.82	4.00	1.86	207	188	5.70	19.2	30.9	354.0	3045
BB-26	2.45	4.40	2.01	183	167	5.65	21.8	35.1	839.8	2965
BB-27	2.72	1.89	3.08	244	221	5.81	19.5	31.4	1085	
BB-29	19.2	3.78	68.4	283	257	5.90	18.8	30.2	4406	
BB-31	19.2	3.78	68.4	271	247	6.09	20.8	33.5	2637	17470

TABLE 9 (Continued)

Run	Silt (%)	Moisture (%)	Surface silt loading (g/m^2)	ALL TRAFFIC						
									Emission factor	
				Weight (English ton)	Weight (metric ton)	Wheels	Speed (mph)	Speed (km/h)	PM_{10} (g/VKT)	TSP (g/VKT)
BB-33	3.02	1.50	5.00	153	139	5.44	29.2	47.0	1606	13510
BB-34	4.88	0.91	14.0	170	154	6.06	28.6	46.0	2672	12520
BB-35	3.71	2.53	13.2	173	157	5.44	28.0	45.1	1878	7682
BB-36	12.9	5.00	245	286	259	6.00	19.3	31.1	3990	23740
BB-38	1.57	10.3	3.32	141	128	5.26	22.0	35.4	910.6	4634
BB-39	1.44	12.3	5.30	137	124	5.25	21.8	35.1	480.8	
BB-40	4.79	5.70	18.4	271	247	6.05	21.2	34.1	736.6	10830
BB-41	6.48	5.03	41.4	267	242	5.92	22.3	35.9	1600	
BB-42	9.48	4.35	84.9	275	249	5.94	22.0	35.4	3672	23730
BB-43	1.78	4.65	3.65	164	149	5.52	30.4	48.9	234.1	2885
BB-44	1.82	0.68	1.81	2.00	1.81	4.00	30.0	48.3	70.50	358.5
BB-46	12.7	4.88	531	63.0	57	4.06	15.5	24.9	3100	
BB-47	14.0	5.11	894	65.0	59	4.00	18.0	29.0	2304	
BB-45	1.95	2.10	0.800	2.00	1.81	4.00	30.0	48.3	22.07	170.0
BB-48	1.95	2.10	0.800	2.00	1.81	4.00	30.0	48.3	34.75	136.9

TABLE 10. COMPARISON OF GEOMETRIC MEAN EMISSION FACTORS (lb/VMT) FOR UNCONTROLLED AND CONTROLLED TESTS OF HAUL TRUCK EMISSIONS

	Uncontrolled		Controlled	
Site	PM-10	TSP	PM-10	TSP
1	6.1	42		
1B	3.6	14	2.2	10
2	7.3	46	2.4	17
4	13	72	5.8	57
Overall	5.5	31	2.6	15

SECTION 4

SPECIAL STUDIES

In addition to the general emission testing program, a number of additional studies were conducted as part of the overall field sampling effort. Many of the studies addressed issues expected during a subsequent field program focusing on ambient air measurements. These included studies to:

1. Determine particle size distributions of emissions from travel sources.

2. Characterize variability in input variables for currently available emission factor models.

3. Obtain an expanded ambient air quality data set for the period of the field exercise.

4. Gain practical experience with "saturation samplers" in anticipation of their use during a second phase of field activities emphasizing air quality monitoring.

5. Collect source activity information for days when air quality sampling took place (i.e., items 3 and 4 above).

Each of these special studies is discussed in greater detail below.

Besides collecting additional field samples, two other special studies were of interest in this program. Both require the incorporation of test results from this program into the historical emission factor data base. With this expanded data base, studies were undertaken to:

6. Evaluate how well currently available emission factors perform for surface coal mines.

7. Perform statistical analyses with a view to reformulating the emission factor models.

Examination of the expanded data base is presented in Section 5.

4.1 MEASURED PARTICLE SIZE DISTRIBUTIONS

During the planning stages for the field program, the Source Receptor Branch (SRB) requested that some particle size distribution data be collected to support the development of a new deposition algorithm. A total of four coal and one overburden haul road sizing tests were conducted during the course of the field exercise; these tests were shown with an "X" suffix in Table 5 and used cyclone/cascade impactor (C/CI) combinations discussed in Section 2.1. Each "X" test deployed C/CI combinations at 1- and 3-m heights at a nominal distance of 5 m from the roadway.

Table 11 presents the particle size distribution data developed during the field program. In general, the data follow the expected patterns of being coarser (a) at lower heights and (b) at higher wind speeds.

4.2 VARIABILITY IN INPUT PARAMETERS FOR CURRENT EMISSION FACTOR MODELS

Table 12 presents the analysis results for all the material and moisture "grab" samples collected during the field exercise. In addition to samples collected in conjunction with specific exposure profiling and particle sizing tests, the table includes three sets of "moisture tracking" samples. "Moisture tracking" refers to a series of grab samples taken over several watering cycles of haul truck routes to better quantify average moisture levels. The principal reason for taking these samples was the anticipation that the expanded data base might yield a relationship between moisture content and emission factor.

Summary statistics for the material sample parameters are presented in Table 13. What is most important to note in Table 13 is the overall variability in the material parameters, especially silt loading and moisture content. One can certainly expect considerable variability in these parameters because of the regular maintenance (grading and laying of new scoria as needed) and watering programs in place at the mine. Because of the variability in the parameters that serve as input to surface coal mine emission factors, the ambient monitoring field exercise being planned as a follow-up to this study provides for a series of roadway surface sampling to better track emission trends.

4.3 EXPANDED AMBIENT AIR QUALITY MEASUREMENTS

Representatives of the Wyoming Mining Association, the Wyoming Department of Environmental Quality, OAQPS, and MRI met in Casper on August 31, 1992, to review the goals of the testing program. That meeting resulted in a decision to conduct additional air sampling with Cordero's high-volume sampling network to approach a 1-day-in-2 frequency rather than the normal 1-day-in-6.

TABLE 11. PARTICLE SIZING DATA

Source	Run No.	Mean 3-m wind speed (mph)	Sample height (m)	Weight percentage of total particulate less than stated size (aerodynamic diameter)					
				15 µmA	10.2 µmA	4.2 µmA	2.1 µmA	1.4 µmA	0.73 µmA
Coal haul road (site 1B)	100X	4.2	1	30.0	21.1	12.2	8.6	8.1	6.2
			3	41.9	32.6	16.7	8.2	3.0	3.0
	102X	18.8	1	16.9	14.0	8.9	4.3	2.0	1.4
			3	19.7	16.1	9.4	5.5	2.8	1.9
Watered coal haul road (site 1)	111X	18.5	1	18.6	14.1	8.7	5.4	4.3	4.3
			3	20.3	14.5	8.1	8.1	6.7	5.1
	112X	22.2	1	13.7	11.3	9.0	8.3	6.2	4.5
			3	28.2	23.8	18.7	8.5	5.1	3.8
Overburden haul road (site 4)	121X	6.6	1	17.0	11.0	3.9	1.3	0.5	0.5
			3	15.0	8.8	2.3	0.8	0.3	0.3

TABLE 12. SURFACE MATERIAL SAMPLES COLLECTED DURING FIELD EXERCISE

Site	Run	Silt %	90 min moisture %	Overnight moisture %	Water added[a]	Total surface loading (g/m^2)	Surface silt loading (g/m^2)
1	Pre BB-2,3	10.1	1.02	1.24	no	1017	102.72
	Post BB-2,3	11.3	0.74	0.92	no	1612	182.16
	Pre BB-10,11	2.25	0.66	1.52	no	432.1	9.72
	Post BB-10,11	3.91	0.33	0.82	no	577.4	22.58
	During BB-111X	2.36		7.8	yes	55.8	1.32
	During BB-111X	0.67		2.8	yes	141.7	0.95
	After BB-111X	2.11		2.1	yes	105.9	2.23
	During BB-112X	0.98		3.1	yes	113.5	1.11
	Post BB-112X	2.27		2	yes	108	2.45
	10/21/92 at 1320	5.15[b]	1.94	2.38	yes	520.7	26.82
	10/21/92 at 1352	5.15[b]	4.53	4.92	yes	359.1	18.49
	10/21/92 at 1411	5.15[b]	2.78	3.12	yes	496.3	25.56
	10/21/92 at 1444	5.15[b]	3.22	3.55	yes	423	21.78
	10/21/92 at 1503	5.15[b]	1.95	4.38	yes	1154	59.43
	10/21/92 at 1547	5.15[b]	5.54	6.16	yes	400.4	20.62
1B	Pre BB-6,7	2.6	0.53	1.38	no	165.4	4.30
	Post BB-6,7	4.53	0.41	1	no	263.3	11.93
	Post BB-8	3.03	0.58	1.01	no	344.4	10.44
	Pre BB-12,13	1.65	0.55	1.18	no	107	1.77
	Post BB-12,13	2.82	0.27	0.99	no	155.9	4.40
	During BB-14	3.32	0.65	1.77	no	235.1	7.81
	Post BB-16	2.05	0.37	1.39	no	169.7	3.48
	Pre BB-17	3.3	0.88	1.94	yes	146.4	4.83
	During BB-17	1.51	1.62	2.32	yes	220.4	3.33
	During BB-17	1.43	0.85	1.13	yes	109.4	1.56
	During BB-18,19	1.25	0.78	1.45	yes	138.6	1.73
	During BB-20	3.29	0.65	1.46	yes	497.4	16.36
	Post BB-20	4.49	0.3	1.33	yes	349.1	15.67
	During BB-21	1.76	1.4	2	yes	988.9	17.40
	During BB-22	1.7	1.9	2.5	yes	750.2	12.75
	Post BB-22	3.19	0.87	1.27	yes	125.9	4.02
	During BB-23	1.48	5.35	6.2	yes	45.86	0.68
	Post BB-23	2.31	1.72	1.99	yes	77.42	1.79
	During BB-25	2.07	4.49	4.85	yes	86.34	1.79
	Post BB-25	5.56	3.14	3.14	yes	34.57	1.92

TABLE 12 (Continued)

Site	Run	Silt %	90 min moisture %	Overnight moisture %	Water added[a]	Total surface loading (g/m^2)	Surface silt loading (g/m^2)
	During BB-26	1.9	6.94	6.94	yes	53.63	1.02
	During BB-26,27	2.99	1.7	1.85	yes	100.3	3.00
	During BB-27	2.45	1.8	1.92	yes	129	3.16
	During BB-38,39	1.69		8.2	yes	79.21	1.34
	During BB-38,39	1.44		12.3	yes	368.1	5.30
	Post BB-48	1.95	1.86	2.1	no	40.86	0.80
2	Pre BB-33	3.02		1.5	no	165.7	5.00
	Post BB-34	4.88		0.91	no	287.7	14.04
	During BB-35	3.56		3.7	yes	437.4	15.57
	During BB-35	4.28		2	yes	376.4	16.11
	After BB-35	3.28		1.9	yes	239.8	7.87
	During BB-43	2.32	5.44	5.65	yes	185.2	4.30
	During BB-43	1.23	3.49	3.65	yes	243.9	3.00
	During BB-44	1.82	0.43	0.68	no	99.25	1.81
	10/21/92 at 1315	2.5[c]	6.95	6.95	yes	128.5	3.21
	10/21/92 at 1330	2.5[c]	2.73	2.9	yes	201.3	5.03
	10/21/92 at 1347	2.5[c]	3.65	3.77	yes	141.2	3.53
	10/21/92 at 1411	2.5[c]	4.7	4.87	yes	200.9	5.02
	10/21/92 at 1429	2.5[c]	2.68	2.96	yes	121.9	3.05
	10/21/92 at 1453	2.5[c]	2.35	2.35	yes	138.6	3.47
	10/21/92 at 1506	2.5[c]	4.87	5.13	yes	130.5	3.26
	10/21/92 at 1525	2.5[c]	2.63	2.78	yes	111.1	2.78
	10/21/92 at 1549	2.5[c]	4.48	4.78	yes	111.3	2.78
	10/21/92 at 1608	2.5[c]	4.25	5.08	yes	581.7	14.54
4	Post BB-31	19.2		3.78	no	356.1	68.37
	During BB-36	12.9		5	no	1901	245.23
	During BB-40	4.07		6.8	yes	505.2	20.56
	During BB-40,41	5.5		4.6	yes	295.1	16.23
	During BB-41	5.1		6.6	yes	1129	57.58
	During BB-41,42	8.84		3.9	yes	571	50.48
	Post BB-42	10.12		4.8	yes	1179	119.31
	Pre BB-121X	5.93	3.83	5.06	no	92.87	5.51
	10/23/92 at 1420	10.5[d]	2.03	2.93	yes	68.82	7.23
	10/23/92 at 1443	10.5[d]	6.93	7.68	yes	82.77	8.69

TABLE 12 (Continued)

Site	Run	Silt %	90 min moisture %	Overnight moisture %	Water added[a]	Total surface loading (g/m^2)	Surface silt loading (g/m^2)
	10/23/92 at 1502	10.5[d]	5.38	6.79	yes	342.6	35.97
	10/23/92 at 1520	10.5[d]	5.5	8.21	yes	332.5	34.91
	10/23/92 at 1539	10.5[d]	2.75	4.97	yes	508	53.34
	10/23/92 at 1558	10.5[d]	2.29	3.92	yes	466.1	48.94
	10/23/92 at 1623	10.5[d]	4.1	5.33	yes	177.5	18.64
	10/26/92 at 1431	5.59[e]		7.46	yes	519.4	29.03
	10/26/92 at 1451	5.59[e]		7.17	yes	605.5	33.85
	10/26/92 at 1511	5.59[e]		6.74	yes	530.9	29.68
	10/26/92 at 1546	5.59[e]		7.91	yes	442.7	24.75
	10/26/92 at 1606	5.59[e]		9.31	yes	651	36.39
	10/26/92 at 1616	5.59[e]		8.1	yes	445.8	24.92
	Overburden pile	12.5		9.73	no		
5	During BB-46	12.7		4.88	no	4180	530.86
	During BB-47	14		5.11	no	6388	894.32

[a,c,d,e] Refers to whether or not testing occurred with supplemental watering of the road surface. Samples were combined after moisture analysis, and a single silt % value was obtained.

TABLE 13. SUMMARY STATISTICS FOR ROAD SURFACE MATERIAL SAMPLES COLLECTED[a]

	Silt %	90 min moisture %	Overnight moisture %	Total surface loading (g/m^2)	Surface silt loading (g/m^2)
Site 1					
Mean	4.11	2.27	3.12	501	35.4
Std. dev.	3.72	1.75	1.99	444	60.2
No. of cases	10	10	15	15	10
Site 1B					
Mean	2.53	1.65	2.83	222	5.48
Std. dev.	1.09	1.71	2.72	225	5.21
No. of cases	26	24	26	26	26
Site 2					
Mean	2.99	3.74	3.42	217	8.04
Std. dev.	1.16	1.65	1.74	131	5.66
No. of cases	9	13	18	18	9
Site 4					
Mean	8.78	4.10	6.05	534	64.3
Std. dev.	4.66	1.73	1.76	424	71.6
No. of cases	10	8	21	21	10
Site 5					
Mean	13.4	–	5.00	5,280	713
Std. dev.	N/A	–	N/A	N/A	N/A
No. of cases	2	0	2	2	2

[a] Refer to Figure 1 for test site locations.

To the extent practical, MRI duplicated Cordero's standard sampling procedures, using media supplied by Inter-Mountain Laboratories (IML). Supplemental high-volume ambient air sampling began as soon as possible after the receipt of filters from IML. A total of nine additional 24-h ambient air sampling periods were realized, beyond the normal 1-day-in-6 frequency for the Cordero network. This essentially doubled the amount of high-volume data available for the period of the field exercise.

Figure 5 shows the locations of the Cordero monitoring stations. Equipment at each of the three sites was as follows:

Site	Air quality monitors
HV1	Standard hi-vol (TSP)
HV2 and HV2A	Two colocated standard hi-vols and two colocated Wedding PM-10 samplers
HV3	Standard hi-vol and Wedding PM-10 sampler

Tables 14 and 15 present the TSP and PM-10 concentrations, respectively, measured during the 1992 field exercise. Appendix A presents copies of monitoring results supplied by IML.

4.4 SATURATION SAMPLING RESULTS

In addition to operating Cordero's monitors on a nominal 1-day-in-2 frequency, MRI also conducted 10 days of "saturation" sampling at the six locations shown in Figure 6. Saturation samples refer to small, battery-powered devices originally developed to "saturate" an area with PM-10 monitors. Sampling locations were chosen to be downwind of the major north pit sources under typical wind conditions. The 10 days provided practical experience and insight into using saturation samplers during a second phase of field activities directed toward air quality measurements.

Table 16 presents the saturation sampling results. As can be seen from the table, MRI encountered several difficulties with the saturation sampling, including negative sample weights on the filters that showed visible discoloring. Negative weights were found on both the quartz and fiber film media recommended by EPA and its equipment contractor (ManTech). Other specific findings are as follows:

1. Contrary to some fears expressed to MRI, the battery packs can reliably provide 24 h of sampling time.

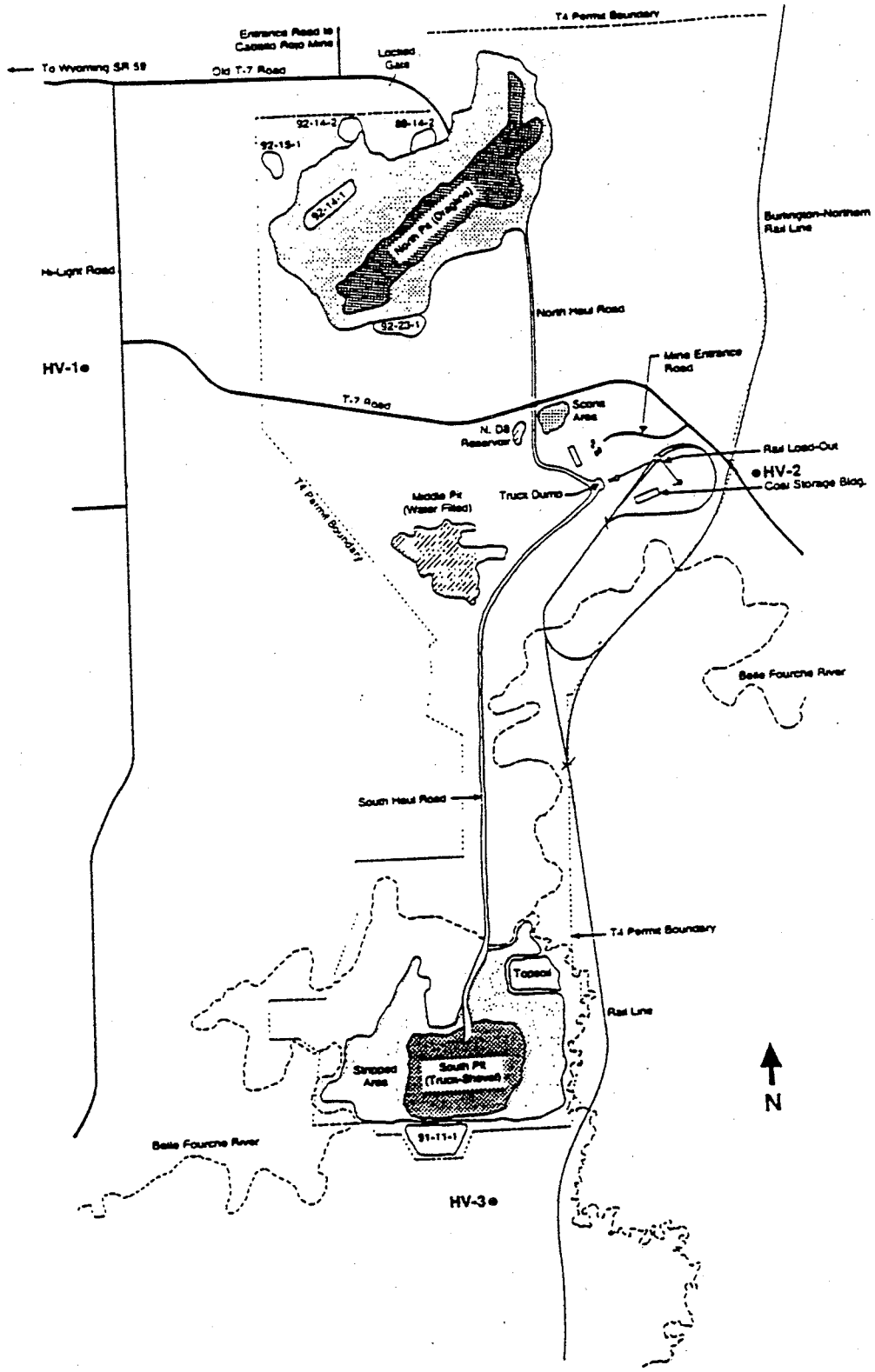


Figure 5. Cordero monitoring sites, HV-1, HV-2, and HV-3.

TABLE 14. MONITORED TSP CONCENTRATIONS ($\mu g/m^3$)

Date	Monitoring station[a]			
	HV1	HV2[b]	HV2a[b]	HV3
09/03/92	37	.	46	26
09/09/92	21	.	44	56
09/15/92	37	.	55	30
09/21/92	.	.	43	46
09/27/92	.	25	32	18
09/11/92	35	42	59	39
09/13/92	25	47	34	.
09/17/92	45	49	63	65
09/23/92	.	47	54	27
09/29/92	.	50	55	27
10/01/92	.	50	62	.
10/03/92	.	29	34	25
10/07/92	8	16	.	11
10/09/92	12	31	.	.
10/13/92	30	36	48	30
10/15/92	17	21	33	16
10/17/92	39	63	77	34
10/21/92	23	51	60	18
10/23/92	25	57	58	23
10/27/92	34	33	33	.

[a] Refer to Figure 5 for monitoring locations.
[b] Colocated monitors.

TABLE 15. MONITORED PM-10 CONCENTRATIONS ($\mu g/m^3$)

Date	Monitoring station[a]		
	HV2[b]	HV2a[b]	HV3[c]
09/03/92	12	11	.
09/09/92	13	13	.
09/15/92	20	21	.
09/21/92	11	10	.
09/27/92	9	8	.
09/11/92	19	19	.
09/13/92	10	10	.
09/17/92	13	13	.
09/23/92	20	20	.
09/29/92	17	17	13
10/01/92	.	.	16
10/03/92	14	13	16
10/07/92	5	5	6
10/09/92	11	11	9
10/13/92	.	13	15
10/15/92	12	11	.
10/17/92	24	25	20
10/21/92	18	18	11
10/23/92	22	22	16
10/27/92	10	11	16

[a] Refer to Figure 5 for station locations.
[b] Colocated monitors.
[c] PM-10 sampler added to station HV3 during September 1993.

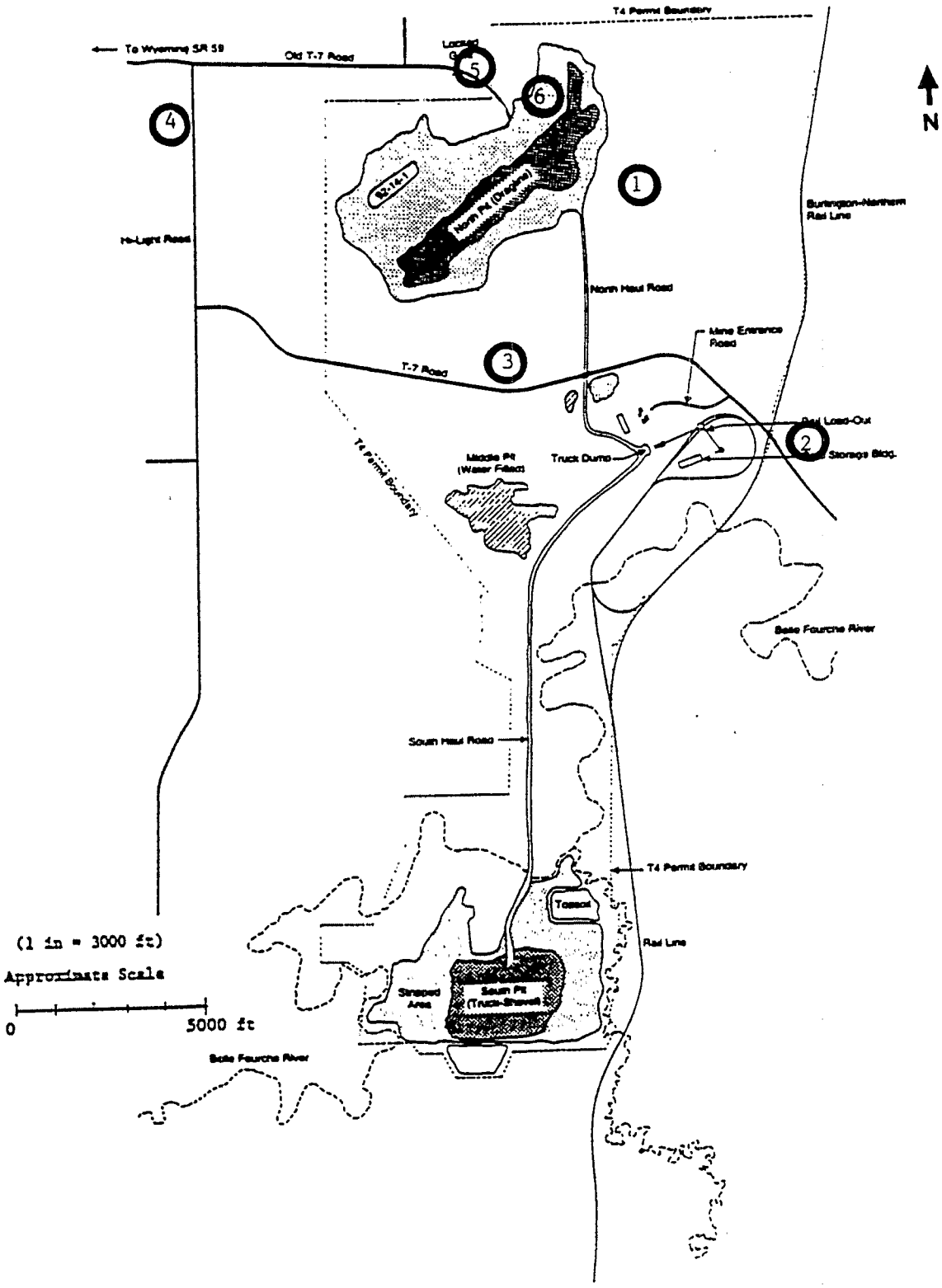


Figure 6. Saturation sampler locations, 1 through 6.

TABLE 16. SATURATION SAMPLER RESULTS

Sampling date	Sampler location	Stop time in hours	Start time in hours	Run time in hours	Average flow in l/min	Filter number	Filter type	Final wt. in mg	Tare wt. in mg	Net sample in mg	PM-10 conc in ug/acm
Oct. 20-21	1	113.3	98.75	14.55	5.20	9235002	quartz	118.07	118.07	0.00	0.00
		137.79	113.3	24.49	5.35	9235013	quartz	117.41	117.44	-0.03	-3.82
	2	387.5	373.17	14.33	5.10	9235001	quartz	122.50	122.33	0.17	38.77
		412.83	387.5	25.33	5.15	9235016	quartz	119.69	119.58	0.11	14.05
	3	354.65	340.27	14.38	4.70	9235004	quartz	119.16	119.35	-0.19	-46.85
		379.94	354.65	25.29	5.00	9235014	quartz	119.14	119.03	0.11	14.50
	4	509.09	494.67	14.42	5.00	9235007	quartz	121.49	121.58	-0.09	-20.80
		534.37	509.09	25.28	5.00	9235015	quartz	121.13	121.10	0.03	3.96
	5	408.13	393.71	14.42	4.70	9235003	quartz	120.84	120.85	-0.01	-2.46
		432.57	408.13	24.44	5.10	9235011	quartz	120.24	120.19	0.05	6.69
	6	435.32	421.1	14.22	5.20	9235006	quartz	122.41	122.40	0.01	2.25
		459.89	435.32	24.57	5.20	9235012	quartz	122.59	122.26	0.33	43.05
Oct. 21-22	1	160.98	137.79	23.19	5.35	9235019	quartz	116.16	116.84	-0.68	-91.35
	2	435.24	412.83	22.41	5.15	9235025	quartz	118.74	118.75	-0.01	-1.44
	3	402.36	379.94	22.42	4.70	9235031	quartz	118.35	118.43	-0.08	-12.65
	4	556.84	534.37	22.47	5.00	9235018	quartz	121.19	121.22	-0.03	-4.45
	5	455.68	432.57	23.11	5.10	9235033	quartz	119.24	119.14	0.10	14.14
	6	483	459.89	23.11	5.20	9235017	quartz	119.85	119.52	0.33	45.77

TABLE 16 (Continued)

Sampling date	Sampler location	Stop time in hours	Start time in hours	Run time in hours	Average flow in l/min	Filter number	Filter type	Final wt. in mg	Tare wt. in mg	Net sample in mg	PM-10 conc in ug/acm
Oct. 22-23	1	185.46	160.98	24.48	5.25	9234004	fib. film	68.79	68.72	0.07	9.08
	2	459.33	435.24	24.09	5.00	9234006	fib. film	69.38	69.31	0.07	9.69
	3	426.52	402.36	24.16	4.70	9234001	fib. film	68.76	68.66	0.10	14.68
	4	580.92	556.84	24.08	5.00	9234005	fib. film	67.77	67.85	-0.08	-11.07
	5	480.19	455.68	24.51	5.10	9234003	fib. film	69.02	69.06	-0.04	-5.33
	6	507.46	483	24.46	5.15	9234002	fib. film	68.36	68.34	0.02	2.65
Oct. 23-24	1	209.85	185.46	24.39	5.35	9234007	fib. film	69.38	69.34	0.04	5.11
	2	483.26	459.33	23.93	5.10	9234012	fib. film	68.17	68.25	-0.08	-10.93
	3	450.38	426.52	23.86	4.75	9234010	fib. film	68.12	68.08	0.04	5.88
	4	604.76	580.92	23.84	5.00	9234011	fib. film	68.10	68.11	-0.01	-1.40
	5	504.57	480.19	24.38	5.15	9234009	fib. film	67.97	68.04	-0.07	-9.29
	6	531.82	507.46	24.36	5.30	9234008	fib. film	68.34	68.13	0.21	27.11
Oct. 24-25	1	234.92	209.85	25.07	5.00	9235027	quartz	117.94	117.82	0.12	15.96
	2	508.82	483.26	25.56	5.30	9235029	quartz	117.02	116.91	0.11	13.53
	3	476.06	450.38	25.68	4.70	9235028	quartz	119.94	119.83	0.11	15.19
	4	630.54	604.76	25.78	5.00	9235026	quartz	117.56	117.57	-0.01	-1.29
	5	529.16	504.57	24.59	5.10	9235030	quartz	118.37	118.25	0.12	15.95
	6	556.38	531.82	24.56	5.20	9235032	quartz	118.15	117.89	0.26	33.93

TABLE 16 (Continued)

Sampling date	Sampler location	Stop time in hours	Start time in hours	Run time in hours	Average flow in l/min	Filter number	Filter type	Final wt. in mg	Tare wt. in mg	Net sample in mg	PM-10 conc in ug/acm
Oct. 25-26	1	257.68	234.92	22.76	5.20	9234019	fib. film	68.88	68.94	-0.06	-8.45
	2	532.51	508.82	23.69	4.90	9235023	quartz	120.50	120.53	-0.03	-4.31
	3	499.62	476.06	23.56	4.80	9235028	quartz	119.94	119.83	0.11	16.21
	4	647.79	630.54	17.25	5.00	9235008	quartz	118.86	118.87	-0.01	-1.93
	5	552.42	529.16	23.26	5.00	9234020	fib. film	67.40	67.39	0.01	1.43
	6	579.68	556.38	23.3	5.10	9234013	fib. film	67.78	67.75	0.03	4.21
Oct. 26-27	1	281.73	257.68	24.05	5.30	9235020	quartz	120.71	120.66	0.05	6.54
	2	555.97	532.51	23.46	5.10	9234015	fib. film	68.22	68.29	-0.07	-9.75
	3	523.07	499.62	23.45	4.80	9234014	fib. film	70.03	70.03	0.00	0.00
	4	671.23	647.74	23.49	5.00	9234021	fib. film	68.43	68.44	-0.01	-1.42
	5	576.44	552.42	24.02	5.10	9235021	quartz	120.14	120.12	0.02	2.72
	6	603.71	579.68	24.03	5.30	9235022	quartz	117.84	117.66	0.18	23.56
Oct. 27-28	1	308.06	281.73	26.33	5.30	9235009	quartz	119.80	119.80	0.00	0.00
	2	581.79	555.97	25.82	5.10	9234027	fib. film	66.29	66.06	0.23	29.11
	3	548.92	523.07	25.85	4.80	9234025	fib. film	67.10	67.14	-0.04	-5.37
	4	696.16	671.23	24.93	5.00	9234026	fib. film	66.29	66.23	0.06	8.02
	5	602.85	576.44	26.41	5.10	9235024	quartz	117.93	117.94	-0.01	-1.24
	6	630.08	603.71	26.37	5.10	9235034	quartz	118.69	118.51	0.18	22.31

2. Sampling cartridges and media appeared to develop considerable static charge which complicated filter handling activities. It is not clear as to how important low relative humidity at the mine is to this phenomenon.

3. Filters appeared to be only slightly discolored after 10 to 12 h of exposure. Taken together with the negative catches, saturation samplers are probably best suited to operation in areas with higher expected concentrations (i.e., "near-field" measurements within the immediate vicinity of PM sources).

4.5 SOURCE ACTIVITY MONITORING RESULTS

In many atmospheric dispersion modeling programs, source activity is often estimated by apportioning annual production equally throughout the year.[7,8] The ability to provide better resolution in source activity levels is important in meeting the field program's second phase goal of model evaluation.

The August 31 meeting in Casper resulted in a decision to collect relatively detailed records about major source activity levels on the days that the Cordero high-volume network was operated. This was later extended to those days when saturation sampling occurred. The following information was obtained for each shift during approximately 15 days of source activity monitoring:

1. The location of each shovel in operation.

2. Number and size of haul trucks assigned to each shovel and route taken.

3. Number and general location of scrapers in use at the mine site.

Table 17 presents summary statistics for the number of trucks assigned per shift to haul either overburden or coal during the 20 days that the Cordero air monitoring or saturation sampler network was operated. Figure 7 presents a bar graph of the number of haul trucks in use per either shift. Figure 8 presents the same type of information for the mine's two scrapers and Figure 9 summarizes the number of equipment in use during any one shift.

Both the table and the figures show that values considerably different form long-term averages are quite likely. As noted earlier, better definition of source activity levels is a major objective of the second phase of field studies.

TABLE 17. SUMMARY STATISTICS FOR DAILY NUMBER OF HAUL TRUCKS IN USE BY MATERIAL AND SHIFT

		Material[a]	
Pit	Shift	Coal	Overburden
North	Day	2.8 ± 1.6	2.5 ± 1.6
North	Evening	2.4 ± 1.9	2.4 ± 1.7
South	Day	0.55 ± 1.4	0.75 ± 1.3
South	Evening	0.35 ± 1.1	0.60 ± 1.4

[a] Entries represent mean ± standard deviation of number of trucks used.

BAR GRAPH OF NO. OF HAUL TRUCKS IN USE (DAY SHIFT)

N = 19

VALUE	COUNT	PERCENT
0.	0	.00
1.	0	.00
2.	0	.00
3.	0	.00
4.	0	.00
5.	5	26.32
6.	5	26.32
7.	2	10.53
8.	3	15.79
9.	2	10.53
10.	1	5.26
11.	1	5.26

BAR GRAPH OF NO. OF HAUL TRUCKS IN USE (EVENING SHIFT)

N = 18

VALUE	COUNT	PERCENT
0.	0	.00
1.	0	.00
2.	0	.00
3.	0	.00
4.	0	.00
5.	5	27.78
6.	5	27.78
7.	4	22.22
8.	2	11.11
9.	2	11.11

Figure 7. Frequency distributions of number of haul trucks in use during the day and evening shifts.

BAR GRAPH OF SCRAPERS IN USE (DAY SHIFT)

N = 19

VALUE	COUNT	PERCENT
0.	3	15.79
1.	10	52.63
2.	6	31.58

BAR GRAPH OF SCRAPERS IN USE (EVENING SHIFT)

N = 18

VALUE	COUNT	PERCENT
0.	2	11.11
1.	10	55.56
2.	6	33.33

Figure 8. Frequency distributions of number of scrapers in use during day and evening shifts.

BAR GRAPH OF NO. OF HAUL TRUCKS IN USE (EITHER SHIFT)

N = 37

VALUE	COUNT	PERCENT
0.	0	.00
1.	0	.00
2.	0	.00
3.	0	.00
4.	0	.00
5.	10	27.03
6.	10	27.03
7.	6	16.22
8.	5	13.51
9.	4	10.81
10.	1	2.70
11.	1	2.70

BAR GRAPH OF SCRAPERS IN USE (EITHER SHIFT)

N = 37

VALUE	COUNT	PERCENT
0.	5	13.51
1.	20	54.05
2.	12	32.43

Figure 9. Frequency distribution of pieces of major equipment in use over either shift.

SECTION 5

REEXAMINATION OF CURRENT EMISSION FACTORS

The field study described in this report is a direct result of 1990 CAAA's requirement to reexamine the accuracy of factors for fugitive particulate emissions at surface coal mines. This section provides further discussion of the emission factors presented in Section 3, focusing on how well available models predict observed emissions.

As discussed in Section 3, the field tests conducted during the field exercise fall into the following three broad classes:

Source	Runs
Haul truck travel	BB-2 through -43 in Table 9
Light-duty vehicle travel	BB-44, -45, -48 in Table 9
Scraper travel	BB-46, -47 in Table 9

Primary emphasis was placed upon haul truck traffic because the earlier emission factor review[2] stressed the need for new data for that source.

The performance of available emission factor models for each of these source categories is discussed below.

5.1 OVERVIEW OF CURRENTLY AVAILABLE EMISSION FACTORS

An objective of this field program was to compare field measurements against emission factors available for surface coal mines. In addition, the new and existing emission factor data bases have been compared in an effort to determine whether the two may be combined for the purpose of developing revised models.

Section 8.24 of EPA Publication AP-42[1]—"Compilation of Air Pollutant Emission Factors"—presents numerous predictive equations and single-valued emission factors for use at western surface coal mines. The predicted equations in the AP-42 section are based upon results from a series of field measurements[9] conducted during the late

1970s and early 1980s. Figures 10 and 11 reproduce AP-42 Tables 8.24-2 and 8.24-4, respectively, and together the two tables represent official EPA guidance on estimating particulate emissions from surface coal mines.

Figure 12 presents TSP emission factors recommended by the WDEQ for surface mining activities.[8] The WDEQ factor for haul roads is based on an old (1978) version of the AP-42 "generic" unpaved road emission factor. As such, the WDEQ factor is not based on a separate surface mine field measurement data set. In addition, WDEQ includes a correction term in each factor to account for fallout of large particles.

At least two points about the evaluation should be noted. First, the only available factors for the PM-10 size range are based on a mean ratio of a factor for different size fractions. The particle sizing data from the field program that resulted in Figure 10 did not lend themselves to developing an "after-the-fact" factor once the PM-10 size range was promulgated as the basis for NAAQS in 1987. Thus, it was important to obtain independent TSP and PM-10 emission test data in order to assess the adequacy of the available PM-10 emission factors.

Second, there have been great changes in what constitutes "typical" conditions at surface coal mines since the testing was conducted 10 or more years ago. For example, since the time that the older data base was developed,

1. "Typical" haul trucks have greatly increased capacity.
2. There is far less general, light-duty traffic.
3. Permanent haul routes have been controlled for many years.

An earlier report[2] presented the history of field testing at surface coal mines and traced the development of the emission factors currently contained in Section 8.24 of AP-42. That report summarized candidate emission factors for different fugitive dust sources at surface coal mines; that summary is presented as Table 18. Note that, throughout this section, emission factors and other variables are described in English units—such as pounds and miles—rather than metric (SI) units—such as kilograms and kilometers.

5.2 HAUL TRUCK TRAVEL

Emissions from haul truck traffic were by far of the most interest in the present study. This level of interest is warranted because prior studies show that haul roads typically account for a very high portion of emissions from surface coal mining.[7,8] Furthermore, as noted in the preceding discussion, haul trucks now have far greater capacity and permanent coal haul routes are typically highly controlled, as compared to the time when the older data base was assembled.

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]				Units	Emission Factor Rating
		TSP $\leq$30 um	$\leq$15 um	$\leq$10 um[d]	$\leq$2.5 um/TSP[e]		
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 10. Photocopy of Table 8.24-2 of AP-42.

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.

Figure 11. Photocopy of Table 8.24-4 of AP-42.

STATE OF WYOMING
DIVISION OF AIR QUALITY
GUIDELINE FOR FUGITIVE DUST EMISSION FACTORS
FOR MINING ACTIVITIES

January, 1979

(Particulate size 30 um and smaller, no fallout function required)

Mining Activity	Emission Factor (Ref) x % Suspended (note)	Control Technique	Control Efficiency
1. Overburden Removal			
Dragline	0.04 lb/yd³(1) x 0.75	———	——
Truck/Shovel	0.02 lb/ton(1) x 0.75	———	——
. Scraper	[1]32 lbs/hr(2)	watering	50%
2. Haul Roads	[2]E = 0.81s(S/30)((365-W)/365) lb/VMT(3)	a. watering	50%
	x 0.62	[3]b. oil or chemical dust suppressant	60%
Access Roads	[2]E = 0.81s(S/30)((365-W)/365) lb/VMT(3)	a. asphalt paving or equal	85%
	x 0.62	b. stabilization of base with chip and seal surface	70%
3. Haul Road Repair and Construction			
Grader	[1]32 lbs/hr(2)	watering	50%
Scrapers	[1]32 lbs/hr(2)	watering	50%
4. Wind Erosion	[4]E = AIKCL'V' ton/acre/yr(4)	———	——
5. Product Removal			
Coal-Truck/Shovel	0.003 lb/ton(1) x 0.70	———	——
Coal-Frontend Loader	[5]0.003 lb/ton x 0.70	———	——
Uranium-Frontend Loader	[6]0.003 lb/ton	———	——
6. Product Dumping			
Coal-Truck Dump	0.017 lb/ton(1) x 0.75	a. coal-water sprays	50%
Uranium	[7]0.017 lb/ton	b. coal-negative pressure collection system	85%
7. Stockpiles (wind erosion)			
Coal	[8]1.2 u lb/acre/hr x 0.75	Enclosure	99%
Uranium	[9]E = 0.05(s/1.5)(d/235)(f/15)(D/90) lbs/ton(5)	watering	50%
8. Blasting			
Overburden	50 lb/blast(1) x 0.75	prevent overshooting	——
Coal	35 lb/blast(1) x 0.75	prevent overshooting	——

Notes:

1. If applicant's estimate of grader and scraper hours includes wet days, then reduce emissions by the factor $\frac{365-W}{365}$ where W = no. of days where rain or snow precipitation is 0.01" or greater

2. From Reference 3 $E = 0.81s(S/30)\left(\frac{365-W}{365}\right)$ lbs/VMT
   where s = silt content of road surface material (%)
   S = vehicle speed in mph
   W = no. of days with 0.01" precipitation or more
   .actor should be squared for speeds less than 30 mph
   Apply correction for number or width of tires compared to light vehicles

3. Frequency and rate of application as per manufacturer's recommendation or as justified by applicant for site, specific road materials and experience.

4. From Reference 4 E = AIKCL'V' ton/acre/yr
   where A = portion of losses which become suspended
   I = soil erodibility
   K = surface roughness factor
   C = climatic factor
   L'= unsheltered field width factor
   = 0.7 for 1000' & 1.0 for 2000' and greater
   V'= vegetative cover factor (use V' = 1.0)

Soil Type	A	I, ton/acre/yr
Rocky, Gravelly	0.025	38
Sandy	0.010	134
Fine	0.041	52
Clay Loam	0.025	47

K - Varies from 0.5 to 1.0; 1.0 is normally used.
C - Table 3.11 of reference or $C = 0.345\ (u^3) + (P-E)^2$
where u = average wind velocity (mph)

5. It was felt that given the similarity of operation of a frontend loader to a shovel that measured emissions from Reference 1 of 10 to 20 times more (loader vs. shovel) were not reasonable, thus the selection of 0.003 lbs/ton.

6. Given the usual wetness of observed uranium ore in surface mines this factor is probably conservative. Factor estimate only - not measured. No correction is made for % suspended material as data is not available.

7. Estimate only - not measured. No correction is made for % suspended material as data is not available.

8. 1.2 u lb/acre/hour where u is wind speed in m/sec. Factor includes some equipment activity around and on piles. Total emission should include truck dumping, etc. Adjust by ratio of dry days to total days in existence.

9. From Reference 5 E = 0.05(s/1.5)(d/235)(f/15)(D/90) lbs/ton throughput through pile
   where s = silt content of material (%)
   d = no. of dry days/yr
   f = percentage of time wind speed exceeds 12 mph
   D = duration of material in storage (days)

References:

(1) EPA-908/1-78-003, "Survey of Fugitive Dust from Coal Mines", by PEDCo Environmental, Inc., February, 1978.

(2) EPA-908/1-76-008, "Wyoming Air Quality Maintenance Area Analysis", by PEDCo Environmental, Inc., May, 1976.

(3) [illegible] 42 "Compilation of Air Pollutant Emission Factors (Supplements 1-8)", May, 1978.

(4) [illegible] "Evaluation of Fugitive Dust Emissions from Mining", by PEDCo Environmental, Inc., April, 1976.

(5) C. Cowherd and R.V. Hendrika, "Development of Fugitive Dust Emission Factors for Industrial Sources", Paper No. 78-35.4, Annual Meeting Air Pollution Control Association, Houston, Texas (June, 1978).

Figure 12. WDEQ emission factors for surface mining activities (as taken from Reference 8).

TABLE 18. SUMMARY OF EMISSION FACTOR EQUATIONS FOR SCMs

Source	Material[a]	Equation/Factor[b]	Particle size	Units	Comments
Blasting	C or O	$961\ A^{0.8}/D^{1.8}M$	TSP	lb/blast	Reference 9. Appeared in previous AP-42.
	C or O	$0.0005\ A^{1.5}$	TSP	lb/blast	Section 8.24 of AP-42. See Note c.
Truck loading	C	$1.16/M^{1.3}$	TSP	lb/ton	Reference 9, AP-42 Section 8.24.
	C	$0.089/M^{0.9}$	PM-10	lb/ton	Section 8.24 of AP-42. See Note d.
	C or O	k	Note e	lb/ton	AP-42 Section 11.2.3.
	C	$(0.0032)(U/5)^{1.3}/(M/2)^{1.4}$	TSP	lb/workday/acre	Reference 10.
		339.6			
Bulldozing	C	$78.4\ s^{1.2}/M^{1.3}$	TSP	lb/hr	Section 8.24 of AP-42, Reference 9.
	C	$14\ s^{1.5}/M^{1.4}$	PM-10	lb/hr	Section 8.24 of AP-42. See Note d.
	O	$5.7\ s^{1.2}/M^{1.3}$	TSP	lb/hr	Reference 9, Section 8.24.
	O	$0.75\ s^{1.5}/M^{1.4}$	PM-10	lb/hr	AP-42 Section 8.24. See Note d.
	O	54	TSP	lb/hr	Reference 10.
Dragline	O	$0.0021\ d^{1.1}/M^{0.3}$	TSP	lb/yd^3	Reference 9. AP-42 Section 8.24.
	O	$0.0016\ d^{0.7}/M^{0.3}$	PM-10	lb/yd^3	Section 8.24 of AP-42. See Note d.
	O	$k(0.0032)(U/5)^{1.3}/(M/2)^{1.4}$	Note e	lb/ton	AP-42 Section 11.2.3.
Scrapers in travel mode		$2.7 \times 10^{-5}\ s^{1.3}\ W^{2.4}$	TSP	lb/vmt	Reference 9. Section 8.24 of AP-42.
		$3.7 \times 10^{-6}\ s^{1.4}\ W^{2.5}$	PM-10	lb/vmt	AP-42 Section 8.24. See Note d.
		$k(5.9)(s/12)(S/30)(W/3)^{0.7}$ $(w/4)^{0.5}(\frac{365-P}{365})$	Note f	lb/vmt	AP-42 Section 11.2.1.
Grading		$0.040\ S^{2.5}$	TSP	lb/vmt	Reference 9. AP-42 Section 8.24.
		$0.031\ S^{2.0}$	PM-10	lb/vmt	Section 8.24 of AP-42. See Note d.
		54	TSP	lb/hr	Reference 10.
General traffic		$5.79/M^{4.0}$	TSP	lb/vmt	Reference 9, AP-42 Section 8.24.
		$1.9/M^{4.3}$	PM-10	lb/vmt	AP-42 Section 8.24. See Note d.
		$k(5.9)(s/12)(S/30)(W/3)^{0.7}$ $(w/4)^{0.5}(365-p)/365$	Note f	lb/vmt	AP-42 Section 11.2.1.
		$4.83(S/45)^{1.50}$	TSP	lb/vmt	Reference 11.
		$1.22(S/45)^{1.86}$	PM-10	lb/vmt	Reference 11.

(continued)

TABLE 18 (Continued)

Source	Material[a]	Equation/Factor[b]	Particle size	Units	Comments
Haul trucks		$0.0067\ w^{3.4}\ L^{0.2}$	TSP	lb/vmt	Reference 9. Section 8.24.
		$0.0031\ w^{3.5}$	PM-10	lb/vmt	Section 8.24. See Note d.
		246.8	TSP	lb/vmt	Reference 10.
		$k(5.9)(s/12)(S/30)(W/3)^{0.7}(w/4)^{0.5}(365-p)/365$	f	lb/vmt	Section 11.2.1 in AP-42.
		22.0 – 5.47N	TSP	lb/vmt	Reference 12

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

[b] Symbols used:

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

[c] Factor based on a reexamination of results in Reference 9.

[d] PM-10 factors based on IP emission factors developed in Reference 9.

[e] For SP (particles less than or equal to 30 microns in aerodynamic diameter), k = 0.74; for PM-10, k = 0.35.

[f] For SP (particles less than or equal to 30 microns in aerodynamic diameter), k = 0.80; for PM-10, k = 0.36.

Figure 13 compares a variety of measurements from the current study (i.e., the "new" data set) to the study[6] that led to the factors in Figure 10. Throughout the remainder of this report, the "old" data set refers to those measurements supporting the AP-42 emission factors (i.e., those presented in Reference 9). The PM-10 and TSP data sets for haul trucks are given in Appendix B. Figure 13 contains several "box and whisker" plots which are convenient means comparing different samples. Each box contains 50% of the observations in a data set. (For example, half of the old data set's PM-10 emission factors lie between approximately 1 and 4 lb/VMT.) The median is represented by the tick mark within the box. The whiskers on each box typically span the range of values observed, except if any values are "outside" certain limits. In that case, outliers are shown as either "0" or "*" and the whiskers denote the range of the values that are not outliers. Finally, parentheses denote approximate 95% confidence intervals for the median.

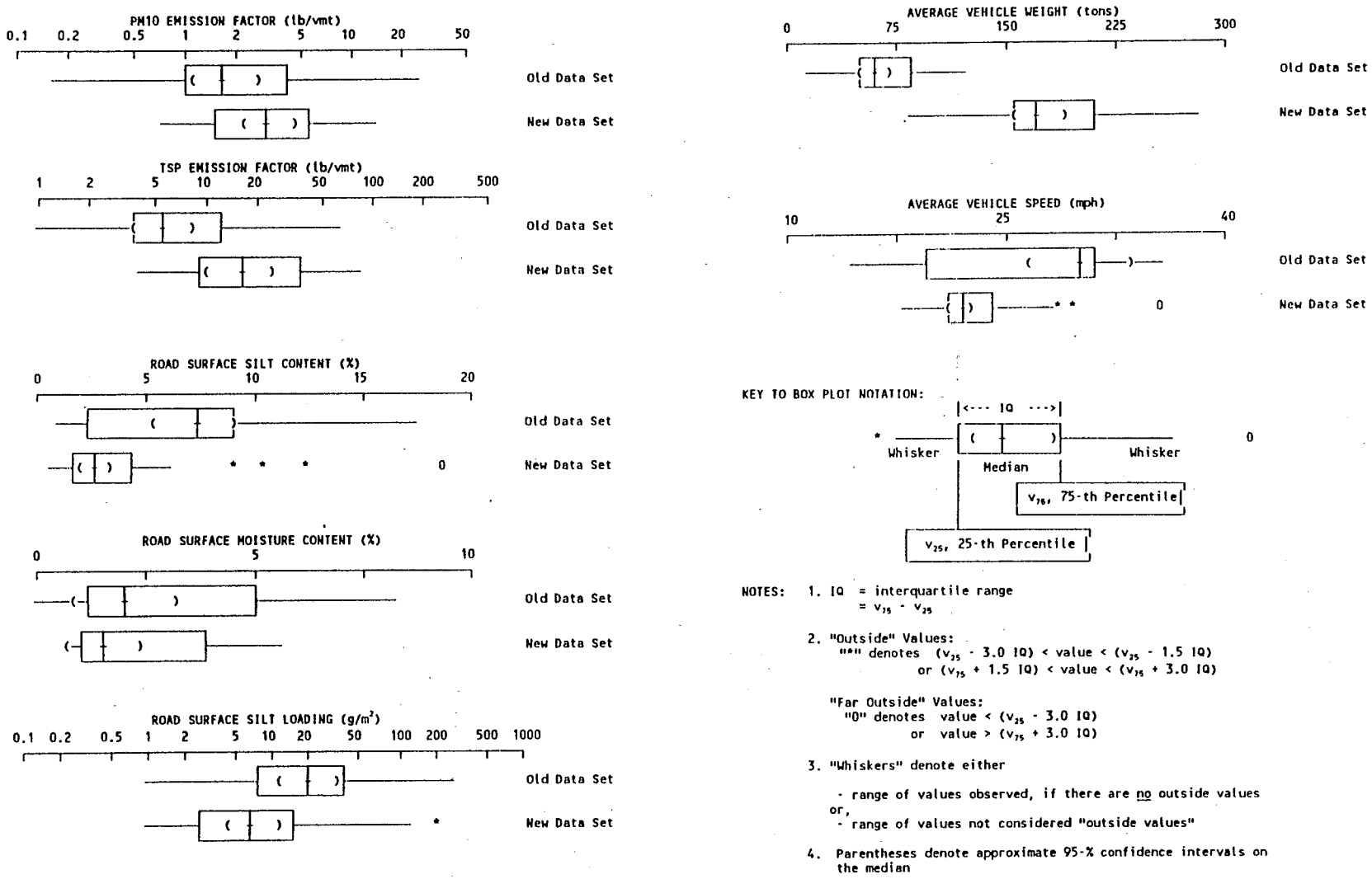
Keeping the explanation of box plots in mind, one can see from Figure 13 that the measured PM-10 emission factors do not differ substantially from one data set to another. TSP emission factors show greater differentiation from one set to the other. As a group, emission factor values from the new set tend to be slightly greater than emission factors in the older set.

Figure 13 also shows that there are very substantial differences between the "source conditions" in the two data sets. In keeping with the trend toward larger haul trucks, average vehicle weights observed in the current program are two to three times greater than in those tests supporting the AP-42 Section 8.24 emission factors.

Silt loading and silt content values do not differ as dramatically as do the vehicle weights; nevertheless, the means in the old and new data sets differ at the 5% level of significance. Furthermore, the mean vehicle speed in the new data set is significantly (at 5% level) lower than in the old data set.

Figure 13 shows that even though the two sets of emission factors are somewhat comparable, similarity in source conditions is not the reason. The new data set has heavier haul trucks; all other things being equal, one would expect the new emission factors to be greater than the old factors. On the other hand, the new data set contains "cleaner" road surfaces and slower-moving vehicles; all other things being equal, one would now expect the new factors to be lower than the old factors.

To better understand how well available emission factors predict measured emission levels, a series of comparisons was undertaken. The old and new measured emissions were compared against values estimated from three different emission factors:



NOTES: 1. IQ = interquartile range
$= v_{75} - v_{25}$

2. "Outside" Values:
"*" denotes $(v_{25} - 3.0\ IQ) < \text{value} < (v_{25} - 1.5\ IQ)$
or $(v_{75} + 1.5\ IQ) < \text{value} < (v_{75} + 3.0\ IQ)$

"Far Outside" Values:
"0" denotes value $< (v_{25} - 3.0\ IQ)$
or value $> (v_{75} + 3.0\ IQ)$

3. "Whiskers" denote either

- range of values observed, if there are no outside values

or,

- range of values not considered "outside values"

4. Parentheses denote approximate 95-% confidence intervals on the median

Figure 13. Box plots of emission factors and independent variables in the old and new haul truck data sets (27 and 34 data points, respectively).

1. Haul truck factor in AP-42 Section 8.24:

$$e_{10} = 0.0031\ (W)^{3.5}$$
$$e_{TSP} = 0.0067\ (w)^{3.4}\ (L)^{0.2}$$

where e_{10}, e_{TSP} = PM-10 or TSP emission factor (lb/VMT)
w = mean number of wheels
L = surface silt loading (g/m^2)

2. The "generic" unpaved road emission factor in AP-42 Section 11.2.1:

$$e = k\ (5.9) \left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}$$

where: e = PM-10 or TSP emission factor (lb/VMT)
k = 0.36 for PM-10, 0.80 for TSP)
s = surface silt content (%)
S = mean vehicle speed (mph)
W = mean vehicle weight (tons)
w = mean number of wheels per vehicle

3. The WDEQ-recommended haul truck factor:

$$e = 0.81\ s \left(\frac{S}{30}\right)$$

where: e = TSP emission factor (lb/VMT)
s = surface silt content (%)
S = mean vehicle speed (mph)

The WDEQ factor for haul roads is based on an old (1978) version of the AP-42 "generic" unpaved road emission factor. As such, the WDEQ factor is not based on a separate surface mine field measurement data set. Note that because the emission factor is being compared against near-source measurements, the 0.62 correction term has not been applied.

The ability of various emission factor models to predict measured emission factors is illustrated in Figures 14 through 23.

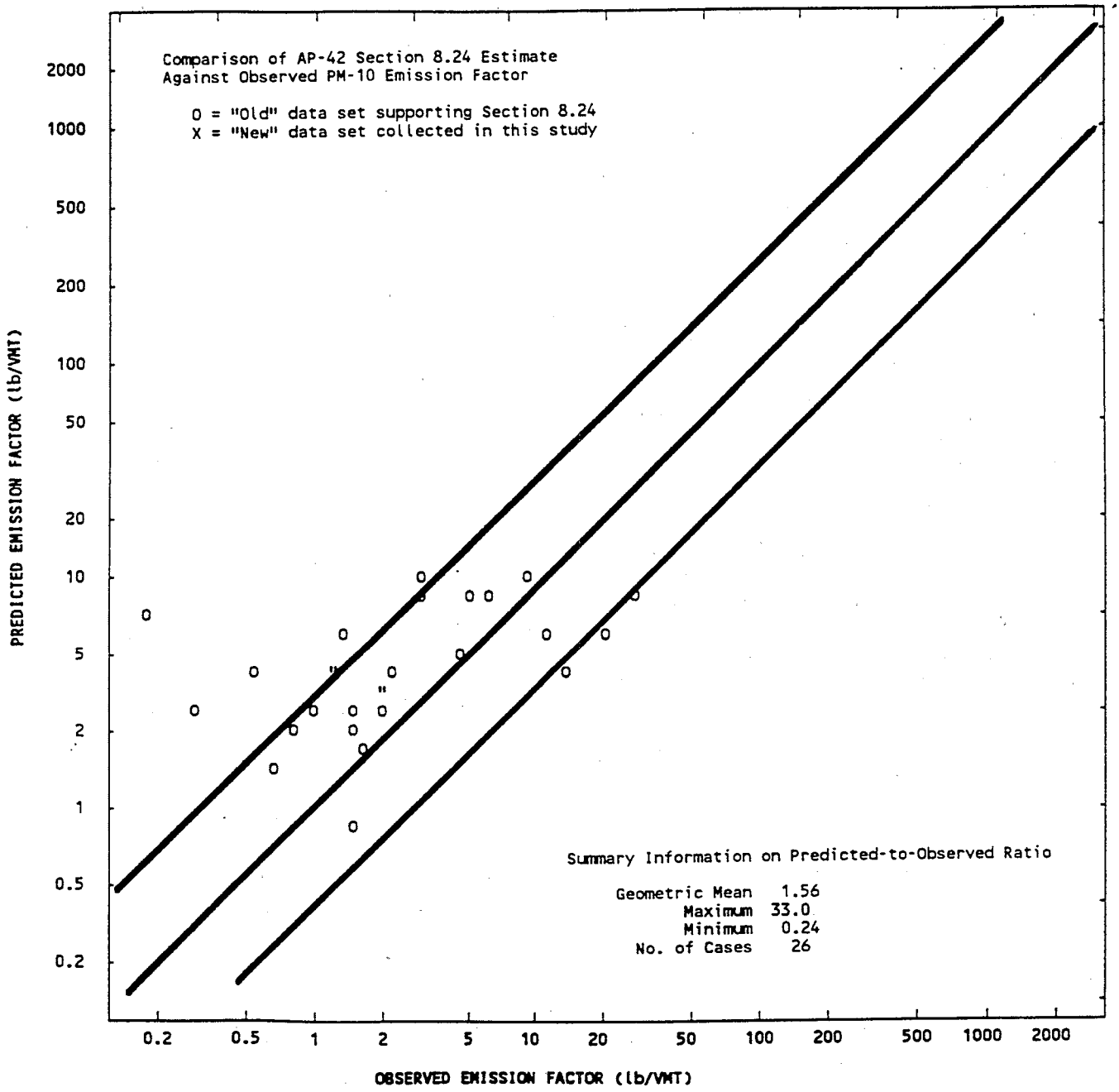


Figure 14. Comparison of measured emission factors against PM_{10} Section 8.24 haul road estimates for the old data sets. Centerline represents perfect agreement, other two lines are factor-of-three bounds.

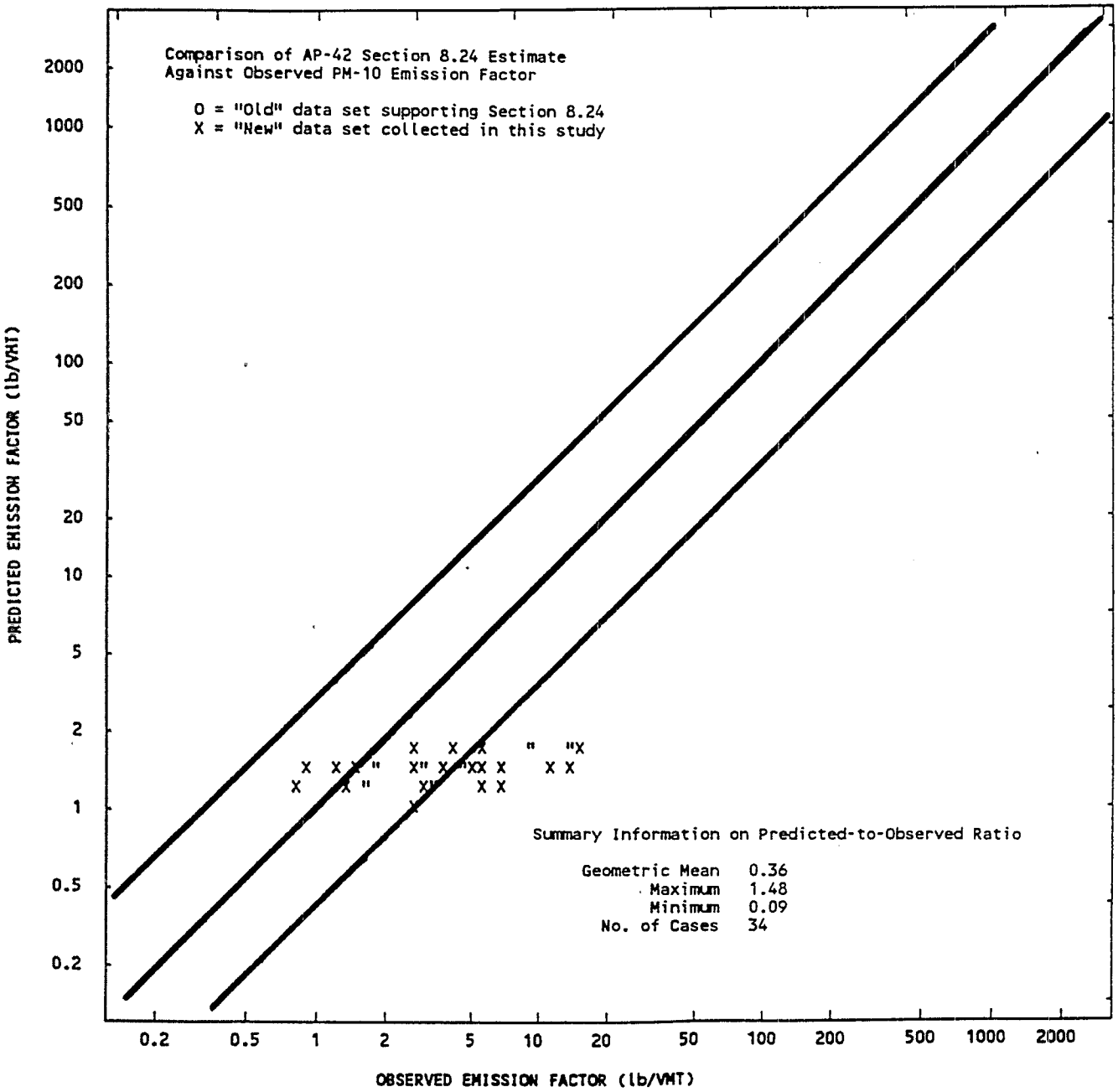


Figure 15. Comparison of measured emission factors against PM_{10} Section 8.24 haul road estimates for the new data sets. Centerline represents perfect agreement, other two lines are factor-of-three bounds.

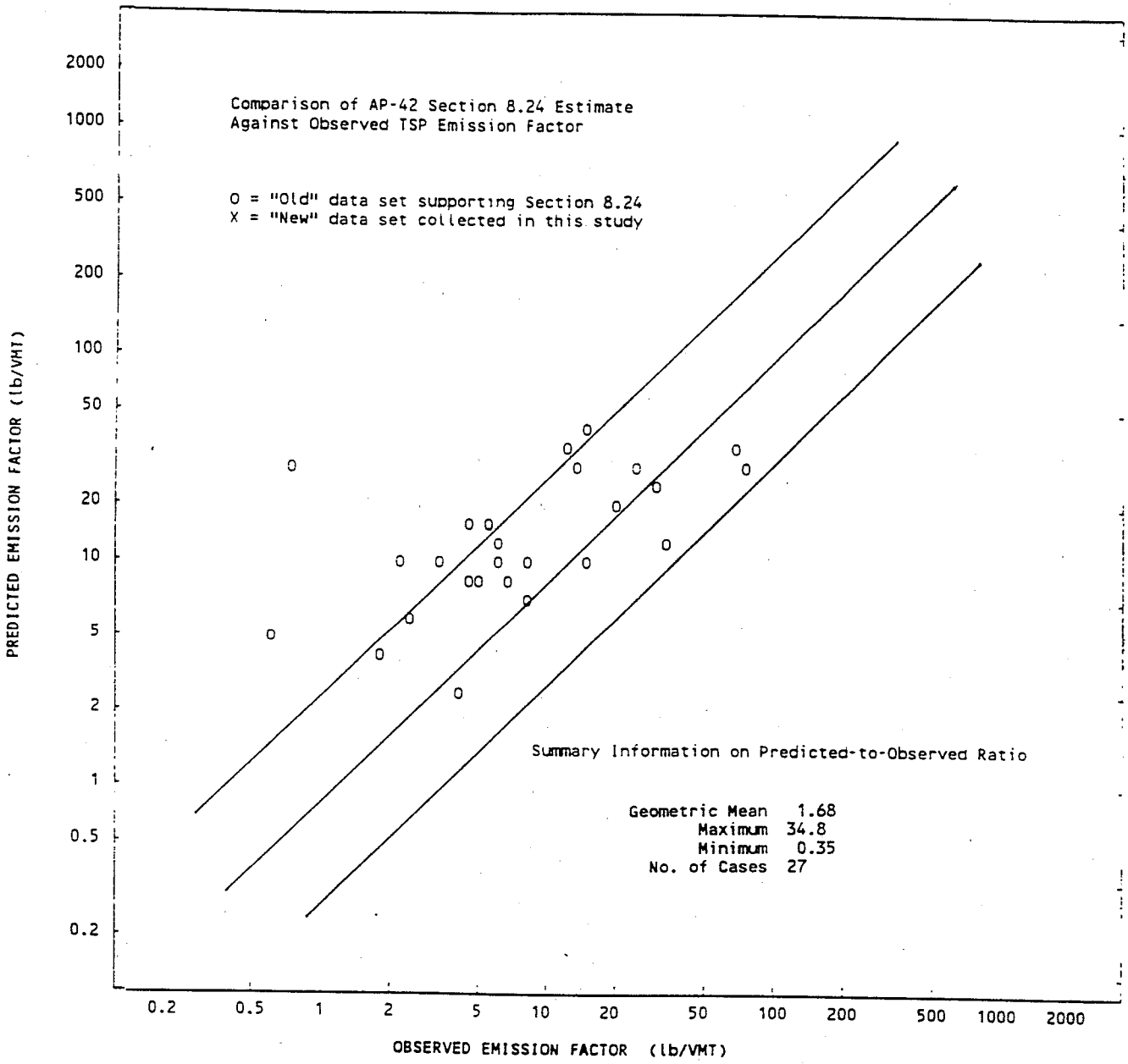


Figure 16. Comparison of measured emission factors against TSP Section 8.24 haul road estimates for the old data sets. Centerline represents perfect agreement, other two lines are factor-of-three bounds.

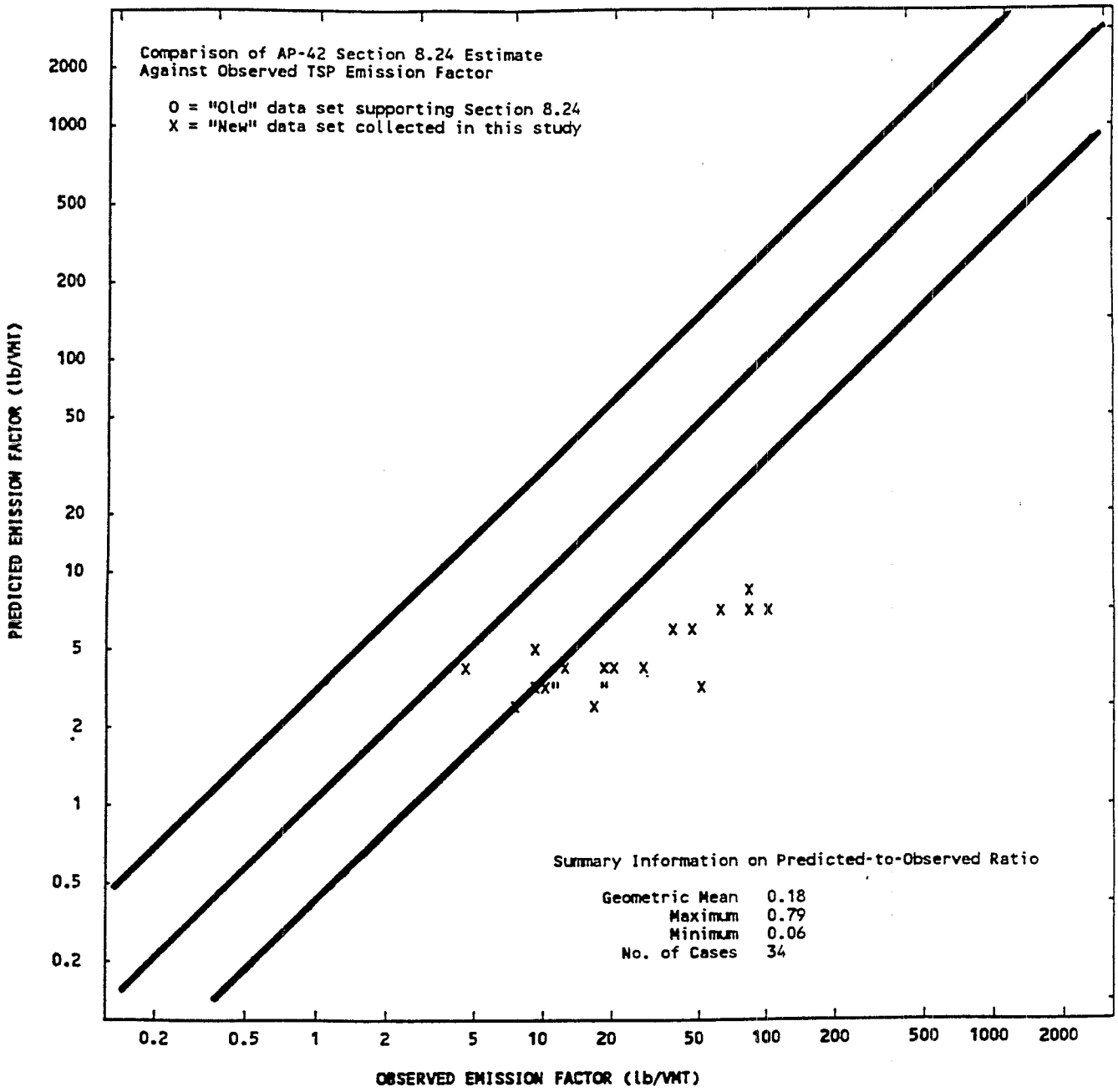


Figure 17. Comparison of measured emission factors against TSP Section 8.24 haul road estimates for the new data sets. Centerline represents perfect agreement, other two lines are factor-of-three bounds.

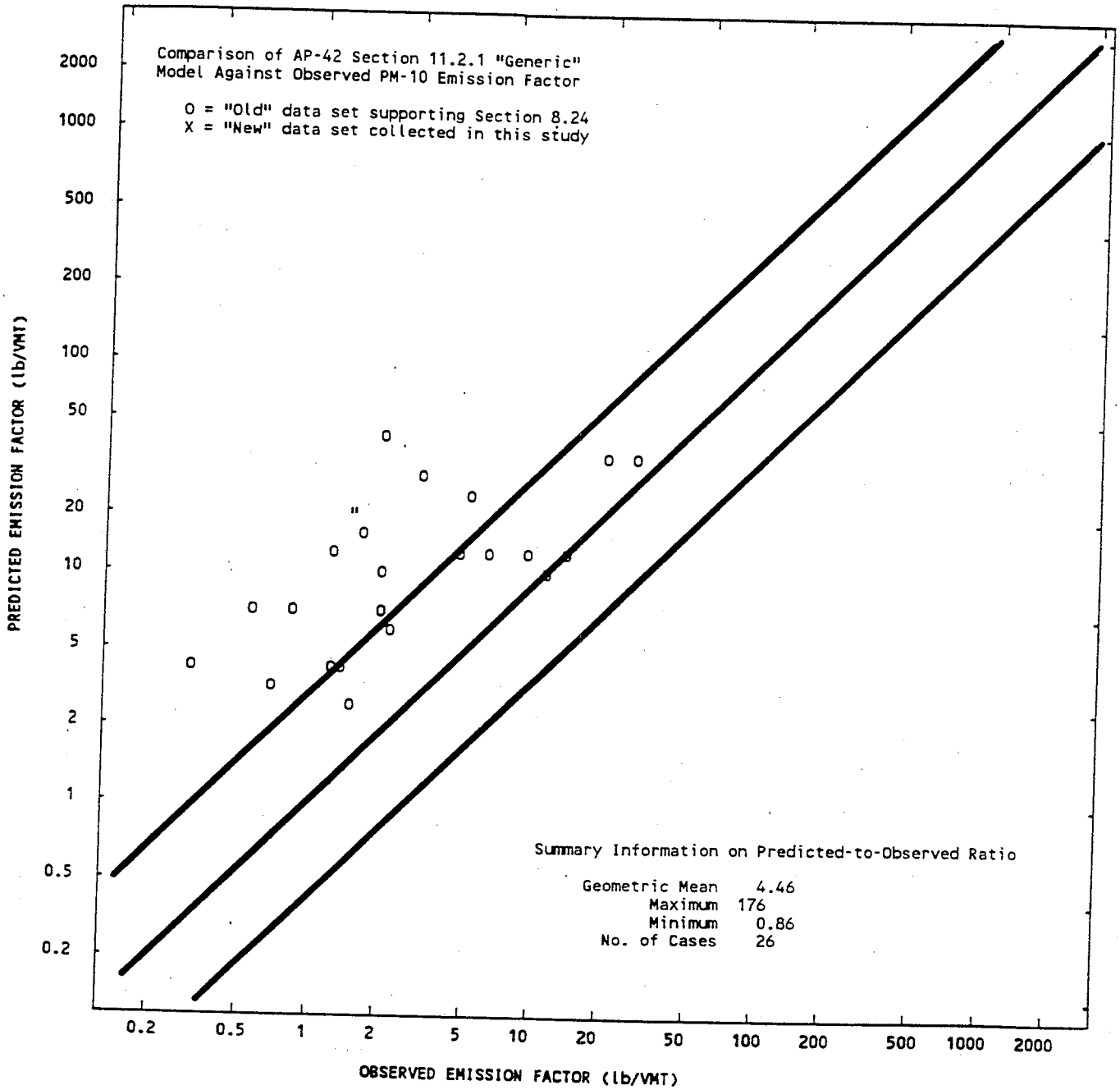


Figure 18. Comparison of measured emission factors against PM_{10} Section 11.2.1 estimates for the old data sets. Centerline represents perfect agreement, other two lines are factor-of-three bounds.

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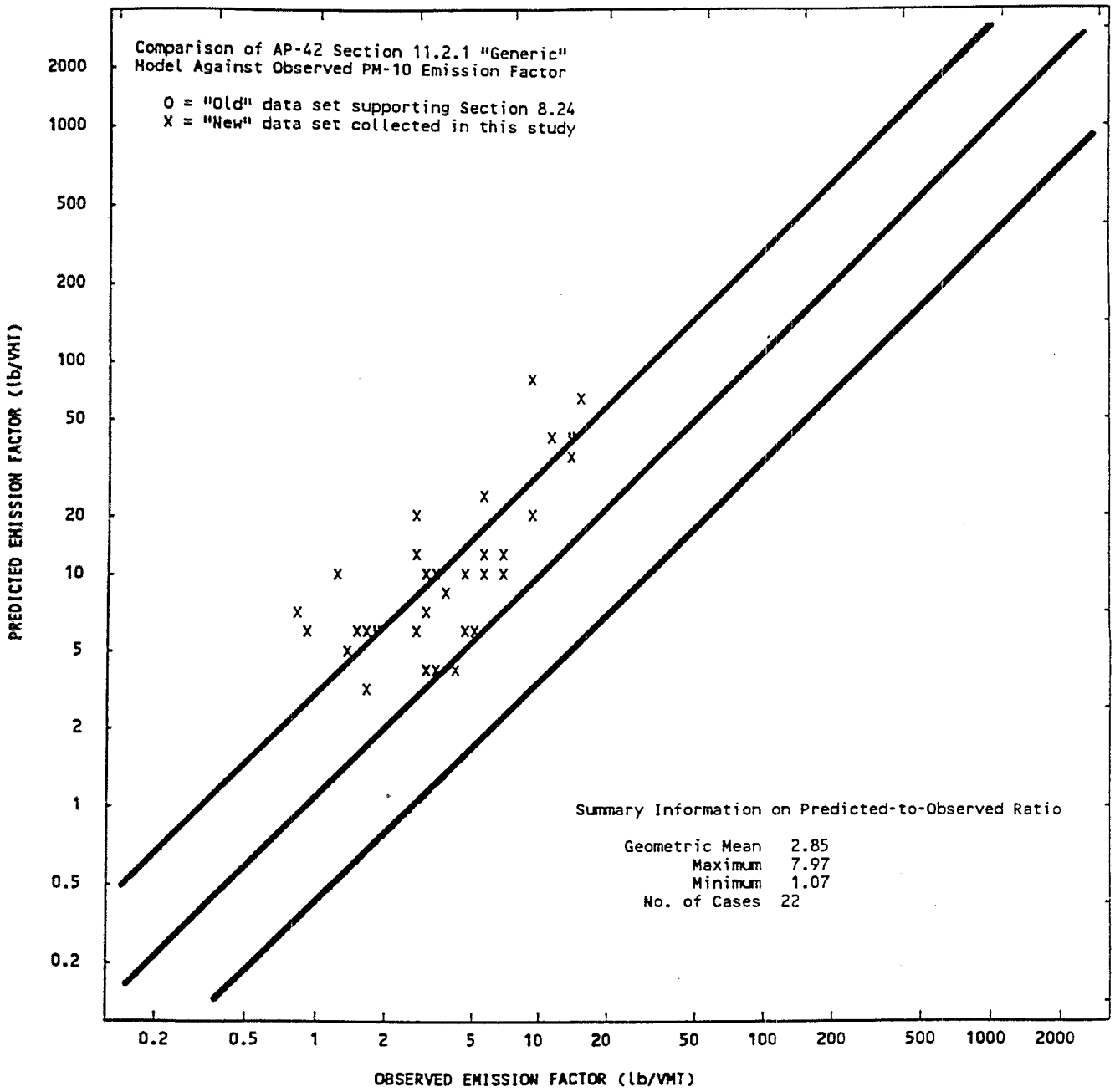

Figure 19. Comparison of measured emission factors against PM_{10} Section 11.2.1 estimates for the new data sets. Centerline represents perfect agreement, other two lines are factor-of-three bounds.

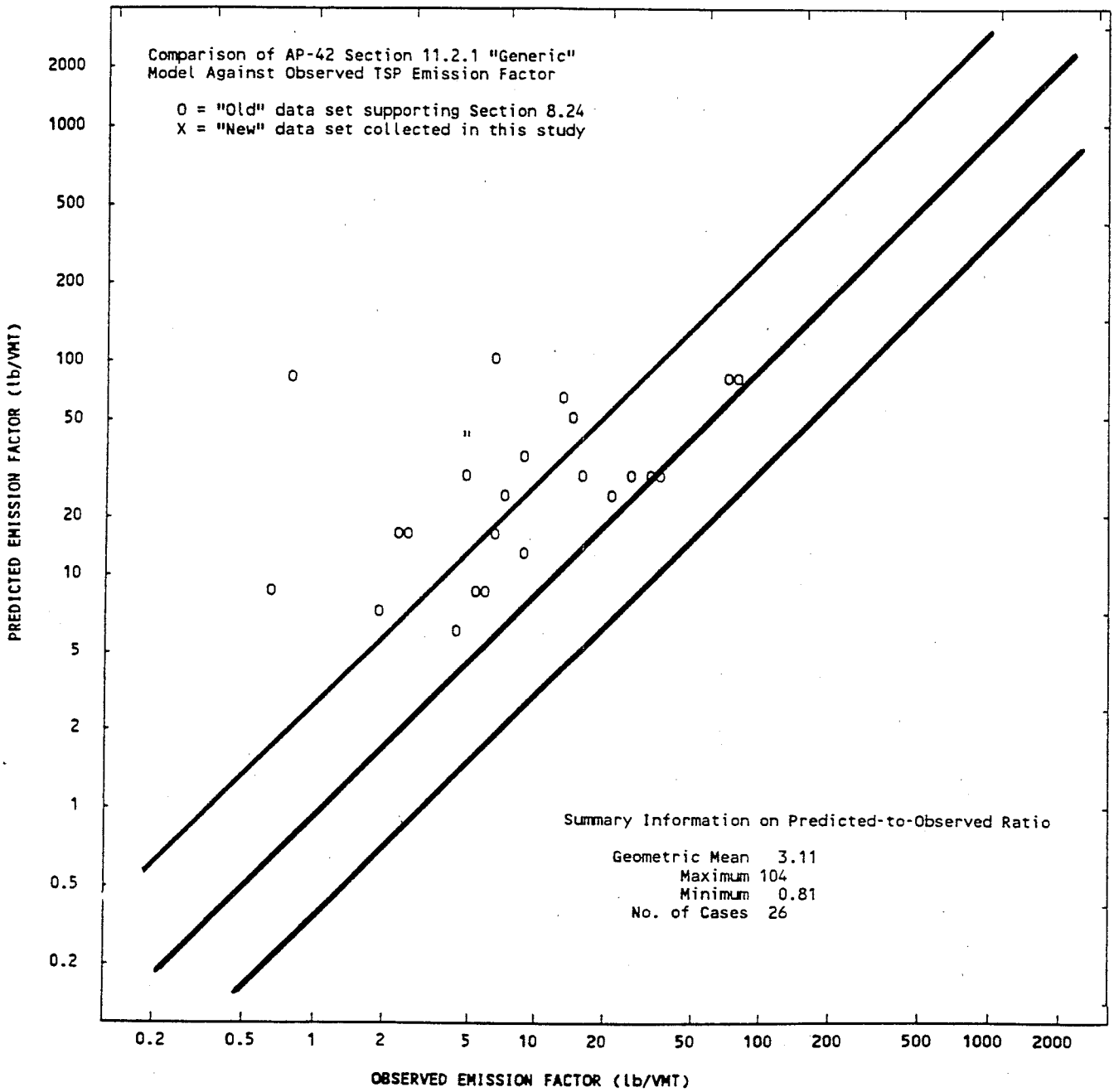

Figure 20. Comparison of measured emission factors against TSP Section 11.2.1 estimates for the old data sets. Centerline represents perfect agreement, other two lines are factor-of-three bounds.

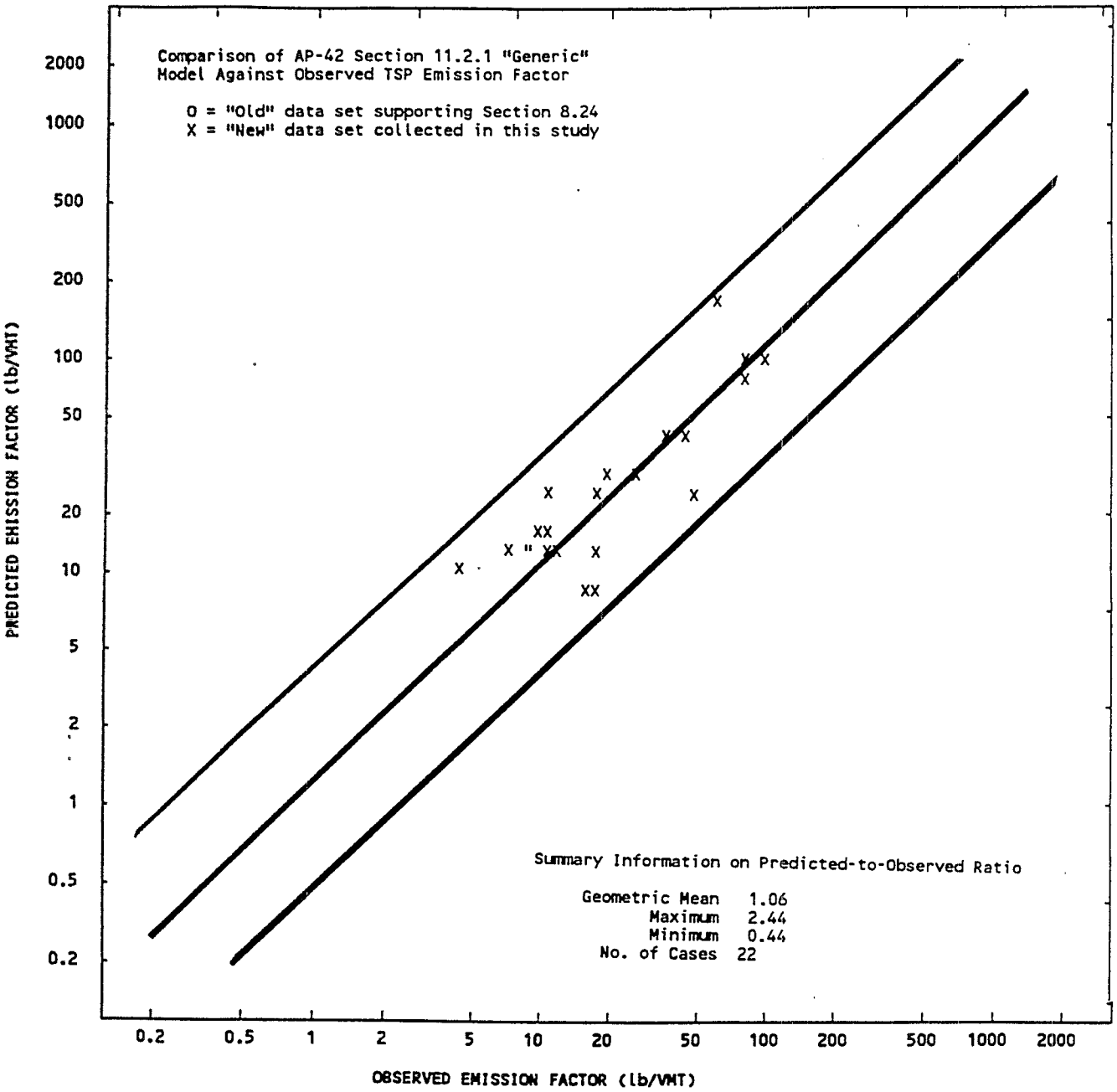

Figure 21. Comparison of measured emission factors against TSP Section 11.2.1 estimates for the new data sets. Centerline represents perfect agreement, other two lines are factor-of-three bounds.

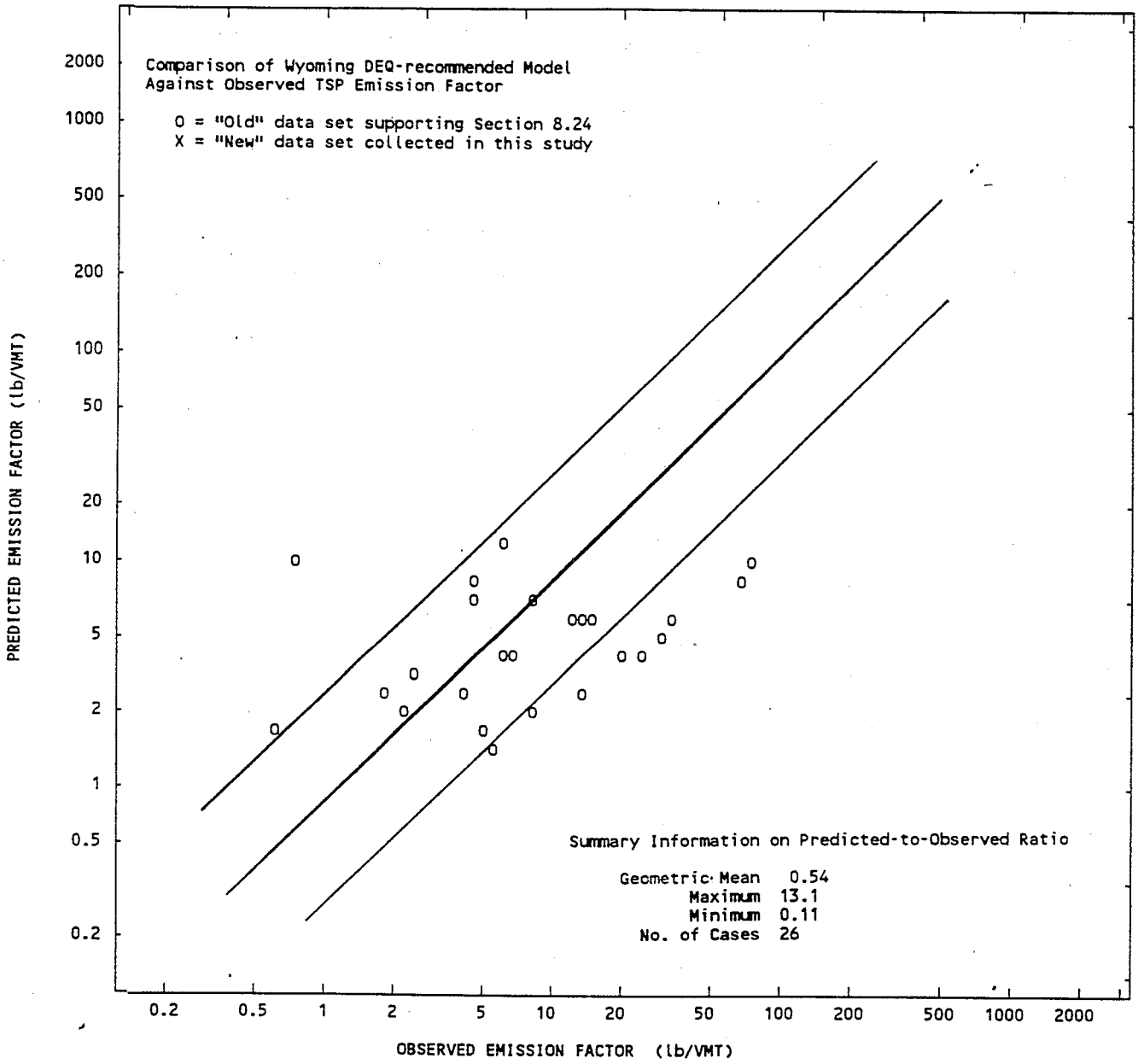

Figure 22. Comparison of measured emission factors against Wyoming suspended haul road estimates for the old data sets. Centerline represents perfect agreement, other two lines are factor-of-three bounds.

MRI-M\R9712-55

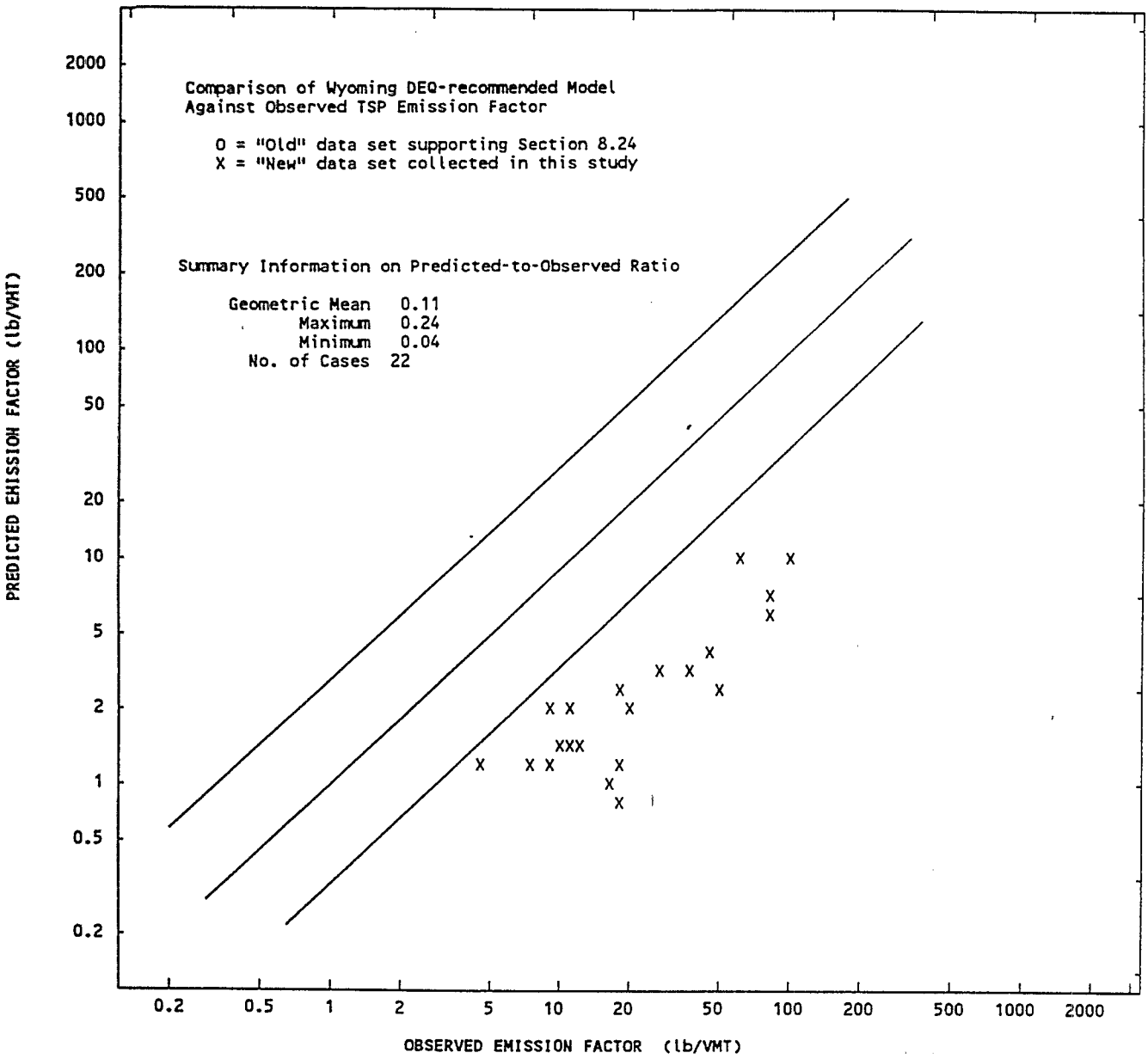

Figure 23. Comparison of measured emission factors against Wyoming suspended haul road estimates for the new data sets. Centerline represents perfect agreement, other two lines are factor-of-three bounds.

Particle size range	Data set	Emission factor model	Figure No.
PM-10	old	AP-42 Section 8.24	14
PM-10	new	AP-42 Section 8.24	15
TSP	old	AP-42 Section 8.24	16
TSP	new	AP-42 Section 8.24	17
PM-10	old	AP-42 Section 11.2.1	18
PM-10	new	AP-42 Section 11.2.1	19
TSP	old	AP-42 Section 11.2.1	20
TSP	new	AP-42 Section 11.2.1	21
TSP	old	WDEQ factor[a]	22
TSP	new	WDEQ factor[a]	23

[a] See Figure 12.

The performance of each model is discussed briefly below.

Haul road models in AP-42 Section 8.24 (Figures 14 through 17)—The discussion will be largely limited to comparisons with the new data set because the older data set was used to develop the Section 8.24 models. In general, these models tend to underpredict the newer independent data set, with the degree of underprediction becoming more pronounced for the higher observed emission factors. For both PM-10 and TSP, the Section 8.24 models yield predicted emission factors in a fairly tight band. This is especially true for PM-10—all predicted factors lie between roughly 1 and 2 lb/VMT, while observed factors span an additional order of magnitude. The tight band of predicted values is due to the fact that the Section 8.24 model includes only the mean number of wheels as a correction parameter, and that parameter did not vary substantially in the new data set. In summary, the Section 8.24 models in their present state substantially underestimated the newer set of measured haul road emission factors. This may not be particularly surprising, given that Figure 13 showed that some underlying source conditions are far different between the two data sets.

"Generic" unpaved road model in AP-42 Section 11.2.1 (Figures 18 through 21)—Because none of the old data set was used to develop the generic unpaved road models, Figures 18 through 21 all represent independent applications of the unpaved road emission factor model. In general, the source conditions of the two data sets are outside the range of source conditions in tests supporting the Section 11.2.1 models. In each comparison, the Section 11.2.1 model tends to overpredict observed haul truck emission factors. The degree of overprediction is less pronounced for the new data set as compared to the old. For only the TSP emissions in the new data set (i.e., Figure 21) can the performance of the generic unpaved road emission factor be considered reasonably acceptable.

Wyoming DEQ haul road model (Figures 22 and 23)—As was the case earlier, the comparisons in Figures 22 and 23 represent independent applications of the WDEQ haul truck factor. As noted earlier, the WDEQ factor is essentially the same as an old version of the AP-42 generic unpaved road equation. There is a trend to underpredict observed emission factors, especially for the new data set. The underprediction results even though the WDEQ's fallout correction factor has not been applied; had the correction been applied, the already too low estimates would be approximately 40% lower still.

In addition to the predictive equations discussed above, Table 16 presents two other candidate TSP emission factors for haul trucks. The single-valued factor of 246.8 lb/VMT (taken from Reference 10) represents extreme overprediction for each data set considered. On the other hand, the expression based upon road waterings per hour[12] appears to predict the new data set fairly well, as shown below:

		Ratio of predicted-to-observed TSP emission factors	
	No. of cases	Geometric mean	Standard geometric deviation
Uncontrolled	10	0.715	2.30
Controlled	12	1.12	2.09
Overall	22	0.915	2.22

However, when this factor is applied to tests in the historical data base, the resulting comparisons are not as favorable. For the "old" data set of Reference 9 which supports AP-42 Section 8.24, the mean predicted-to-observed ratio is 1.77, with a standard geometric deviation of 2.61. Only uncontrolled tests can be readily compared because the test report does not contain the information necessary to compute road watering frequency.

None of the available emission factor models appear fully capable of accurately predicting independent haul truck emission data, as a whole. This is especially true for the PM-10 size range. The issue is further discussed in Section 5.4 of this report.

5.3 LIGHT- AND MEDIUM-DUTY TRAFFIC

The review of emission factors[2] recommended that the "generic" unpaved road equation in AP-42 Section 11.2.1 replace the current factor for light- to medium-duty vehicle emission factor in Section 8.24. That recommendation was based on a comparison against independent emission data.

This study provided new independent test data against which the recommended factor could be evaluated. A total of three light-duty vehicle emission tests (Runs BB-44, -45, and -48) were conducted with captive traffic during the present study. (The old and new light- to medium-duty vehicle data sets are presented in Appendix B.) Although the AP-42 Section 8.24 model can produce very accurate estimates in many cases, the same model has been found to be capable of providing a very unacceptable estimate. This is believed to be the result of the model's dependence on the fourth power of moisture content (see Figure 10). For all three light- to medium-duty vehicle tests conducted int he present study, the moisture contents were outside the range in the supporting data set.

Table 19 compares the new test results to estimates obtained from the recommended "generic" model.

TABLE 19. RESULTS FROM LIGHT-DUTY VEHICLE EMISSION TEST COMPARISONS

Size range	Run		Measured emission factors (lb/VMT)	AP-42 Section 11.2.1 estimates (lb/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

The generic unpaved road emission factor model in AP-42 Section 11.2.1 appears to produce acceptable predictions over a broad range of source conditions. In fact, when the generic unpaved road emission factor is applied to the combined light- and medium-duty data sets, the following mean ratios are 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 above comparisons indicate that the generic unpaved road emission factor model can provide very acceptable estimates for light- to medium-duty traffic at surface coal mines.

5.4 SCRAPERS

Two tests (Runs BB-46 and -47) were conducted of emissions from scrapers in a travel mode. (The combined scraper data sets are presented in Appendix B.) Measured emissions were compared to:

1. The scraper emission factor model given in AP-42 Section 8.24.

2. The generic unpaved road emission factor model in Section 11.2.1 of AP-42.

Table 20 presents the results from these comparisons.

TABLE 20. RESULTS FROM SCRAPER EMISSION TEST COMPARISONS

		Ratio of predicted to observed	
Size range	Run	AP-42 Section 8.24	AP-42 Section 11-2.1
PM10	BB-46	0.374	0.897
	BB-47	0.624	1.57
Geometric mean		0.482	1.18

Although Table 20 suggests that the generic unpaved road model might be preferable to the current scraper expression in AP-42 Section 8.24, that conclusion does not appear to be warranted upon further examination. When applied to the combined scraper emission data sets, the generic unpaved road equation substantially overpredicts observed emissions:

		Predicted-to-observed ratio	
Size range	No. of cases	Geometric mean	Std. geometric deviation
PM-10	15	2.43	3.52
TSP	13	1.50	3.21

Unlike haul trucks and haul routes, current scraper activities at surface coal mines are not substantially different from the time when the old data set was

assembled. Based on the limited data available for comparison, the Section 8.24 scraper model is recommended for emission estimation purposes. A recent update to AP-42 Section 11.2 has placed a high priority on the need for additional emission field testing of earthmoving activities.[13]

5.5 REVISION OF HAUL TRUCK EMISSION FACTOR

Section 5.2 found none of the currently available emission factor models to be fully capable of accurately estimating independent emission data, especially for the PM-10 size range. This finding may not come as a surprise because of the differences in the data sets. Although emission factors are fairly comparable, there are very pronounced differences in source conditions between the data sets. The new haul truck data set is characterized by higher mean vehicle weights, slower speeds, and lower silt loadings.

A primary purpose of any emission factor is to project what emission levels will be in the future. For that reason it is important that emission factors reflect the source conditions that can be expected in the future. Even though Section 5.2 found a few combinations of measured and predicted emissions that agreed fairly well, the favorable comparisons were certainly not the result of similarities in underlying source conditions. For example, the generic unpaved road emission factor model performed quite acceptably in estimating the new TSP emission data set. Nevertheless, this does not occur because the new source conditions are similar to those in the underlying data base. The new tests' mean vehicle weights can be twice as high as the highest value in the supporting data base. Furthermore, even though all vehicle weights are less than that maximum, the generic factor substantially overpredicts the old data set.

To better estimate haul truck emissions in the future, this study developed a new model from the test data. Although one would prefer to assemble a larger data base, it was not believed that the differences between the two data sets allowed them to be combined. By using only newer test data, it is believed that the resulting emission factor would best match source conditions that can be expected at surface coal mines in the future.

Stepwise multiple linear regression was used to develop a predictive model with the final data set. The potential correction factors include:

- surface silt content, s
- surface moisture content, M
- silt loading, sL
- mean vehicle weight, W
- mean vehicle speed, S
- mean number of wheels, w

All variables were log-transformed in order to obtain a multiplicative model as in the past. Figure 24 presents the correlation matrix of the log-transformed independent and dependent variables. The most notable features of the correlation matrix are the high degree of interdependence between silt content and the emission factors,

PEARSON CORRELATION MATRIX

	LEF10	LSILT	LSL	LMOIST	LTONS	LMPH	LWHLS
LEF10	1.00						
LSILT	0.76	1.00					
LSL	0.71	0.85	1.00				
LMOIST	-0.16	0.05	0.04	1.00			
LTONS	0.29	0.35	0.25	0.25	1.00		
LMPH	0.11	0.04	0.24	-0.40	-0.46	1.00	
LWHLS	0.34	0.43	0.25	-0.04	0.75	-0.35	1.00

NUMBER OF OBSERVATIONS: 34

	LEFTSP	LSILT	LSL	LMOIST	LTONS	LMPH	LWHLS
LEFTSP	1.00						
LSILT	0.82	1.00					
LSL	0.74	0.83	1.00				
LMOIST	-0.03	0.07	-0.00	1.00			
LTONS	0.38	0.33	0.29	0.30	1.00		
LMPH	0.18	-0.02	0.13	-0.43	-0.39	1.00	
LWHLS	0.47	0.51	0.38	0.09	0.76	-0.33	1.00

NUMBER OF OBSERVATIONS: 22

Figure 24. Correlation matrix of log-transformed emission factors and independent variables.

together with the low degree of interdependence between silt and moisture. This suggests that silt and moisture contents may be effectively used to derive an emission factor model. Stepwise regression of the data did indeed result in a PM-10 model of that type.

Several points should be noted about the regression results. First, the expression for PM-10 was considered first so that models comparable over the different size ranges would result.

Second, during an exploratory phase, it was found that a TSP model based solely on a stepwise regression of the data would result in a model involving silt, weight, and speeds. In addition, the independent variables were found to be raised to powers fairly comparable to those in the generic unpaved road model in AP-42 Section 11.2.1. This is in keeping with the results shown in Figure 21. Nevertheless, to maintain similarity between the different emission factor models, the final TSP model was derived to resemble the PM-10 model.

The following equation presents the final recommended emission factor models.

$$e = k \left(\frac{s}{3}\right)^a \left(\frac{M}{2}\right)^b$$

where e is emission factor in lb/VMT, s is silt content (%), M is moisture content (%), and k, a, and b are given in Table 21.

TABLE 21. RECOMMENDED EMISSION FACTOR MODELS

Size range	Sample size	k	a	b	Multiple R^2
PM-10	34	3.4	0.8	–0.2	0.611
TSP	22	16	0.9	–0.2	0.660

Both models "explain" roughly 60% of the variability in the emission factors.

Because of the differences in the old and new data sets, no attempt was made to apply the revised factors to the older, independent data. However, another type of validation study was undertaken to assess the predictive capability of the revised emission model for PM-10. This employed a standard cross-validation (CV) technique. Using this technique, each point in the underlying data base is excluded one at a time, and the equation generated from the reduced data base is used to estimate the missing value. This method generates "quasi-independent" comparisons.

By using a CV technique, "n" quasi-independent estimates are obtained from a data base of "n" tests, and the overall validity of using stepwise regression to obtain a model of the form

$$e = k \left(\frac{s}{3}\right)^a \left(\frac{M}{2}\right)^b$$

is evaluated. Summary information is shown in Table 22.

TABLE 22. RESULTS OF CROSS-VALIDATION STUDY

	Variable	Minimum	Maximum	Mean	Std. deviation
a	Exponent of silt	0.793	0.878	0.827	0.021
b	Exponent of moisture	–0.323	–0.182	–0.223	0.026
k	Leading term	3.32	3.54	3.43	1.037[a]
	Ratio of quasi-independent estimate to measured emission factor	0.345	3.03	0.991[a]	1.73[a]

[a] Geometric mean/standard deviation.

Figure 25 presents the cumulative frequency distribution of the ratio of the quasi-independent estimate obtained from the cross validation to the measured PM-10 emission factor. A little over 80% of the estimates are within a factor of 2 and approximately 35% are within a factor of 1.5. The 95% confidence interval corresponds to a factor of approximately 2.4. Results for the TSP model cross-validation are similar, with 73% within a factor 2.

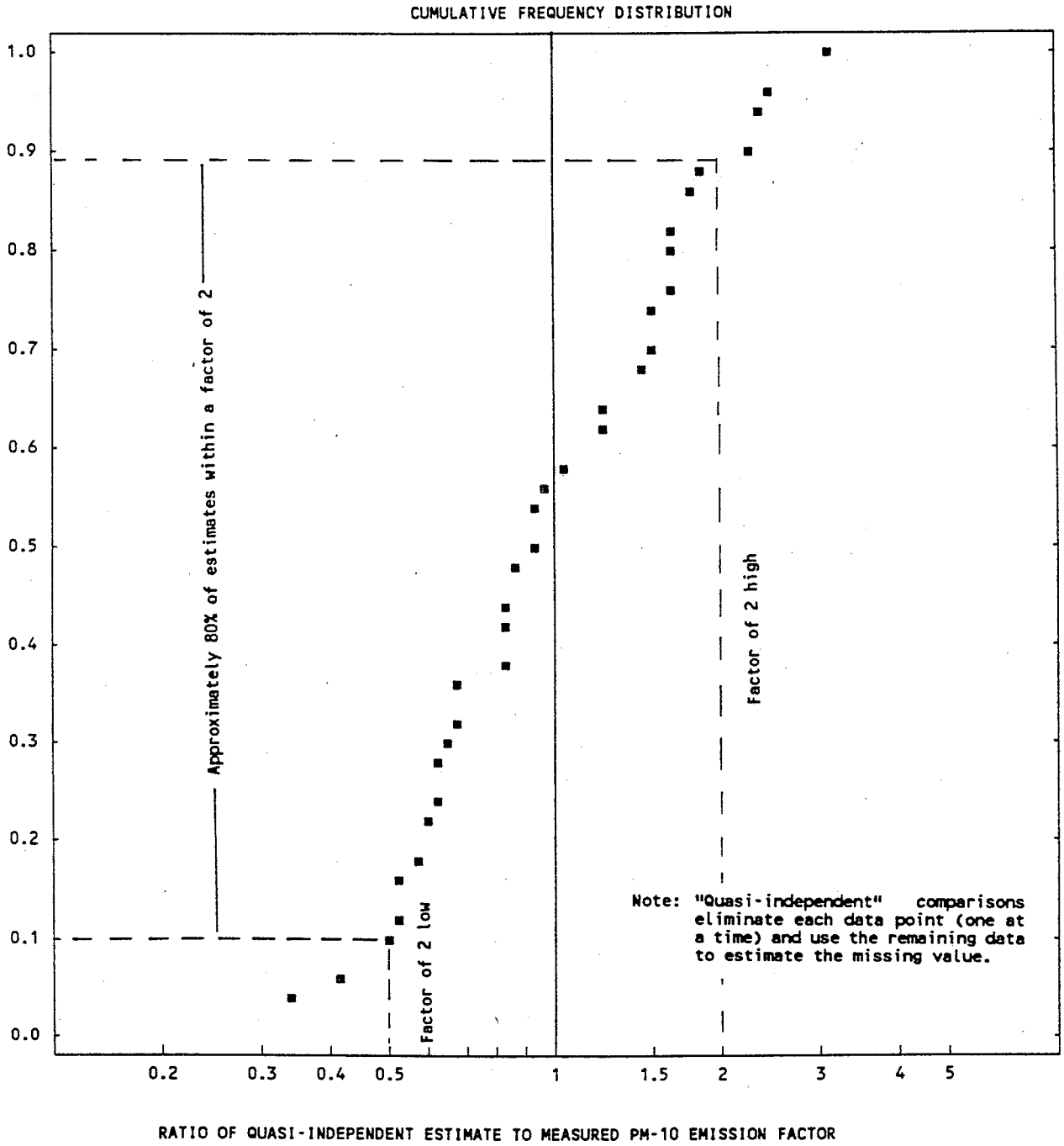

Figure 25. Cumulative frequency of the ratio of the quasi-independent estimate to the measured PM10 emission factor.

Finally, the nonparametic runs test[14] was used to examine the residuals (error in prediction). This exercise found a tendency for the recommended emission factor model to underestimate measured emissions at fairly high silt contents.

Readers should keep in mind that the recommended emission factor model tends to overpredict for silt contents in excess of 12 to 15%. This tendency to overestimate measured emissions is not considered a major limitation because silt contents that high are relatively infrequent. All haul road silts used in Reference 8 were less than 10%. Appendix B indicates that one silt content in 9 exceeds 12%. Furthermore, silt contents reported in Reference 7 are also well below 10%.

SECTION 6

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APPENDIX A

AMBIENT AIR QUALITY MONITORING RESULTS

This appendix presents air quality monitoring results reported by Inter-Mountain Laboratories. The results are for the period September through October 1992. Pages A-3 through A-15 contain the results for the days when Cordero personnel operated the mine's sampling network and page A-16 presents results for days when MRI personnel operated the network.

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CONSULTANT
SHERIDAN, WY.

	AREA	SITE	PRO
SAMPLER ID	0080	888	J02

YEAR 1992

DATE	CONC UG/M3	FILTER NO.	FLOW** CMM	FLOW*** CMM	TIME MIN	VOL CM	GROSS G	TARE G	NET G
09/03/92	37	36157	1.4659	1.5778	1425.0	2089	3.7799	3.7028	0.0771
09/09/92	21	36161	1.5736	1.6756	1431.5	2253	3.7383	3.6919	0.0464
09/15/92	37	36165	1.4857	1.6041	1432.1	2128	3.7651	3.6868	0.0783
09/21/92		36170	INVALID: NO TRANSDUCER READING						
09/27/92		36174	INVALID: TRANSDUCER FAILED						

* low flow rate
** corrected flow
*** uncorrected flow

	Arithmetic Mean	Geometric Mean
September	32	31
Quarter	32	31

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SAMPLER ID	0080	BFM	HV2

YEAR 1992

DATE	CONC UG/M3	FILTER NO.	FLOW** CMM	FLOW*** CMM	TIME MIN	VOL CM	GROSS G	TARE G	NET G
09/03/92		36158	INVALID: RUNTIME NOT MIDNIGHT TO MIDNIGHT						
09/09/92		36163	INVALID: RAN ON WRONG DAY						
09/15/92		36167	INVALID: INSUFFICIENT RUNTIME						
09/21/92		36169	INVALID: START TIME 3:30 A.M.						
09/27/92	25	36172	1.6878	1.7861	1440.0	2430	3.7401	3.6800	0.0601

* low flow rate
** corrected flow
*** uncorrected flow

	Arithmetic Mean	Geometric Mean
September	25	25
Quarter	25	25

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SAMPLER ID	0080	BFM	HV2A

YEAR 1992

DATE	CONC UG/M3	FILTER NO.	FLOW** CMM	FLOW*** CMM	TIME MIN	VOL CM	GROSS G	TARE G	NET G
09/03/92	46	36159	1.5041	1.6183	1420.4	2136	3.7967	3.6991	0.0976
09/09/92	44	36162	1.5982	1.7011	1440.2	2302	3.7943	3.6932	0.1011
09/15/92	55	36166	1.5700	1.6944	1439.8	2261	3.8091	3.6847	0.1244
09/21/92	43	36168	1.4226	1.5217	1439.9	2048	3.7712	3.6832	0.0880
09/27/92	32	36173	1.4231	1.5060	1440.2	2050	3.7524	3.6868	0.0656

* low flow rate
** corrected flow
*** uncorrected flow

	Arithmetic Mean	Geometric Mean
September	44	43
Quarter	44	43

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SAMPLER ID	0080	889	J02

YEAR 1992

DATE	CONC UG/M3	FILTER NO.	FLOW** CMM	FLOW*** CMM	TIME MIN	VOL CM	GROSS G	TARE G	NET G
09/03/92	26	36156	1.5776	1.6971	1420.1	2240	3.7485	3.6910	0.0575
09/09/92	56	36160	1.6256	1.7300	1414.9	2300	3.8215	3.6937	0.1278
09/15/92	30	36164	1.5780	1.7027	1416.8	2236	3.7527	3.6856	0.0671
09/21/92	46	36171	1.6083	1.7199	1415.0	2276	3.7856	3.6802	0.1054
09/27/92	18	36175	1.6256	1.7199	1440.7	2342	3.7180	3.6761	0.0419

* low flow rate
** corrected flow
*** uncorrected flow

	Arithmetic Mean	Geometric Mean
September	35	32
Quarter	35	32

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	AREA	SITE	PRO
SAMPLER ID	0080	PM2	

YEAR 1992

DATE	CONC UG/M3	FILTER NO.	FLOW** CMM	FLOW*** CMM	TIME MIN	VOL CM	GROSS G	TARE G	NET G
09/03/92	12	35971	0.9367	1.0843	1428.8	1338	4.5158	4.5000	0.0158
09/09/92	13	35973	0.9468	1.0727	1433.6	1357	4.5125	4.4945	0.0180
09/15/92	20	35975	0.9337	1.0876	1433.6	1339	4.4981	4.4710	0.0271
09/21/92	11	35985	0.9421	1.0779	1433.5	1351	4.4821	4.4679	0.0142
09/27/92	9	35977	0.9523	1.0664	1432.8	1365	4.5184	4.5066	0.0118

* low flow rate
** corrected flow
*** uncorrected flow

	Arithmetic Mean	Geometric Mean
September	13	13
Quarter	13	13

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SAMPLER ID	0080	PM2	A

YEAR 1992

DATE	CONC UG/M3	FILTER NO.	FLOW** CMM	FLOW*** CMM	TIME MIN	VOL CM	GROSS G	TARE G	NET G
09/03/92	11	35972	0.9611	1.1126	1444.4	1388	4.5120	4.4963	0.0157
09/09/92	13	35974	0.9715	1.1007	1444.4	1403	4.5369	4.5182	0.0187
09/15/92	21	35976	0.9582	1.1161	1448.9	1388	4.5100	4.4814	0.0286
09/21/92	10	35986	0.9668	1.1061	1448.8	1401	4.4714	4.4570	0.0144
09/27/92	8	35978	0.9648	1.0804	1449.8	1399	4.5426	4.5308	0.0118

* low flow rate
** corrected flow
*** uncorrected flow

	Arithmetic Mean	Geometric Mean
September	13	12
Quarter	13	12

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	AREA	SITE	PRO
SAMPLER ID	0080	888	J02

YEAR 1992

DATE	CONC UG/M3	FILTER NO.	FLOW** CMM	FLOW*** CMM	TIME MIN	VOL CM	GROSS G	TARE G	NET G
10/03/92		36177	INVALID:	POWER	FAILURE				
10/09/92	12	37190	1.4975	1.5797	1429.9	2141	3.5528	3.5278	0.0250
10/15/92	17	36182	1.6209	1.6799	1430.8	2319	3.7274	3.6891	0.0383
10/21/92	23	36186	1.5036	1.6131	1431.7	2153	3.7433	3.6949	0.0484
10/27/92	34	36188	1.5265	1.6131	1431.9	2186	3.7714	3.6963	0.0751

* low flow rate
** corrected flow
*** uncorrected flow

	Arithmetic Mean	Geometric Mean
October	22	20
Quarter	22	20

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	AREA	SITE	PRO
SAMPLER ID	0080	BFM	HV2

YEAR 1992

DATE	CONC UG/M3	FILTER NO.	FLOW** CMM	FLOW*** CMM	TIME MIN	VOL CM	GROSS G	TARE G	NET G
10/03/92	29	36179	1.5546	1.6787	1440.0	2239	3.7420	3.6775	0.0645
10/09/92	31	37189	1.6090	1.6966	1440.0	2317	3.6071	3.5364	0.0707
10/15/92	21	36180	1.7413	1.8040	1440.0	2508	3.7325	3.6805	0.0520
10/21/92	51	36185	1.6655	1.7861	1440.0	2398	3.8194	3.6966	0.1228
10/27/92	33	36189	1.6908	1.7861	1440.0	2435	3.7748	3.6953	0.0795

* low flow rate
** corrected flow
*** uncorrected flow

	Arithmetic Mean	Geometric Mean
October	33	32
Quarter	33	32

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	AREA	SITE	PRO
SAMPLER ID	0080	BFM	HV2A

YEAR 1992

DATE	CONC UG/M3	FILTER NO.	FLOW** CMM	FLOW*** CMM	TIME MIN	VOL CM	GROSS G	TARE G	NET G
10/03/92	34	36178	1.3511	1.4589	1440.2	1946	3.7367	3.6713	0.0654
10/09/92		37188	INVALID: RUNTIME TOO LONG						
10/15/92	33	36181	1.5143	1.5688	1440.3	2181	3.7567	3.6848	0.0719
10/21/92	60	36184	1.4482	1.5531	1440.1	2086	3.8250	3.7001	0.1249
10/27/92	33	36190	1.4703	1.5531	1440.2	2118	3.7728	3.7025	0.0703

* low flow rate
** corrected flow
*** uncorrected flow

	Arithmetic Mean	Geometric Mean
October	40	39
Quarter	40	39

CORDERO MINING COMPANY
CORDERO MINE
GILLETTE, WY.

INTER-MOUNTAIN LABORATORIES, INC.
CONSULTANT
SHERIDAN, WY.

	AREA	SITE	PRO
SAMPLER ID	0080	889	J02

YEAR 1992

DATE	CONC UG/M3	FILTER NO.	FLOW** CMM	FLOW*** CMM	TIME MIN	VOL CM	GROSS G	TARE G	NET G
10/03/92	25	36176	1.5931	1.7199	1416.0	2256	3.7180	3.6627	0.0553
10/09/92		37191	INVALID: NO TRANSDUCER RECORDER READING						
10/15/92	16	36183	1.8265	1.8919	1439.1	2629	3.7390	3.6977	0.0413
10/21/92	18	36187	1.6682	1.7887	1440.3	2403	3.7332	3.6901	0.0431
10/27/92		36191	INVALID: MOTOR OR CLOCK FAILURE						

* low flow rate
** corrected flow
*** uncorrected flow

	Arithmetic Mean	Geometric Mean
October	20	19
Quarter	20	19

CORDERO MINING COMPANY
CORDERO MINE
GILLETTE, WY.

INTER-MOUNTAIN LABORATORIES, INC.
CONSULTANT
SHERIDAN, WY.

	AREA	SITE	PRO
SAMPLER ID	0080	PM2	

YEAR 1992

DATE	CONC UG/M3	FILTER NO.	FLOW** CMM	FLOW*** CMM	TIME MIN	VOL CM	GROSS G	TARE G	NET G
10/03/92	14	35980	0.9333	1.0882	1431.5	1336	4.5420	4.5240	0.0180
10/09/92	11	37097	0.9557	1.0626	1431.3	1368	4.3432	4.3279	0.0153
10/15/92	12	35984	0.9912	1.0638	1433.5	1421	4.5030	4.4866	0.0164
10/21/92	18	37953	0.9397	1.0807	1433.0	1347	4.4209	4.3973	0.0236
10/27/92	10	37956	0.9540	1.0645	1438.4	1372	4.4640	4.4500	0.0140

* low flow rate
** corrected flow
*** uncorrected flow

	Arithmetic Mean	Geometric Mean
October	13	13
Quarter	13	13

CORDERO MINING COMPANY
CORDERO MINE
GILLETTE, WY.

INTER-MOUNTAIN LABORATORIES, INC.
CONSULTANT
SHERIDAN, WY.

	AREA	SITE	PRO
SAMPLER ID	0080	PM2	A

YEAR 1992

DATE	CONC UG/M3	FILTER NO.	FLOW** CMM	FLOW*** CMM	TIME MIN	VOL CM	GROSS G	TARE G	NET G
10/03/92	13	35981	0.9455	1.1024	1449.7	1371	4.5214	4.5032	0.0182
10/09/92	11	37096	0.9932	1.1043	1447.3	1438	4.3770	4.3610	0.0160
10/15/92	11	35983	0.9982	1.0713	1450.5	1448	4.4941	4.4778	0.0163
10/21/92	18	37954	0.9643	1.1090	1454.0	1402	4.4810	4.4563	0.0247
10/27/92	11	37957	0.9790	1.0924	1450.2	1420	4.4823	4.4671	0.0152

* low flow rate
** corrected flow
*** uncorrected flow

	Arithmetic Mean	Geometric Mean
October	13	13
Quarter	13	13

CORDERO MINING COMPANY
CORDERO MINE
GILLETTE, WY.

INTER-MOUNTAIN LABORATORIES, INC.
CONSULTANT
SHERIDAN, WY.

	AREA	SITE	PRO
SAMPLER ID	0080	PM3	

YEAR 1992

DATE	CONC UG/M3	FILTER NO.	FLOW** CMM	FLOW*** CMM	TIME MIN	VOL CM	GROSS G	TARE G	NET G
10/03/92	16	35979	0.9589	1.1176	1462.0	1402	4.4733	4.4512	0.0221
10/09/92	9	37098	0.9820	1.0914	1463.5	1437	4.3398	4.3272	0.0126
10/15/92		35982	INVALID:	POWER	FAILURE				
10/21/92	11	37955	0.9655	1.1100	1459.6	1409	4.4263	4.4111	0.0152
10/27/92	16	37958	0.9802	1.0933	1459.1	1430	4.4586	4.4357	0.0229

* low flow rate
** corrected flow
*** uncorrected flow

	Arithmetic Mean	Geometric Mean
October	13	13
Quarter	13	13

FILTNO	KIND	TARWT	EXPWT	NETWT	SITE	RUNDAY	RUNTIME	INRDG RATIO	ACAL	BCAL	QR QA	STAPR	TEMP	QSTD	VOL	TSP PM-10
37160	COD	3.5114	3.6021	0.0907	885J02	09/11/92	1394.1	51.0	0.0358	-0.1471	1.6787	25.23	290.3	1.5618	2177	42
37161	COD	3.5124	3.6414	0.1290	885J09	09/11/92	1439.9	53.0	0.0314	-0.0169	1.6473	25.23	290.3	1.5326	2206	59
37162	COD	3.5041	3.5772	0.0731	888J02	09/11/92	1428.4	49.0	0.0316	0.0241	1.5725	25.21	290.3	1.4624	2088	35
37163	COD	3.5055	3.5931	0.0876	889J02	09/11/92	1442.2	49.0	0.0344	-0.0173	1.6683	25.24	290.3	1.5525	2239	39
37079	COD	4.2417	4.2670	0.0253	PM2	09/11/92	1435.7	0.94	8.3055	0.4120	1.0832	25.23	290.3	0.9376*	1346	19
37080	COD	4.2642	4.2901	0.0259	PM2A	09/11/92	1446.2	0.94	12.0088	0.1566	1.1115	25.23	290.3	0.9621*	1391	19
37167	COD	3.5076	3.6151	0.1075	885J02	09/13/92	1440.0	51.5	0.0358	-0.1471	1.6966	25.23	285.4	1.5920	2292	47
37166	COD	3.5128	3.5904	0.0776	885J09	09/13/92	1440.0	54.5	0.0314	-0.0169	1.6944	25.23	285.4	1.5899	2289	34
37165	COD	3.5137	3.5673	0.0536	888J02	09/13/92	1433.0	50.5	0.0316	0.0241	1.6199	25.21	285.4	1.5194	2177	25
37164	COD				889J02	09/13/92	INVALID: RAN TOO LONG									
37082	COD	4.2423	4.2562	0.0139	PM2	09/13/92	1434.5	0.94	8.3055	0.4120	1.0740	25.23	285.4	0.9456*	1356	10
37081	COD	4.2203	4.2341	0.0138	PM2A	09/13/92	1444.1	0.94	12.0088	0.1566	1.1021	25.23	285.4	0.9704*	1401	10
37171	COD	3.5079	3.6241	0.1162	885J02	09/17/92	1439.9	52.5	0.0358	-0.1471	1.7324	25.23	283.0	1.6325	2350	49
37170	COD	3.5000	3.6259	0.1259	885J09	09/17/92	1440.1	47.5	0.0314	-0.0169	1.4746	25.23	283.0	1.3895	2001	63
37169	COD	3.5088	3.6071	0.0983	888J02	09/17/92	1430.6	50.5	0.0316	0.0241	1.6199	25.21	283.0	1.5258	2182	45
37168	COD	3.5108	3.6629	0.1521	889J02	09/17/92	1439.5	51.0	0.0344	-0.0173	1.7371	25.24	283.0	1.6372	2356	65
37083	COD	4.2693	4.2873	0.0180	PM2	09/17/92	1431.0	0.94	8.3055	0.4120	1.0695	25.23	283.0	0.9497*	1359	13
37084	COD	4.2650	4.2837	0.0187	PM2A	09/17/92	1448.0	0.94	12.0088	0.1566	1.0974	25.23	283.0	0.9744*	1410	13
37172	COD	3.5511	3.6596	0.1085	885J02	09/23/92	1439.7	52.0	0.0358	-0.1471	1.7145	25.23	292.0	1.5905	2289	47
37173	COD	3.5507	3.6577	0.1070	885J09	09/23/92	1439.7	48.0	0.0314	-0.0169	1.4903	25.23	292.0	1.3825	1990	54
37174	COD				888J02	09/23/92	INVALID: NO TRANSDUCER TRACE									
37175	COD	3.5470	3.6062	0.0592	889J02	09/23/92	1440.8	49.0	0.0344	-0.0173	1.6683	25.24	292.0	1.5479	2230	27
37085	COD	4.2429	4.2695	0.0266	PM2	09/23/92	1433.6	0.94	8.3055	0.4120	1.0863	25.23	292.0	0.9348*	1340	20
37086	COD	4.2568	4.2844	0.0276	PM2A	09/23/92	1451.3	0.93	12.0088	0.1566	1.1005	25.23	292.0	0.9471*	1374	20
37176	COD	3.5456	3.6514	0.1058	885J02	09/29/92	1440.0	48.5	0.0358	-0.1471	1.5892	25.23	288.3	1.4837	2136	50
37177	COD	3.5407	3.6501	0.1094	885J09	09/29/92	1440.0	47.5	0.0314	-0.0169	1.4746	25.23	288.3	1.3767	1982	55
37178	COD				888J02	09/29/92	INVALID: NO TRANSDUCER TRACE									
37179	COD	3.5425	3.6053	0.0628	889J02	09/29/92	1441.9	50.0	0.0344	-0.0173	1.7027	25.24	288.3	1.5900	2292	27
37088	COD	4.2549	4.2774	0.0225	PM2	09/29/92	1434.4	0.94	8.3055	0.4120	1.0794	25.23	288.3	0.9408*	1349	17
37087	COD	4.2773	4.3006	0.0233	PM2A	09/29/92	1449.5	0.94	12.0088	0.1566	1.1077	25.23	288.3	0.9655*	1399	17
37089	COD	4.2833	4.3015	0.0182	PM3	09/29/92	1457.7	0.93	17.1748	-0.1814	1.0988	25.24	288.3	0.9581*	1396	13
37182	COD	3.5381	3.6522	0.1141	885J02	10/01/92	1440.0	52.0	0.0358	-0.1471	1.7145	25.23	290.7	1.5940	2295	50
37183	COD	3.5321	3.6476	0.1155	885J09	10/01/92	1439.8	45.0	0.0314	-0.0169	1.3961	25.23	290.7	1.2980	1868	62
37181	COD				888J02	10/01/92	INVALID: NO TRANSDUCER TRACE									
37180	COD				889J02	10/01/92	INVALID: RAN TOO LONG									
37092	COD				PM2	10/01/92	INVALID: INSUFFICIENT RUN TIME									
37091	COD				PM2A	10/01/92	INVALID: INSUFFICIENT RUN TIME									
37090	COD	4.3312	4.3538	0.0226	PM3	10/01/92	1462.1	0.94	17.1748	-0.1814	1.1132	25.24	290.7	0.9627*	1407	16
37185	COD	3.5365	3.5743	0.0378	885J02	10/07/92	1438.9	53.0	0.0358	-0.1471	1.7503	25.23	273.5	1.6777	2414	16
37184	COD				885J09	10/07/92	INVALID: INSUFFICIENT RUN TIME									
37186	COD	3.5406	3.5577	0.0171	888J02	10/07/92	1431.5	55.0	0.0334	-0.2072	1.6298	25.21	273.5	1.5616	2235	8
37187	COD	3.5453	3.5740	0.0287	889J02	10/07/92	1439.8	53.5	0.0344	-0.0173	1.8231	25.24	273.5	1.7478	2516	11
37094	COD	4.3205	4.3278	0.0073	PM2	10/07/92	1435.5	0.95	8.3055	0.4120	1.0713	25.23	273.5	0.9343*	1413	5
37093	COD	4.3468	4.3541	0.0073	PM2A	10/07/92	1450.4	0.95	12.0088	0.1566	1.0926	25.23	273.5	1.0039	1456	5
37095	COD	4.3473	4.3555	0.0082	PM3	10/07/92	1459.9	0.94	17.1748	-0.1814	1.0798	25.24	273.5	0.9925*	1449	6
37192	COD	3.5308	3.6181	0.0873	885J02	10/13/92	1440.0	54.0	0.0358	-0.1471	1.7861	25.23	282.3	1.6851	2426	36
37193	COD	3.5368	3.6355	0.0987	885J09	10/13/92	1440.2	48.5	0.0314	-0.0169	1.5060	25.23	282.3	1.4209	2046	48
37194	COD	3.5277	3.5938	0.0661	888J02	10/13/92	1434.4	54.5	0.0334	-0.2072	1.6131	25.21	282.3	1.5213	2182	30
37195	COD	3.5274	3.5998	0.0724	889J02	10/13/92	1440.3	52.5	0.0344	-0.0173	1.7887	25.24	282.3	1.6879	2431	30
38100	COD	4.3405	4.3590	0.0185	PM2A	10/13/92	1450.4	0.95	12.0088	0.1566	1.1101	25.23	282.3	0.9882*	1433	13
38101	COD	4.3348	4.3558	0.0210	PM3	10/13/92	1458.3	0.94	17.1748	-0.1814	1.0970	25.24	282.3	0.9769*	1424	15
37196	COD	3.5216	3.6812	0.1596	885J02	10/17/92	1440.0	56.0	0.0358	-0.1471	1.8577	25.23	275.9	1.7729	2553	63
37197	COD	3.5207	3.6825	0.1618	885J09	10/17/92	1440.2	49.5	0.0314	-0.0169	1.5374	25.23	275.9	1.4672	2113	77
37198	COD	3.5198	3.6075	0.0877	888J02	10/17/92	1430.0	55.5	0.0334	-0.2072	1.6465	25.21	275.9	1.5707	2246	39
37199	COD	3.5171	3.6026	0.0855	889J02	10/17/92	1440.7	54.0	0.0344	-0.0173	1.8403	25.24	275.9	1.7566	2530	34
38203	COD	4.2889	4.3219	0.0330	PM2	10/17/92	1433.2	0.94	8.3055	0.4120	1.0560	25.23	275.9	0.9618*	1378	24
38102	COD	4.3583	4.3937	0.0354	PM2A	10/17/92	1449.0	0.94	12.0088	0.1566	1.0836	25.23	275.9	0.9869*	1430	25
38204	COD	4.2583	4.2874	0.0291	PM3	10/17/92	1461.0	0.93	17.1748	-0.1814	1.0749	25.24	275.9	0.9794*	1430	20
37204	COD	3.5284	3.6626	0.1342	885J02	10/23/92	1440.0	52.5	0.0358	-0.1471	1.7324	25.23	283.6	1.6307	2348	57
37205	COD	3.5266	3.6503	0.1237	885J09	10/23/92	1440.0	51.0	0.0314	-0.0169	1.5845	25.23	283.6	1.4915	2147	58
37206	COD	3.5328	3.5861	0.0533	888J02	10/23/92	1430.5	53.5	0.0334	-0.2072	1.5797	25.21	283.6	1.4864	2126	25
37207	COD	3.5315	3.5878	0.0563	889J02	10/23/92	1440.3	52.5	0.0344	-0.0173	1.7887	25.24	283.6	1.6841	2425	23
38212	COD	4.2135	4.2440	0.0305	PM2	10/23/92	1433.8	0.94	8.3055	0.4120	1.0706	25.23	283.6	0.9486*	1360	22
38213	COD	4.2545	4.2858	0.0313	PM2A	10/23/92	1448.4	0.94	12.0088	0.1566	1.0986	25.23	283.6	0.9734*	1409	22
38214	COD	4.2721	4.2949	0.0228	PM3	10/23/92	1462.5	0.93	17.1748	-0.1814	1.0898	25.24	283.6	0.9660*	1412	16

APPENDIX B

COMBINED DATA SETS

This appendix presents both the data set supporting the emission factor predictive equations currently contained in AP-42 Section 8.24 as well as the data set developed during the study described in the main body of the report. Please note that the PM-10 factors reported for the old data sets are based on log-normal interpolation of particle size data presented in Reference 6 of the report.

HAUL TRUCKS

	Run	Road Surface Parameters: Silt (%)	Moisture (%)	Silt Loading (g/m²)	Mean Vehicle Parameters: Speed (mph)	Weight (tons)	No. of Wheels	PM-10 Emission Factor (lb/VMT)
		Old Data Set						
1	J-6	7.9	5.4	.	.	.	.	.
2	J-9	9.4	3.4	3.8	19.3	65.0	8.0	4.6
3	J-10	9.4	2.2	12.2	19.3	60.0	7.7	14.1
4	J-11	8.2	4.2	6.7	20.0	60.0	9.9	9.4
5	J-12	14.2	6.8	33.4	15.0	99.0	9.5	4.9
6	J-20	11.6	8.5	38.3	16.8	125.0	10.0	2.9
7	J-21	.	.	.	15.0	110.0	9.3	3.1
8	K-1	7.7	2.2	60.1	32.9	63.0	6.1	1.6
9	K-6	2.2	7.9	7.8	34.8	89.0	7.4	0.6
10	K-7	2.8	0.9	10.1	34.2	24.0	4.9	1.6
11	K-8	3.1	1.7	10.2	36.0	65.0	6.3	0.8
12	K-9	4.7	1.5	22.1	29.2	74.0	6.7	2.0
13	K-10	7.7	2.0	22.3	36.0	69.0	6.6	1.5
14	K-11	8.9	2.0	25.8	30.0	73.0	6.5	1.5
15	K-12	11.8	2.3	34.2	36.0	95.0	7.3	2.0
16	K-13	1.8	2.7	1.2	31.7	64.0	6.6	0.3
17	K-26	.	.	.	31.7	84.0	6.8	1.0
18	L-1	13.0	7.7	58.5	26.1	95.0	8.8	0.2
19	L-3	13.8	4.9	75.9	20.0	107.0	9.3	27.7
20	L-4	18.0	5.1	253.8	20.0	86.0	8.3	20.9
21	P-1	4.7	0.4	23.0	26.7	79.0	8.5	11.3
22	P-2	4.7	0.4	23.0	26.1	42.0	7.2	2.0
23	P-3	4.1	0.3	23.8	31.1	94.0	9.7	6.3
24	P-4	2.0	0.3	4.0	31.7	55.0	7.6	1.2
25	P-5	3.1	0.0	4.1	31.1	47.0	7.1	3.4
26	P-6	2.8	2.9	13.7	31.7	25.0	5.6	0.7
27	P-7	2.4	1.5	11.0	31.1	61.0	7.6	2.3
28	P-8	7.7	15.3	52.4	29.2	47.0	7.5	1.2
29	P-9	1.6	20.1	7.0	31.1	58.0	8.7	1.4
		New Data Set						
30	BB-2	10.7	1.1	142.0	36.4	131.0	5.5	10.8
31	BB-3	10.7	1.1	142.0	36.4	131.0	5.5	13.6
32	BB-6	3.6	1.2	8.1	22.7	200.0	5.8	4.7
33	BB-7	3.6	1.2	8.1	22.4	200.0	5.7	6.5
34	BB-8	3.8	1.0	11.2	21.2	220.0	5.6	5.2
35	BB-10	3.1	1.2	16.2	27.5	160.0	5.5	3.3
36	BB-11	3.1	1.2	16.2	27.5	160.0	5.5	2.9
37	BB-12	2.2	1.1	3.1	22.6	155.0	5.8	1.8
38	BB-13	2.2	1.1	3.1	22.6	155.0	5.8	1.5
39	BB-14	3.3	1.8	7.8	22.9	92.0	5.2	2.6
40	BB-15	2.1	1.4	3.5	21.3	183.0	5.7	4.4
41	BB-16	2.1	1.4	3.5	22.1	178.0	5.6	5.2
42	BB-17	2.1	1.8	3.2	24.6	169.0	5.5	1.6
43	BB-18	1.3	1.3	1.7	23.0	184.0	6.0	4.2
44	BB-19	1.3	1.5	1.7	22.8	192.0	5.7	3.1
45	BB-20	3.9	1.4	16.0	24.3	175.0	5.7	2.7
46	BB-21	1.8	2.0	17.4	22.8	218.0	5.8	1.8
47	BB-22	1.7	2.5	12.8	24.3	161.0	5.5	1.4
48	BB-23	1.9	4.1	1.2	22.6	181.0	5.7	0.9
49	BB-25	3.8	4.0	1.9	19.2	207.0	5.7	1.3
50	BB-26	2.5	4.4	2.0	21.8	183.0	5.7	3.0
51	BB-27	2.7	1.9	3.1	19.5	244.0	5.8	3.8
52	BB-29	19.2	3.8	68.4	18.8	283.0	5.9	15.6
53	BB-31	19.2	3.8	68.4	20.8	271.0	6.1	9.4
54	BB-33	3.0	1.5	5.0	29.2	153.0	5.4	5.7
55	BB-34	4.9	0.9	14.0	28.6	170.0	6.1	9.5
56	BB-35	3.7	2.5	13.2	28.0	173.0	5.4	6.7
57	BB-36	12.9	5.0	245.0	19.3	286.0	6.0	14.2
58	BB-38	1.6	10.3	3.3	22.0	141.0	5.3	3.2
59	BB-39	1.4	12.3	5.3	21.8	137.0	5.3	1.7
60	BB-40	4.8	5.7	18.4	21.2	271.0	6.1	2.6
61	BB-41	6.5	5.0	41.4	22.3	267.0	5.9	5.7
62	BB-42	9.5	4.4	84.9	22.0	275.0	5.9	13.0
63	BB-43	1.8	4.7	3.7	30.4	164.0	5.5	0.8

HAUL TRUCKS

	Run	Road Surface Parameters: Silt (%)	Moisture (%)	Silt Loading (g/m^2)	Mean Vehicle Parameters: Speed (mph)	Weight (tons)	No. of Wheels	TSP Emission Factor (lb/VMT)
		Old Data Set						
1	J-6	7.9	5.4	.	.	.	.	.
2	J-9	9.4	3.4	3.8	19.3	65.0	8.0	15.2
3	J-10	9.4	2.2	12.2	19.3	60.0	7.7	33.0
4	J-11	8.2	4.2	6.7	20.0	60.0	9.9	30.2
5	J-12	14.2	6.8	33.4	15.0	99.0	9.5	12.9
6	J-20	11.6	8.5	38.3	16.8	125.0	10.0	12.3
7	J-21	.	.	.	15.0	110.0	9.3	14.2
8	K-1	7.7	2.2	60.1	32.9	63.0	6.1	8.2
9	K-6	2.2	7.9	7.8	34.8	89.0	7.4	2.2
10	K-7	2.8	0.9	10.1	34.2	24.0	4.9	3.9
11	K-8	3.1	1.7	10.2	36.0	65.0	6.3	2.5
12	K-9	4.7	1.5	22.1	29.2	74.0	6.7	6.4
13	K-10	7.7	2.0	22.3	36.0	69.0	6.6	4.4
14	K-11	8.9	2.0	25.8	30.0	73.0	6.5	4.5
15	K-12	11.8	2.3	34.2	36.0	95.0	7.3	6.0
16	K-13	1.8	2.7	1.2	31.7	64.0	6.6	0.6
17	K-26	.	.	.	31.7	84.0	6.8	3.4
18	L-1	13.0	7.7	58.5	26.1	95.0	8.8	0.7
19	L-3	13.8	4.9	75.9	20.0	107.0	9.3	67.2
20	L-4	18.0	5.1	253.8	20.0	86.0	8.3	73.1
21	P-1	4.7	0.4	23.0	26.7	79.0	8.5	20.6
22	P-2	4.7	0.4	23.0	26.1	42.0	7.2	6.3
23	P-3	4.1	0.3	23.8	31.1	94.0	9.7	24.1
24	P-4	2.0	0.3	4.0	31.7	55.0	7.6	5.1
25	P-5	3.1	0.0	4.1	31.1	47.0	7.1	14.1
26	P-6	2.8	2.9	13.7	31.7	25.0	5.6	1.8
27	P-7	2.4	1.5	11.0	31.1	61.0	7.6	8.4
28	P-8	7.7	15.3	52.4	29.2	47.0	7.5	4.3
29	P-9	1.6	20.1	7.0	31.1	58.0	8.7	5.6
		New Data Set						
30	BB-2	10.7	1.1	142.0	36.4	131.0	5.5	95.1
34	BB-8	3.8	1.0	11.2	21.2	220.0	5.6	20.2
35	BB-10	3.1	1.2	16.2	27.5	160.0	5.5	18.3
37	BB-12	2.2	1.1	3.1	22.6	155.0	5.8	11.7
39	BB-14	3.3	1.8	7.8	22.9	92.0	5.2	9.0
40	BB-15	2.1	1.4	3.5	21.3	183.0	5.7	18.6
42	BB-17	2.1	1.8	3.2	24.6	169.0	5.5	11.2
44	BB-19	1.3	1.5	1.7	22.8	192.0	5.7	18.0
46	BB-21	1.8	2.0	17.4	22.8	218.0	5.8	9.5
47	BB-22	1.7	2.5	12.8	24.3	161.0	5.5	4.6
48	BB-23	1.9	4.1	1.2	22.6	181.0	5.7	7.3
49	BB-25	3.8	4.0	1.9	19.2	207.0	5.7	10.8
50	BB-26	2.5	4.4	2.0	21.8	183.0	5.7	10.5
53	BB-31	19.2	3.8	68.4	20.8	271.0	6.1	62.0
54	BB-33	3.0	1.5	5.0	29.2	153.0	5.4	47.9
55	BB-34	4.9	0.9	14.0	28.6	170.0	6.1	44.4
56	BB-35	3.7	2.5	13.2	28.0	173.0	5.4	27.2
57	BB-36	12.9	5.0	245.0	19.3	286.0	6.0	84.2
58	BB-38	1.6	10.3	3.3	22.0	141.0	5.3	16.4
60	BB-40	4.8	5.7	18.4	21.2	271.0	6.1	38.4
62	BB-42	9.5	4.4	84.9	22.0	275.0	5.9	84.2
63	BB-43	1.8	4.7	3.7	30.4	164.0	5.5	10.2

SCRAPERS

	Run	Road Surface Parameters: Silt (%)	Moisture (%)	Silt Loading (g/m^2)	Mean Vehicle Parameters: Speed (mph)	Weight (tons)	No. of Wheels	PM-10 Emission Factor (lb/VMT)
		Old Data Set						
1	J-1	8.9	5.7	10.8	19.3	50.0	4.1	2.480
2	J-2	23.4	2.3	73.2	19.3	53.0	4.0	2.090
3	J-3	15.8	4.1	49.0	24.2	54.0	4.1	16.3
4	J-4	14.6	1.5	8.0	20.0	36.0	4.0	0.963
5	J-5	10.6	0.9	32.9	18.0	70.0	4.0	5.8
6	K-15	.	.	.	28.0	46.0	4.0	4.540
7	K-16	25.2	6.0	96.8	30.0	64.0	4.0	10.3
8	K-17	25.2	6.0	96.8	23.0	57.0	4.1	20.9
9	K-18	25.2	6.0	96.8	25.0	66.0	4.0	10.7
10	K-22	21.6	5.4	65.0	31.7	45.0	4.0	2.920
11	K-23	24.6	7.8	78.2	28.0	54.0	4.0	6.610
12	L-5	21.0	.	50.0	21.1	53.0	4.0	115.0
13	L-6	21.0	.	50.0	20.0	50.0	4.0	51.3
14	P-15	7.2	1.0	.	16.2	42.0	4.0	.
15	P-18	7.2	1.0	.	10.0	64.0	4.0	0.714
		New Data Set						
16	BB-46	12.7	4.880	531.0	15.5	63.0	4.060	10.990
17	BB-47	14.0	5.110	894.0	18.0	65.0	4.0	8.170

SCRAPERS

	Run	- Road Surface Parameters - Silt (%)	Moisture (%)	Silt Loading (g/m^2)	- - Mean Vehicle Parameters - - Speed (mph)	Weight (tons)	No. of Wheels	TSP Emission Factor (lb/VMT)
		- - -

LIGHT AND MEDIUM DUTY

	Run	Road Surface Parameters: Silt (%)	Moisture (%)	Silt Loading (g/m^2)	Mean Vehicle Parameters: Speed (mph)	Weight (tons)	No. of Wheels	PM-10 Emission Factor (lb/VMT)
		Old Data Set						
1	J-7	3.0	3.6	21.0	25.0	7.0	4.2	
2	J-8	3.0	3.6	21.0	25.0	3.0	4.0	0.270
3	J-13	10.1	1.0	13.9	25.0	2.2	4.0	3.220
4	J-18	8.8	1.1	47.5	25.0	2.6	4.0	5.320
5	J-19	8.2	0.9	44.3	25.0	2.3	4.1	3.690
6	K-2	4.9	1.6	5.9	35.0	2.3	4.0	0.195
7	K-3	4.9	1.6	5.9	35.0	2.4	4.0	0.242
8	K-4	5.3	1.7	48.2	35.0	2.4	4.0	0.225
9	K-5	5.3	1.7	48.2	35.0	2.4	4.0	0.351
10	P-11	5.5	0.9	5.9	42.5	2.0	4.0	2.560
11	P-12	5.5	0.9	5.9	43.1	2.0	4.0	2.940
12	P-13	5.5	0.9	5.9	43.1	2.0	4.0	2.520
		New Data Set						
13	BB-44	1.820	0.680	1.8	30.0	2.0	4.0	0.250
14	BB-45	1.950	2.1	0.8	30.0	2.0	4.0	0.078
15	BB-48	1.950	2.1	0.8	30.0	2.0	4.0	0.123

LIGHT AND MEDIUM DUTY

	Run	Road Surface Parameters: Silt (%)	Moisture (%)	Silt Loading (g/m^2)	Mean Vehicle Parameters: Speed (mph)	Weight (tons)	No. of Wheels	TSP Emission Factor (lb/VMT)
		Old Data Set						
1	J-7	3.0	3.6	21.0	25.0	7.0	4.2	.
2	J-8	3.0	3.6	21.0	25.0	3.0	4.0	0.350
3	J-13	10.1	1.0	13.9	25.0	2.2	4.0	5.5
4	J-18	8.8	1.1	47.5	25.0	2.6	4.0	8.2
5	J-19	8.2	0.9	44.3	25.0	2.3	4.1	6.7
6	K-2	4.9	1.6	5.9	35.0	2.3	4.0	0.640
7	K-3	4.9	1.6	5.9	35.0	2.4	4.0	0.760
8	K-4	5.3	1.7	48.2	35.0	2.4	4.0	0.6
9	K-5	5.3	1.7	48.2	35.0	2.4	4.0	0.930
10	P-11	5.5	0.9	5.9	42.5	2.0	4.0	8.5
11	P-12	5.5	0.9	5.9	43.1	2.0	4.0	9.0
12	P-13	5.5	0.9	5.9	43.1	2.0	4.0	7.8
		New Data Set						
13	BB-44	1.820	0.680	1.8	30.0	2.0	4.0	1.271
14	BB-45	1.950	2.1	0.8	30.0	2.0	4.0	0.603
15	BB-48	1.950	2.1	0.8	30.0	2.0	4.0	0.486

APPENDIX C

TIME HISTORIES OF ROAD SURFACE MATERIAL MOISTURE CONTENT

This appendix presents time histories of the moisture content in the road surface material. Included are data collected not only during emissions and particle sizing tests but also during the "moisture tracking" sampling in October 1992:

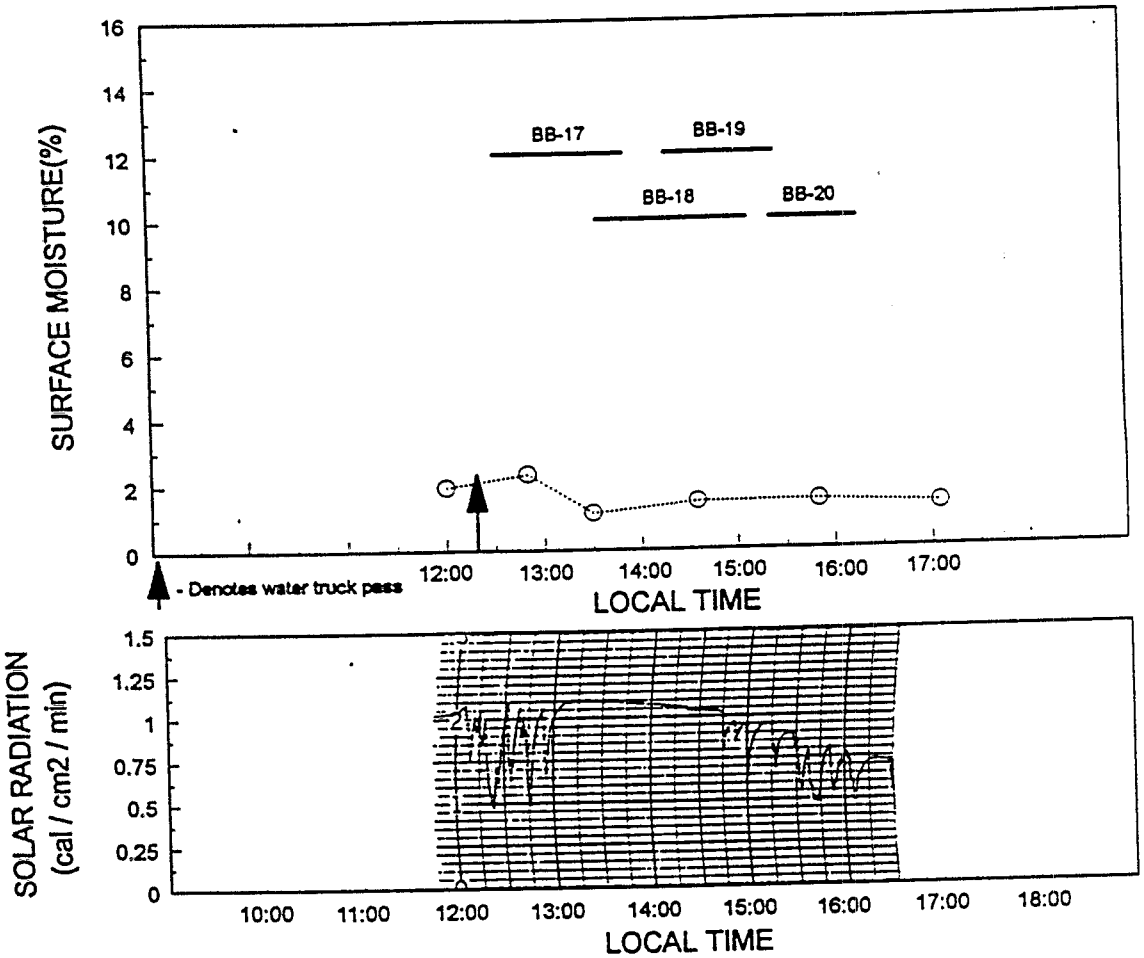
Page	Date	Site	Remarks
C-4	9/21/92	1B	Collected during Runs BB-17 through -20
C-5	9/22/92	1B	Collected during Runs BB-21 and -22
C-6	9/23/92	1B	Collected during Run BB-23
C-7	9/28/92	1B	Collected during Runs BB-25 through -27
C-8	10/10/92	2	Collected during Runs BB-33 and -34 (uncontrolled) as well as watered Run BB-35
C-9	10/13/92	1B	Collected during Runs BB-38 and -39
C-10	10/14/92	4	Collected during Runs BB-40 through -42
C-11	10/09/92	1	Collected during particle sizing tests BB-111X and -112X.
C-12	10/21/92	1	Moisture tracking samples
C-13	10/21/92	2	Moisture tracking samples
C-14	10/23/92	4	Moisture tracking samples
C-15	10/26/92	4	Moisture tracking samples

Each time-history presents a graph showing road surface material moisture content at the time the sample was collected. In addition, the time of road waterings is also shown on the graph. For most histories, other information is presented, including

a. photocopy of the pyranograph trace collected, qualitatively showing incoming solar radiation at the sampling location

b. summary information on the amount of water/surfactant applied

c. general meteorological conditions (ambient air temperature and wind speed) during the sampling period

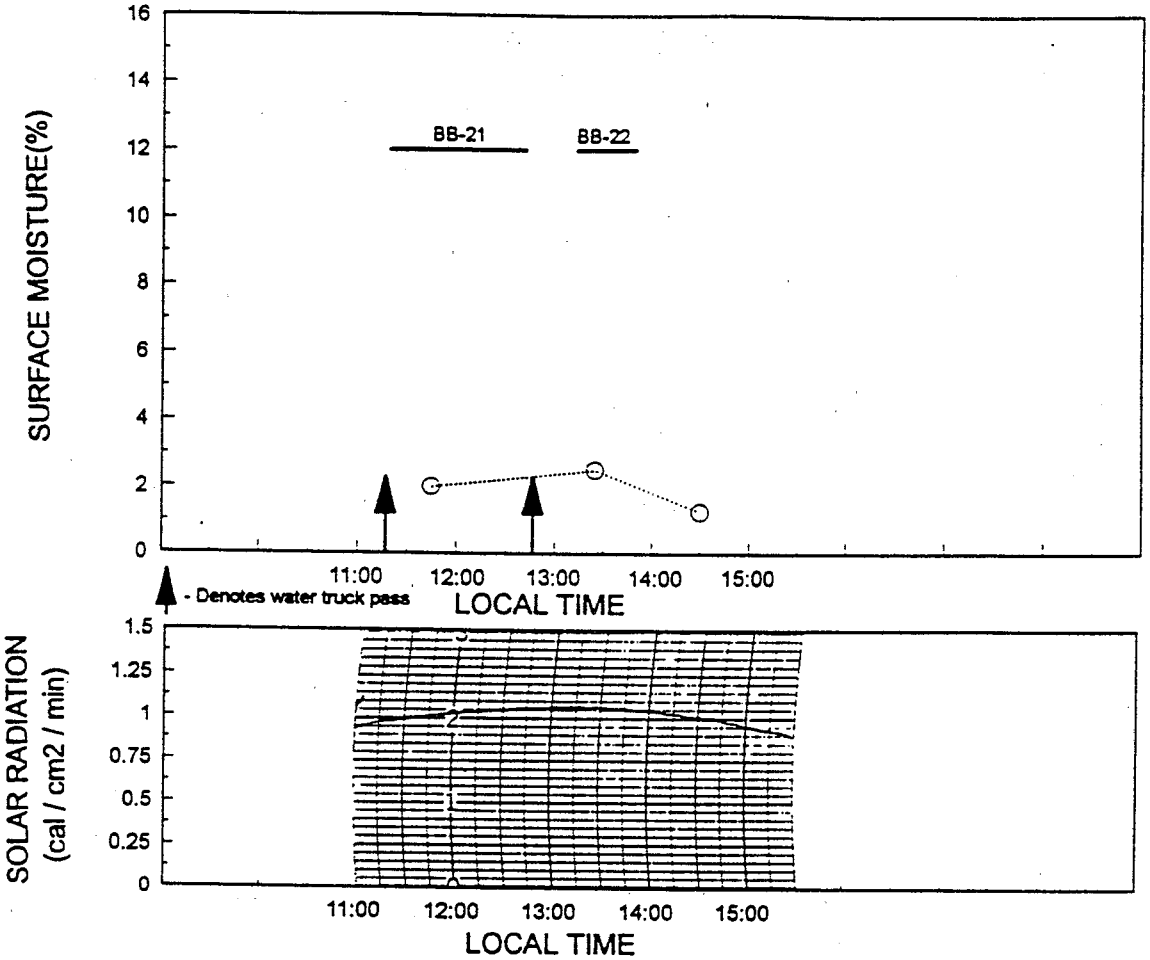


WATERING INFORMATION

Time of water truck passes	Number of samples	Application intensity (gal/yd^2)			
		Maximum	Minimum	Mean	Std. deviation
12:22	9	0.144	0.0011	0.0608	0.0384

METEOROLOGICAL CONDITIONS DURING RUN

Run	Temperature (°F)	Mean wind speed (mph)
BB-17	65	12.73
BB-18	65	9.92
BB-19	65	8.15
BB-20	68	7.98

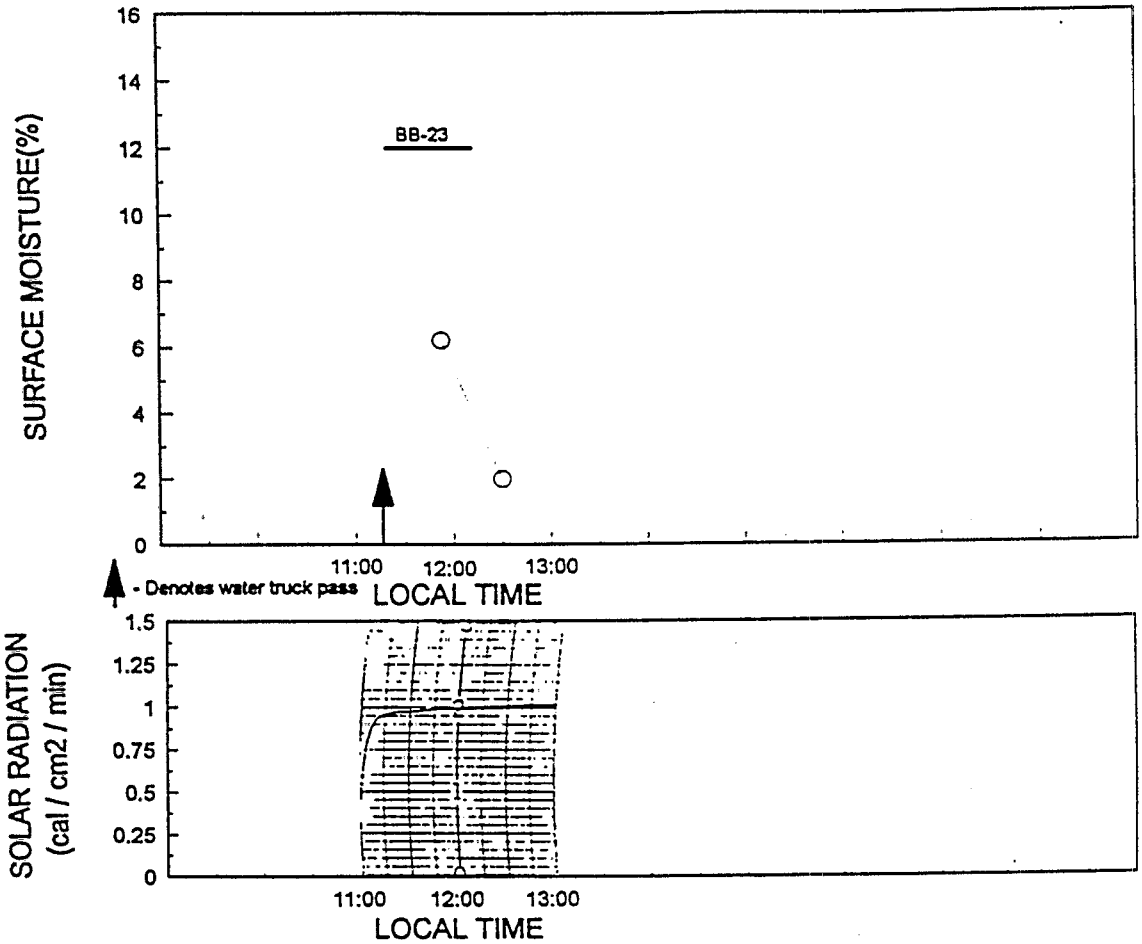


WATERING INFORMATION

Time of water truck passes	Number of samples	Application intensity (gal/yd^2)			
		Maximum	Minimum	Mean	Std. deviation
11:17	6	0.141	0.013	0.0725	0.0476
12:45	3	0.051	0.015	0.034	0.0180

METEOROLOGICAL CONDITIONS DURING RUN

Run	Temperature (°F)	Mean wind speed (mph)
BB-21	78	8.11
BB-22	82	4.54

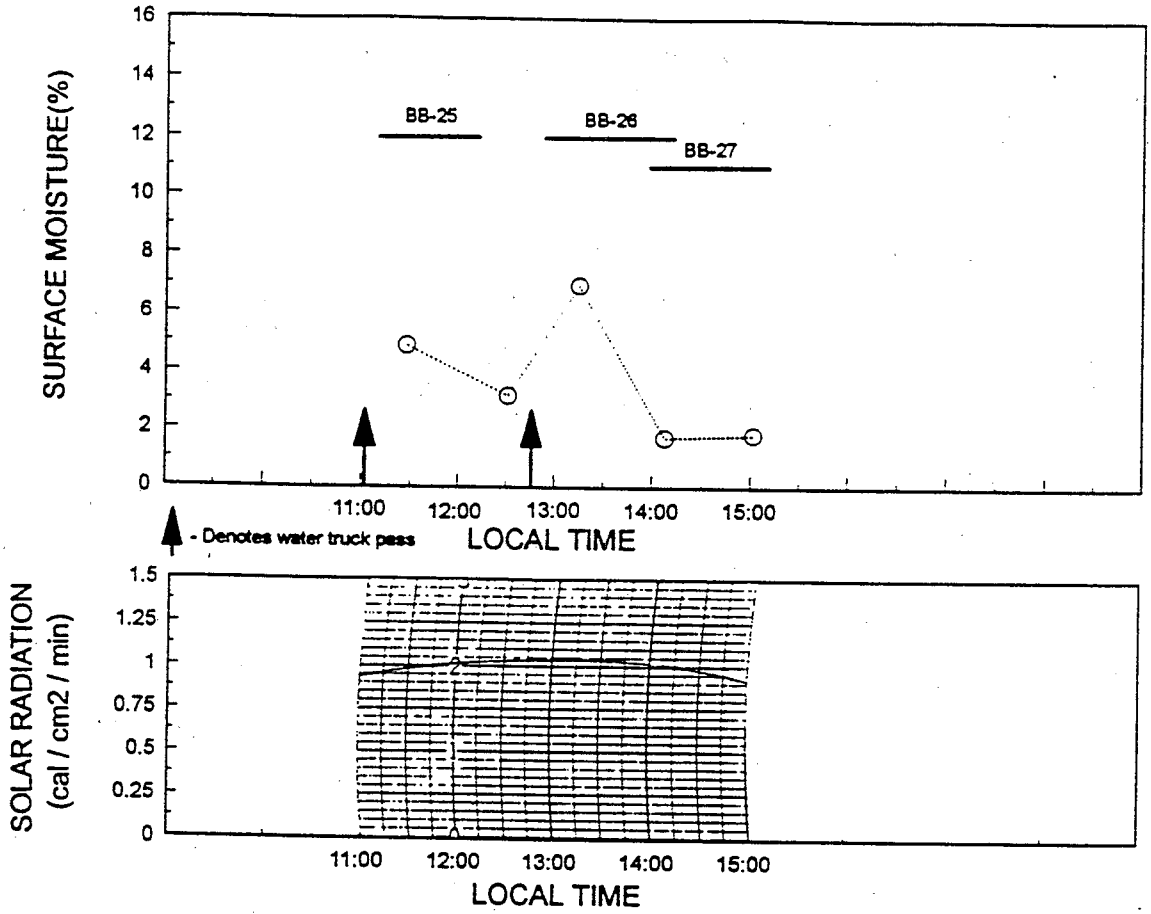


WATERING INFORMATION

Time of water truck passes	Number of samples	Application intensity (gal/yd^2)			
		Maximum	Minimum	Mean	Std. deviation
11:16	4	0.051	0.033	0.041	0.0093

METEOROLOGICAL CONDITIONS DURING RUN

Run	Temperature (°F)	Mean wind speed (mph)
BB-23	87	7.55

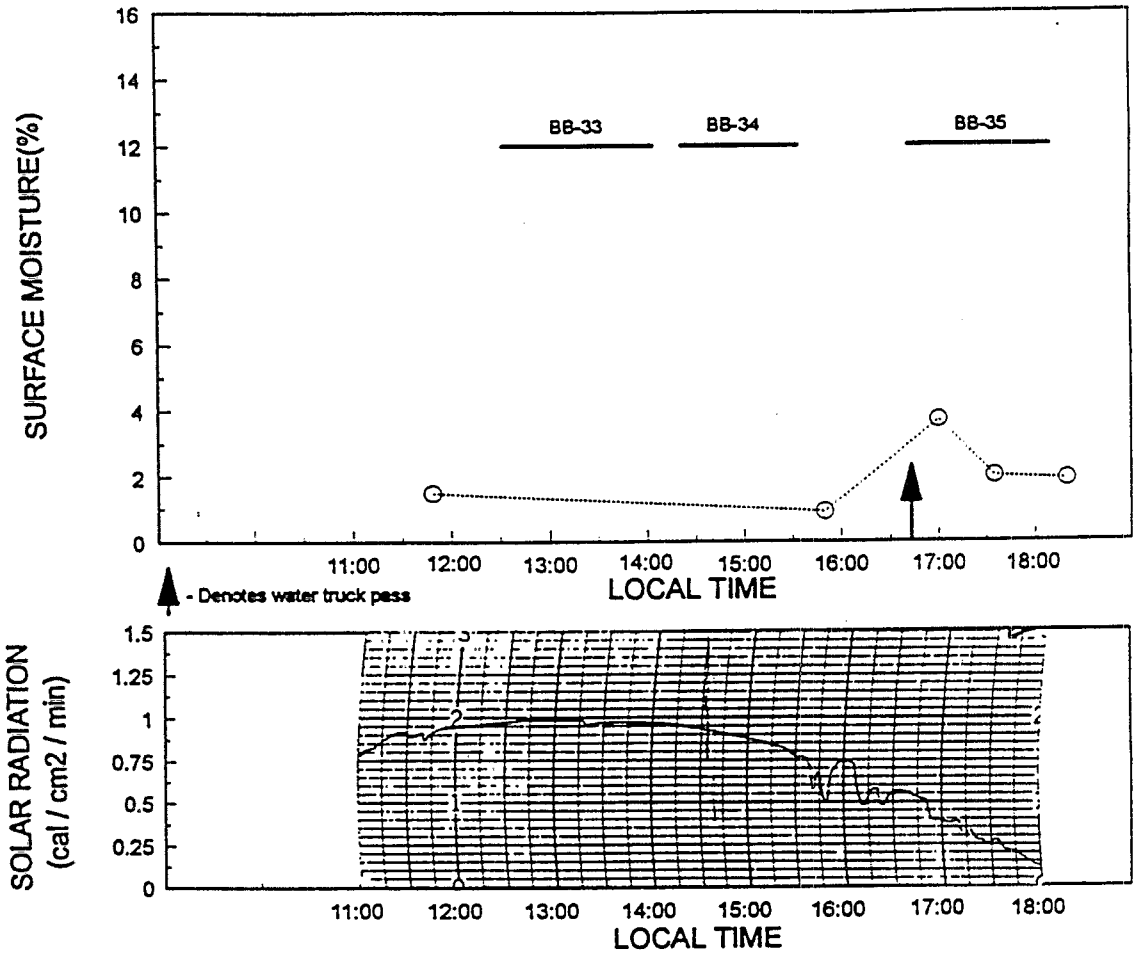


WATERING INFORMATION

Time of water truck passes	Number of samples	Application intensity (gal/yd^2)			
		Maximum	Minimum	Mean	Std. deviation
11:04	6	0.211	0.011	0.123	0.0852
12:44	6	0.310	0.029	0.161	0.112

METEOROLOGICAL CONDITIONS DURING RUN

Run	Temperature (°F)	Mean wind speed (mph)
BB-25	60	18.17
BB-26	66	13.51
BB-27	69	12.05

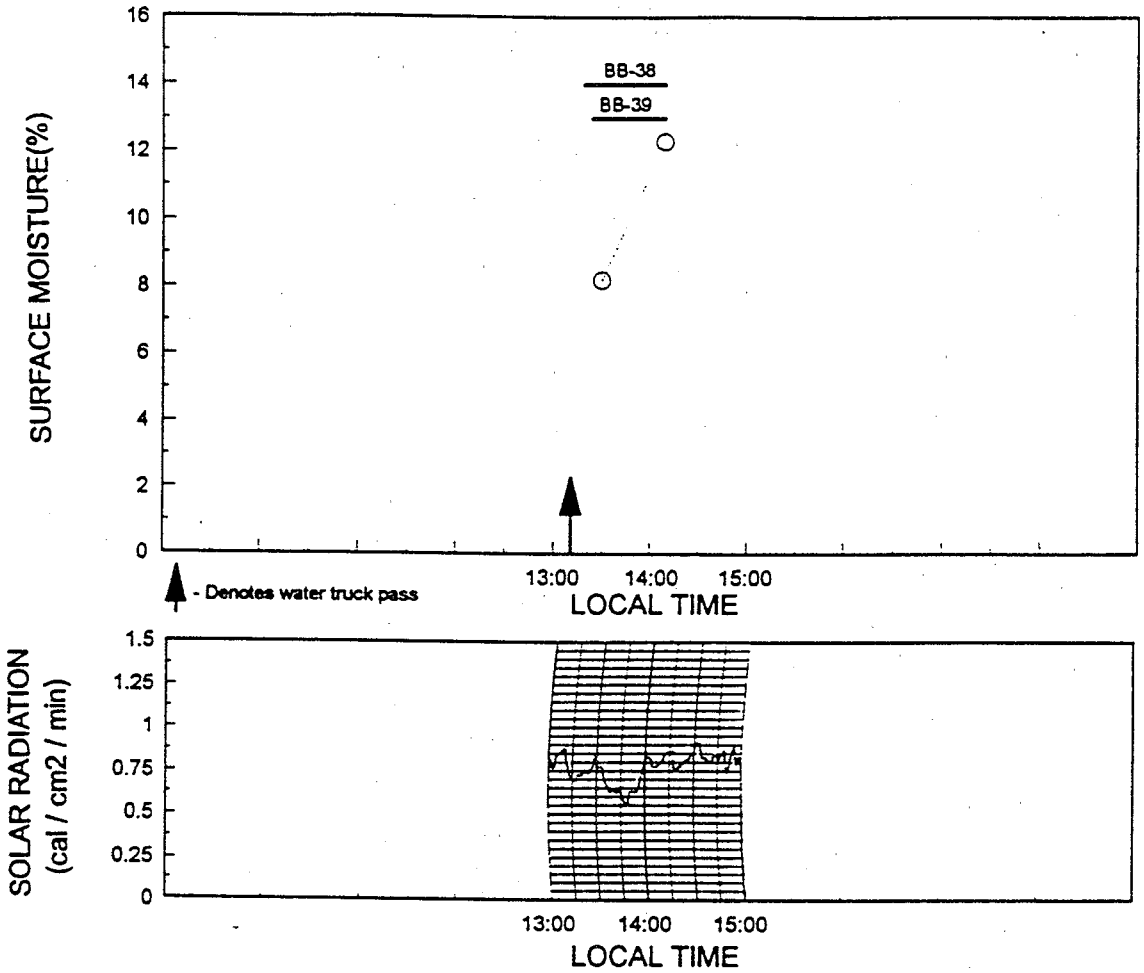


WATERING INFORMATION

Time of water truck passes	Number of samples	Application intensity (gal/yd^2)			
		Maximum	Minimum	Mean	Std. deviation
16:42	4	0.082	0.029	0.052	0.023

METEOROLOGICAL CONDITIONS DURING RUN

Run	Temperature (°F)	Mean wind speed (mph)
BB-33	61	13.72
BB-34	63	12.24
BB-35	60	8.27

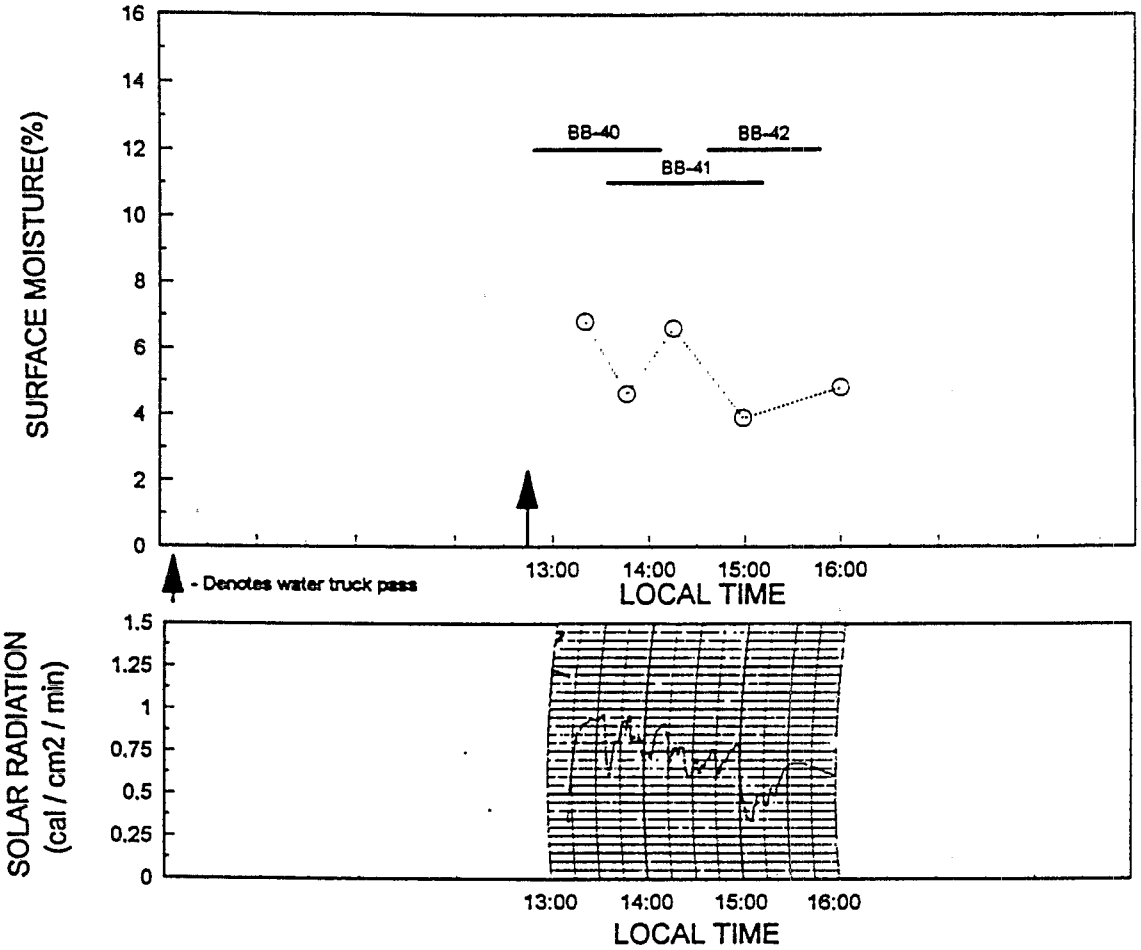


WATERING INFORMATION

Time of water truck passes	Number of samples	Application intensity (gal/yd^2)			
		Maximum	Minimum	Mean	Std. deviation
13:13	6	0.109	0.003	0.0795	0.0396

METEOROLOGICAL CONDITIONS DURING RUN

Run	Temperature (°F)	Mean wind speed (mph)
BB-38	53	22.71
BB-39	53	22.52

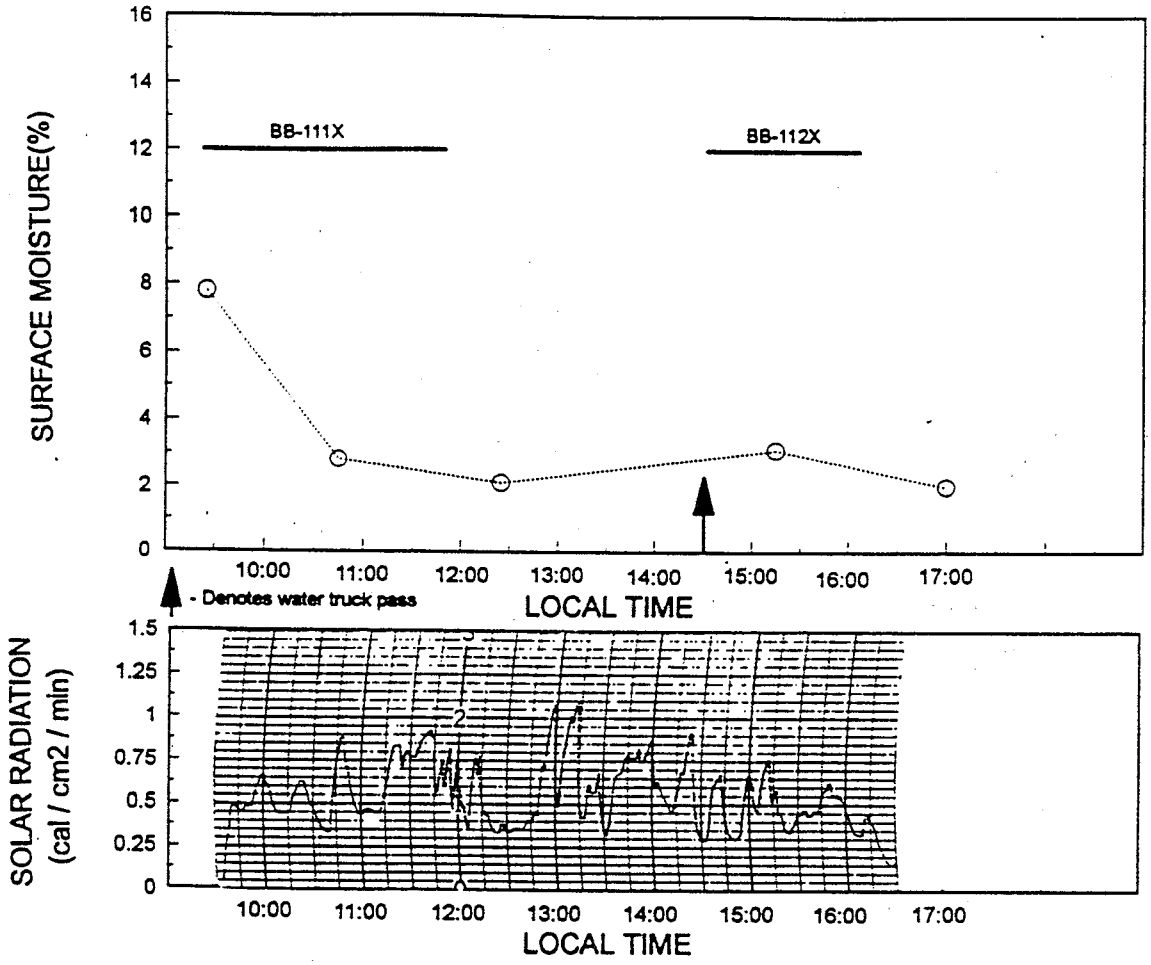


WATERING INFORMATION

Time of water truck passes	Number of samples	Application intensity (gal/yd^2)			
		Maximum	Minimum	Mean	Std. deviation
12:45	4	0.340	0.062	0.157	0.126

METEOROLOGICAL CONDITIONS DURING RUN

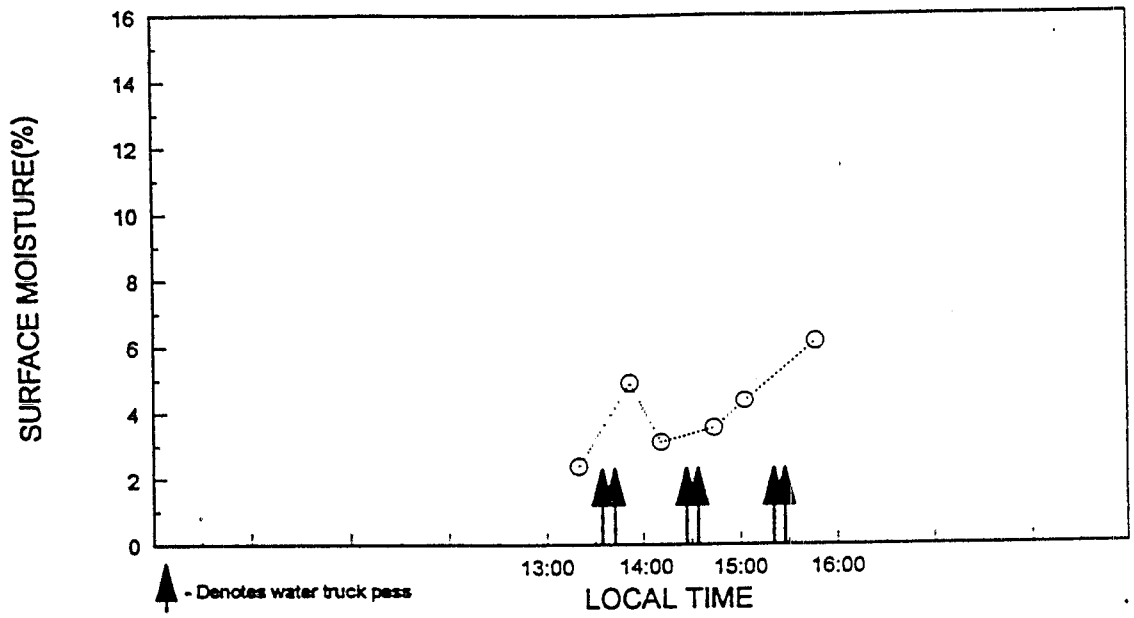
Run	Temperature (°F)	Mean wind speed (mph)
BB-40	45	12.24
BB-41	45	11.88
BB-42	44	11.63

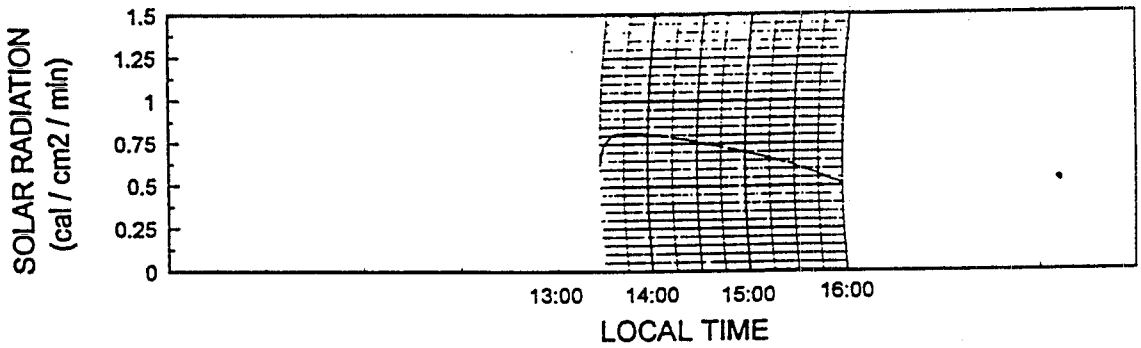


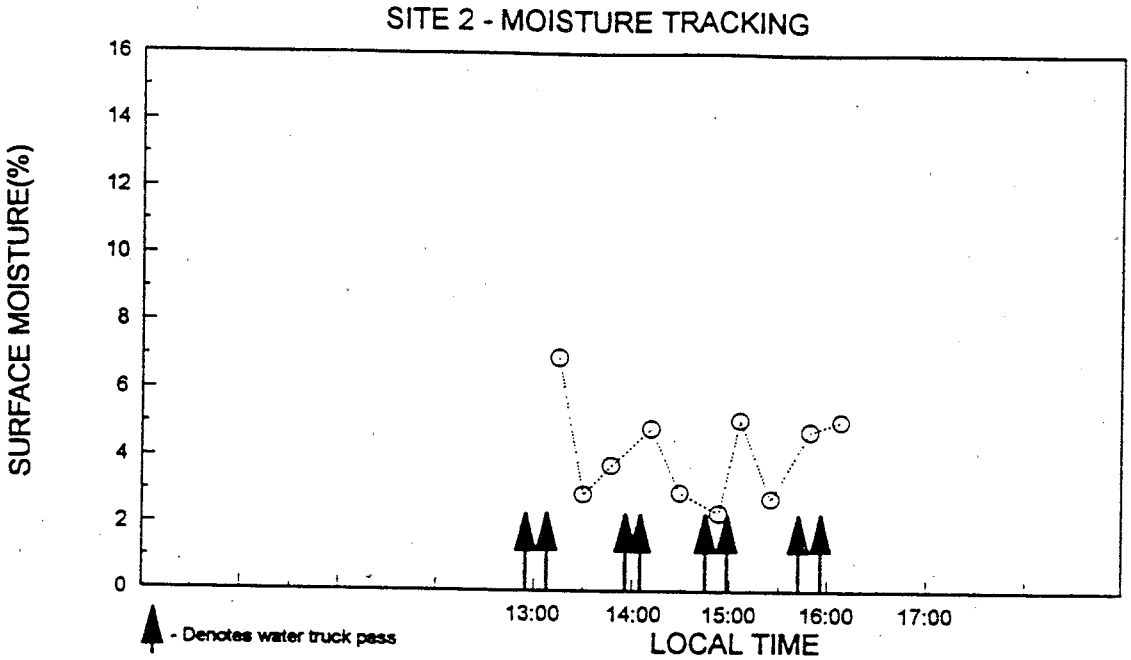
METEOROLOGICAL CONDITIONS DURING RUN

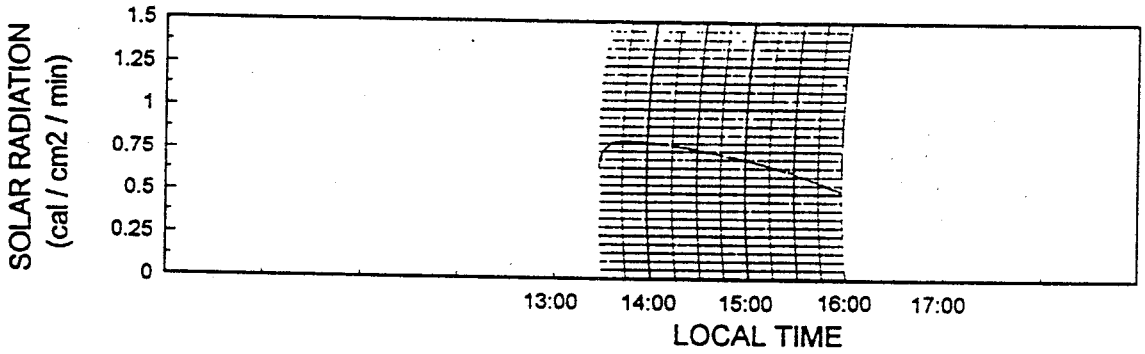
Run	Temperature (°F)	Mean wind speed (mph)
BB-111X	46	18.51
BB-112X	54	22.22

SITE 1 - MOISTURE TRACKING

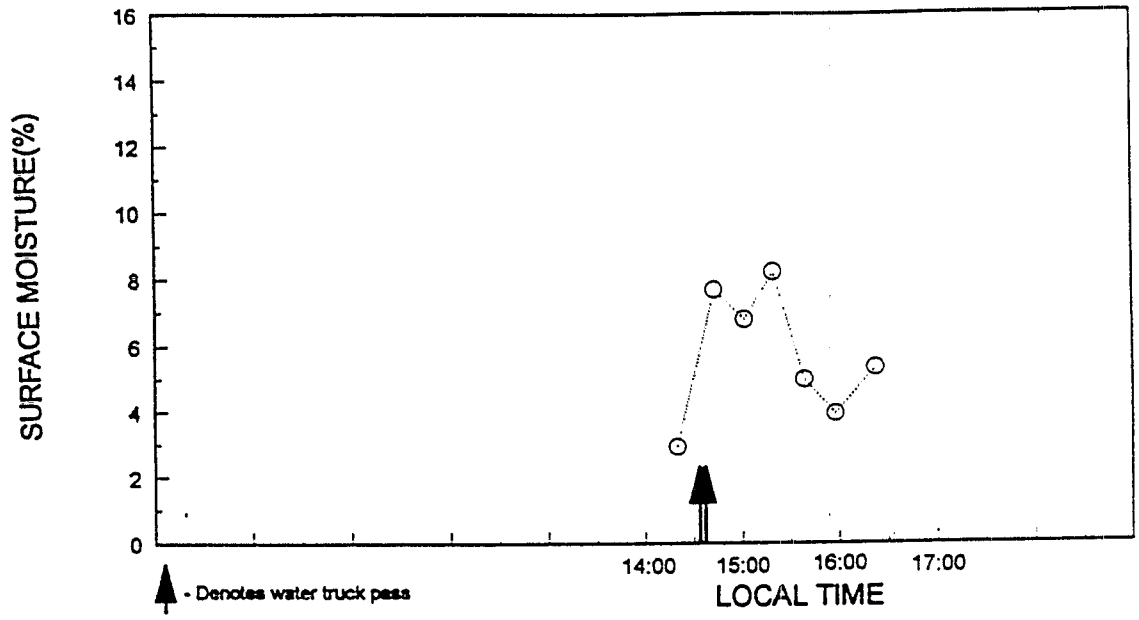


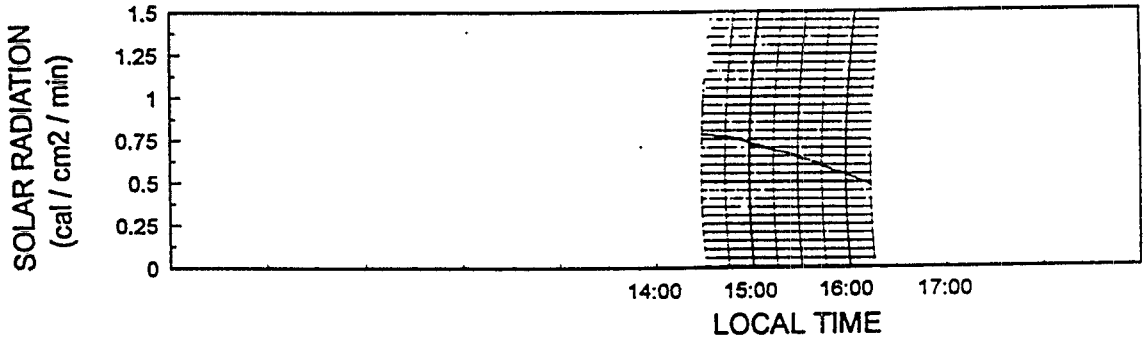


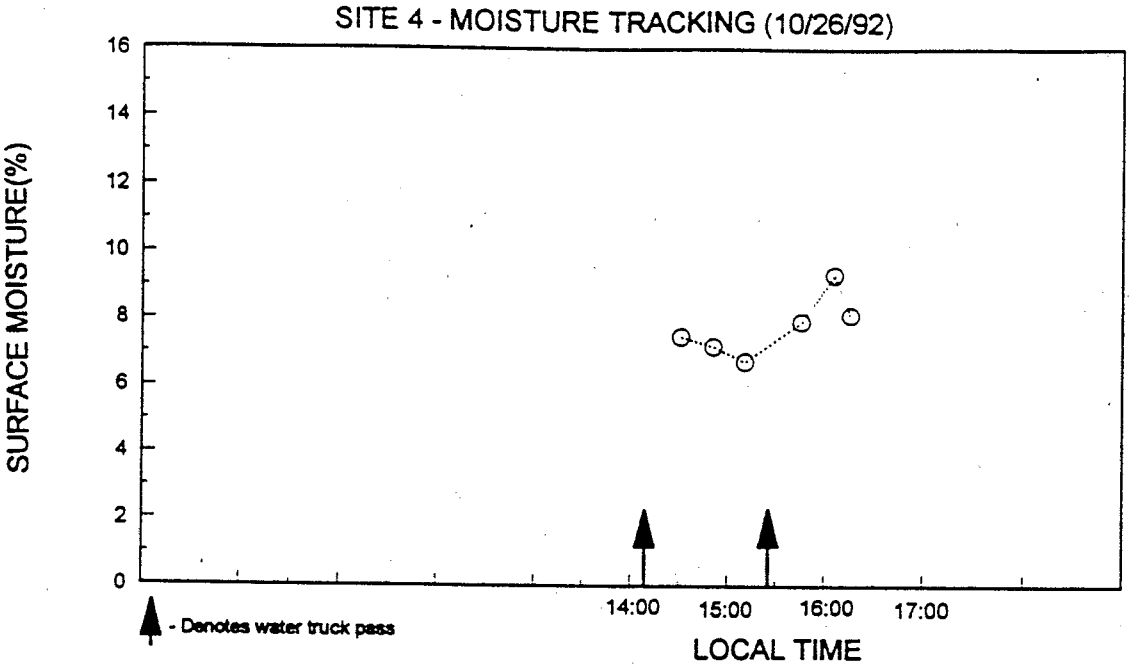

SITE 2 - MOISTURE TRACKING
SURFACE MOISTURE(%)
16
14
12
10
8
6
4
2
0
13:00
14:00
15:00
16:00
17:00
LOCAL TIME
- Denotes water truck pass

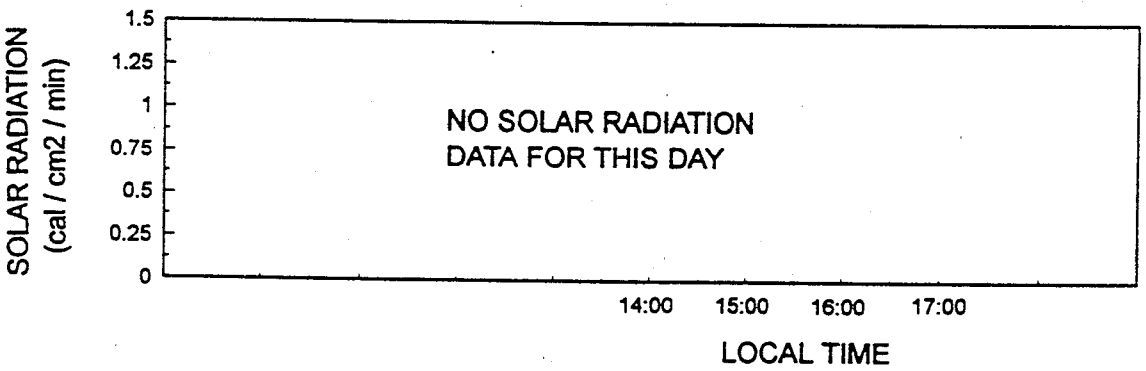

SOLAR RADIATION
(cal / cm2 / min)
1.5
1.25
1
0.75
0.5
0.25
0
13:00
14:00
15:00
16:00
17:00
LOCAL TIME

SITE 4 - MOISTURE TRACKING (10/23/92)






SITE 4 - MOISTURE TRACKING (10/26/92)
SURFACE MOISTURE(%)
16
14
12
10
8
6
4
2
0
14:00
15:00
16:00
17:00
LOCAL TIME
- Denotes water truck pass


SOLAR RADIATION
(cal / cm2 / min)
1.5
1.25
1
0.75
0.5
0.25
0
NO SOLAR RADIATION
DATA FOR THIS DAY
14:00
15:00
16:00
17:00
LOCAL TIME

APPENDIX D

COMPARISON OF EMISSION FACTORS

APPENDIX D

COMPARISON OF EMISSION FACTORS

This appendix presents a brief summary comparison between emission factors currently contained in AP-42 Section 8.24 (Western Surface Coal Mining) and those recommended based on results of the field study. Section 5 in the body of the report presents similar comparisons, but in greater detail.

D.1 SUPPORTING DATA SETS

It is important to recall that the predictive emission factors were developed from measurement-based data sets. These data sets contain not only the measured emission factors but also indicators of "source conditions." These include variables such as the texture and amount of material on a road surface as well as the speed and weight of vehicles traveling over the road. For discussion purposes, the measurement data set[D-1] supporting the current AP-42 Section 8.24 emission factors has been termed the "old" data set. Similarly, the data collected during the field study discussed in the main body of the report constitute the "new" data set. (Appendix B to the report presents these two data sets.)

It is also important to remember that the two data sets were collected at different times. The old data set supporting the current version of Section 8.24 dates from 1980 and earlier. The new data set consists of measurements made in the fall of 1992. In the intervening 12 years, at least two major changes occured.

First, the basis for the National Ambient Air Quality Standards for particulate was revised from total suspended particulate (TSP) to PM10 (particulate matter no greater than 10 microns in aerodynamic diameter). The predictive emission factors for PM10 in Section 8.24 were scaled from factors for other particle size ranges. <u>The present study is the first coal mining study to (a) directly measure PM10 emission factors and (b) to develop predictive emission factors specific to PM10</u>. In addition, the present study also interpolated PM10 emission factors for the old data set from information presented in the test report.[D-1]

Second, the surface coal mining industry has changed substantially since the time that old data base was developed. For example, "typical" haul truck capacities have increased by a factor of two to three. Not surprisingly, average vehicle speeds on haul routes are lower. Also, there is now less general, light-duty traffic on mine roads. In addition, because many permanent haul routes have been treated for dust control for many years, one can expect that physical properties of the permanent road surfaces (i.e., the amount and texture of loose aggregate) to be different.

Because of these differences in "typical" source conditions, one has little reason to

expect that a predictive emission factor developed from the old data set will necessarily accurately predict measured emissions in the new data set.

D.2 HAUL TRUCKS

The geometric mean measured haul truck emission factors in the old and new data sets are shown in Table D-1:

Table D-1 Geometric Mean Measured Haul Truck Emission Factors

	Haul Truck Emission Factor (lb/VMT)	
	PM10	TSP
Old Data Set	2.3	7.4
New Data Set	3.8	21

The emission factors are expressed in terms of pounds of particulate emitted per vehicle-mile-traveled. The rest of this section discusses how well the different predictive emission factors estimate measured values. Because the predictive emission factors are expressed as equations of different independent variables ("correction factors"), one cannot simply tabulate the measured and predicted values for comparison. Consequently, a different approach had to be undertaken. Two types of comparisons were made; each is discussed below.

D.2.1 Predictive Emission Factors for Haul Trucks

The haul truck emission factors currently contained in AP-42 Section 8.24 are:

$$e_{10} = 0.0031\ (w)^{3.5} \qquad \text{(D-1a)}$$

$$e_{TSP} = 0.0067\ (w)^{3.4}\ (L)^{0.2} \qquad \text{(D-1b)}$$

where

e_{10} , e_{TSP} = PM10 or TSP emission factor, expressed in pounds emitted per vehicle-mile-traveled (lb/VMT)

w = mean number of wheels per vehicle traveling the road

L = surface silt loading, representing the mass per unit area (g/m^2) of loose material that passes a 200 mesh screen upon dry sieving

The new emission factor equations presented in Section 5 of this report are:

$$e_{10} = 3.4\ (s/3)^{0.8}\ (M/2)^{-0.2} \qquad \text{(D-2a)}$$

$$e_{TSP} = 16\ (s/3)^{0.9}\ (M/2)^{-0.2} \qquad \text{(D-2b)}$$

where:

e_{10}, e_{TSP} = PM_{10} or TSP emission factor, expressed in pounds emitted per vehicle-mile-traveled (lb/VMT)

s = surface material silt content, representing the mass fraction (%) of loose road surface material that passes a 200 mesh screen upon dry sieving

M = surface material moisture content, representing the mass fraction (%) of water in the road surface material, as determined by weight loss upon drying

D.2.2 Comparison Between Mean Measured and Predicted Emission Factors

The first comparison investigated how well the predictive equations could predict "typical" emission factors on the basis of "typical" correction parameters. This approach compared the geometric mean measured emission factor against the value predicted when the geometric mean value for each correction parameter is substituted into the predictive equation. Tables D-2 and D-3 shows the results from these comparisons, for PM10 and TSP, respectively.

Several features are evident in the first comparison:

1. The current factors (Equations D-1a and D-1b) overpredict the old measurement data set. In other words, the current factors are not "centered" -- that is, the current factors possess a slight degree of systematic overprediction of the measured emission factors in the old data set used to develop the predictive factors.

2. On the other hand, when the current factors were applied independently (i.e, to data that were not used to develop the predictive emission factor), the current emission factor equations severely underestimate measured emission factors in the new data set.

3. When Equations D-2a and D-2b are applied independently, the new factors overpredict measured emission factors in the old data set.

4. Agreement for the PM10 size fraction is better than that for the TSP size

Table D-2 Comparison of Mean Measured[a] PM10 Haul Truck Emission Factors (lb/vmt) and Predictions Based on Geometric Mean Correction Factors

Predictive Emission Factor Equation	Data Set	"Typical" Correction Factors[b]	Predicted Emission Factor	Geometric Mean Measured Emission Factor
Equation D-1a	Old	w = 8.1 wheels[c]	4.7	2.3
Equation D-1a	Old	w = 7.6 wheels	3.8	2.3
Equation D-1a	New	w = 5.7 wheels	1.4	3.8
Equation D-2a	Old	s = 5.6% silt M = 2.5 % moisture	5.4	2.3
Equation D-2a	New	s = 3.5% silt M = 2.2 % moisture	3.8	3.8

[a] Old data set PM10 measurements estimated on the basis of log-normal interpolation of data presented in the test report[D-1].

[b] Except where noted, predictive equation correction factors represent the geometric mean of the values in the data set. (See Appendix B for listing of data sets.)

[c] Values given in Table 13-9 of in old data set test report[D-1].

Table D-3 Comparison of Mean Measured TSP Haul Truck Emission Factors (lb/vmt) and Predictions Based on Geometric Mean Correction Factors

Predictive Emission Factor Equation	Data Set	"Typical" Correction Factors[a]	Predicted Emission Factor	Geometric Mean Measured Emission Factor
Equation D-1b	Old	w = 8.1 wheels[b] L = 40.8 g/m^2 silt loading[b]	17	7.4
Equation D-1b	Old	w = 7.6 wheels L = 17 g/m^2 silt loading	12	7.4
Equation D-1b	New	w = 5.7 wheels L = 9.9 g/m^2 silt loading	3.9	21
Equation D-2b	Old	s = 5.6% silt M = 2.5 % moisture	27	7.4
Equation D-2b	New	s = 3.5% silt M = 2.2 % moisture	18	21

[a] Except where noted, predictive equation correction factors represent the geometric mean of the values in the data set. (See Appendix B for listing of data sets.)

[b] Values given in Table 13-9 of in old data set test report[D-1].

fraction in all comparisons.

Thus, this comparison indicates that the old factors possess some degree of overprediction of the old emission data set and that they do not provide acceptable estimates for emissions from haul trucks of type currently in use. Section 5 of the report discusses this issue in more detail.

D.2.3 Comparison between Mean and Predicted "Production-Based" Emission Factors

The second comparison attempts to at least partially correct for the most important difference between source conditions in the old and new data sets. The old data set consists of tests with haul trucks of approximately 100 ton capacity (roughly 85 to 120 tons) while haul trucks in the new data base are almost all 240 ton in capacity, with a few 170-ton capacity vehicles.

To take the difference in haul truck capacity into account, the second comparison considered emission factors referenced to "production" -- defined here as moving a mass of material a certain distance -- rather than simply vehicle miles traveled (VMT). To illustrate the approach, consider a hypothetical situation of moving a fixed amount of coal (say, 10,000,000 tons per year) a fixed distance (say, 2 miles). As Table D-4 shows, the mean measured PM10 emission factors would lead one to estimate annual PM10 emissions of 460 tons in the first case and 320 tons in the second.

Table D-4 Hypothetical Production Example

Case	Annual VMT required for Production[a]	Mean Measured Emission Factor (lb/VMT)	Estimated Annual Emissions (tons/yr)
100-ton capacity trucks	400,000	2.3	460
240-ton capacity trucks	170,000	3.8	320

[a] Vehicle-miles-traveled required found by dividing mass of material to be moved (10,000,000 tons per year) by the capacity of the haul trucks and multiplying by twice the distance (2 miles) the material is to be transported. (Each mile of transport involves two miles of travel -- one with the truck loaded, one with the truck empty.)

The above example also illustrates how haul truck emission factors can be expressed in terms of emissions due to "production". One can change the basis from pounds

emitted from one mile of haul truck travel to pounds emitted to transport one ton of material (coal or overburden) one mile. Thereafter, one can again consider how well the predictive equations predict "typical" emission factors, except that emission factors have been reexpressed in terms of production. Tables D-5 and D-6 shows the results from these comparisons, for PM10 and TSP, respectively.

In Tables D-5 and D-6, measured production-based emission factors were found by dividing by the geometric mean measured emission factor by the range of nominal haul truck capacity for the data set -- 85 to 120 tons for the olde data set, 170 to 240 for the new. The predicted production-based emission factors were found by dividing the predicted emission factor by the range of nominal truck capacity in the data base underlying the emission factor equation. That is, predictions from Equation D-1a or D-1b are divided by the range of 85 to 120 tons. Predictions from Equation D-2a or D-2b are divided by the range of 170 to 240 tons.

The change in the basis of the emission factor does not affect any comparisons between an emission factor and its supporting data base. Thus, for example, the current Section 8.24 factors are still not "centered" and show slight overprediction of measured emission factors in the older data set.

On the other hand, the change in basis partially "corrects" for some shortcomings of the emission factors applied to independent (i.e., not used in the development of the factors) data:

1. Although the current factors (Equations D-1a and D-1b) still underestimate measured emission factors in the new data set, the degree of underprediction is substantially lower for the production-based emissions. Using the nominal haul truck capacities of 100 and 240 ton respectively for the old and new data sets, the recast PM10 factor is underpredicted by only 30%.

2. Similarly, while the new factors (Equations D-2a and D-2b) still overpredict measured emission factors in the old data set, the degree of overestimation is far less. When nominal capacities are used, the recast PM10 factor is only overpredicted by 20%.

3. Agreement is still better for PM10 than for TSP.

In summary, the new haul truck emission factors (Equations D-2 and D-2b) will almost always result in higher "lb/VMT" values than the emission factors currently in Section 8.24. Recall, however, that the emission factors were developed from data sets with very different source conditions. When emissions are considered on the basis of production, however, the predictive emission factors do a far better job of estimating measured emissions in the independent data set.

Table D-5 Comparison of Mean Measured[a] and Predicted "Production-Based" PM10 Haul Truck Emission Factors (lb/ton-mile)

Predictive Emission Factor Equation	Data Set	"Typical" Correction Factors[b]	Predicted Emission Factor[c]	Geometric Mean Measured Emission Factor[d]
Equation D-1a	Old	w = 8.1 wheels[e]	0.078 - 0.11	0.038 - 0.054
Equation D-1a	Old	w = 7.6 wheels	0.063 - 0.089	0.038 - 0.054
Equation D-1a	New	w = 5.7 wheels	0.023 - 0.033	0.032 - 0.045
Equation D-2a	Old	s = 5.6% silt M = 2.5 % moisture	0.045 - 0.063	0.038 - 0.054
Equation D-2a	New	s = 3.5% silt M = 2.2 % moisture	0.032 - 0.045	0.032 - 0.45

[a] Old data set PM10 measurements estimated on the basis of log-normal interpolation of data presented in the test report[D-1].

[b] Except where noted, predictive equation correction factors represent the geometric mean of the values in the data set. (See Appendix B for listing of data sets.)

[c] Range of measured production-based emission factors found by dividing by the geometric mean measured emission factor by the range of nominal haul truck capacity for the data set.

[d] Range of predicted production-based emission factors found by dividing the predicted emission factor by the range of nominal truck capacity in the data base underlying the emission factor equation. That is, predictions from Equation D-1a are divided by the range of 85 to 120 tons. Predictions from Equation D-2a are divided by the range of 170 to 240 tons.

[e] Values given in Table 13-9 of in old data set test report[D-1].

Table D-6 Comparison of Mean Measured and Predicted "Production-Based" TSP Haul Truck Emission Factors (lb/ton-mile)

Predictive Emission Factor Equation	Data Set	"Typical" Correction Factors[a]	Predicted Emission Factor[b]	Geometric Mean Measured Emission Factor[c]
Equation D-1b	Old	w = 8.1 wheels[d] L = 40.8 g/m^2 silt loading[d]	0.28 - 0.40	0.12 - 0.17
Equation D-1b	Old	w = 7.6 wheels L = 17 g/m^2 silt loading	0.20 - 0.28	0.12 - 0.17
Equation D-1b	New	w = 5.7 wheels L = 9.9 g/m^2 silt loading	0.065 - 0.092	0.18 - 0.25
Equation D-2b	Old	s = 5.6% silt M = 2.5 % moisture	0.22 - 0.32	0.12 - 0.17
Equation D-2b	New	s = 3.5% silt M = 2.2 % moisture	0.15 - 0.21	0.18 - 0.25

[a] Except where noted, predictive equation correction factors represent the geometric mean of the values in the data set. (See Appendix B for listing of data sets.)

[b] Range of measured production-based emission factors found by dividing by the geometric mean measured emission factor by the range of nominal haul truck capacity for the data set.

[c] Range of predicted production-based emission factors found by dividing the predicted emission factor by the range of nominal truck capacity in the data base underlying the emission factor equation. That is, predictions from Equation D-1b are divided by the range of 85 to 120 tons. Predictions from Equation D-2b are divided by the range of 170 to 240 tons.

[d] Values given in Table 13-9 of in old data set test report[D-1].

D.3 Light- and Medium-Duty Vehicular Traffic

A earlier review of emission factors[D-2] recommended that the "generic" unpaved road equation in AP-42 Section 11.2.1 replace the current factor for light- to medium-duty traffic emission factor in Section 8.24. That recommendation was based on a comparison against independent emission data. The present study reinforced the earlier recommendation, based on not only "new" data but also reexamination of the "old" data set supporting the current Section 8.24 expression.

The current Section 8.24 emission factor for light- to medium- duty traffic is

$$e_{10} = 2.23\ (M)^{-4.3} \qquad \text{(D-3a)}$$

$$e_{TSP} = 5.79\ (M)^{-4.0} \qquad \text{(D-3b)}$$

where

e_{10}, e_{TSP} = PM10 or TSP emission factor, expressed in terms of pounds emitted per vehicle-mile-traveled (lb/VMT)

M = surface material moisture content, representing the mass fraction (%) of water in the road surface material, as determined by weight loss upon drying

The "generic" unpaved road emission factor expression in AP-42 Section 11.2.1 is

$$e_{10} = 2.1\ (s/12)\ (S/30)\ (W/3)^{0.7}\ (w/4)^{0.5} \qquad \text{(D-4a)}$$

$$e_{TSP} = 4.7\ (s/12)\ (S/30)\ (W/3)^{0.7}\ (w/4)^{0.5} \qquad \text{(D-4b)}$$

where:

e_{10}, e_{TSP} = PM_{10} or TSP emission factor, expressed in pounds emitted per vehicle-mile-traveled (lb/VMT)

s = surface material silt content, representing the mass fraction (%) of loose road surface material that passes a 200 mesh screen upon dry sieving

S = average speed (mph) of vehicles traveling the road

W = average weight (tons) of vehicles traveling the road

w = mean number of wheels per vehicle traveling the road

The most important feature of the current Section 8.24 emission factors (Equations D-3a and D-3b) is the highly nonlinear dependence upon moisture content. The range

of moisture contents presented in Section 8.24 is quite small, only 0.9 through 1.7%. These emission factors have been found to be capable of producing very unacceptable estimates. The earlier review[D-2] found that the current Section 8.24 factors for light- to medium-duty vehicles could overpredict independent measured emission factors by two orders of magnitude. The present study reinforced this finding; one measured PM10 emission factor was overestimated by a factor of 40, while the TSP factor was overestimated by a factor of 20.

The present study combined the old and new data sets and found that the generic unpaved road emission factors (Equations D-4a and D-4b) capable of producing acceptable estimates over a broad range of source conditions at surface coal mines. Based on results from the the combined old and new data sets, the recommended use of the generic emission factor in place of the Section 8.24 will reduce predicted emissions approximately 20% for PM10 and 40% for TSP.

REFERENCES

D-1. Axetell, K. and C. Cowherd. Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources. Two Volumes, U.S. Environmental Protection Agency. July 1981.

D-2. Muleski, G. E. Review of Surface Coal Mining Emission Factors. U.S. Environmental Protection Agency Contract No. 68-DO-0137, Assignment 10. July 1991.

APPENDIX E

LOG OF COMMENTS

RESPONSES TO COMMENTS MADE IN SEPTEMBER 15, 1993 LETTER FROM WYOMING DEQ TO D. SHIPMAN

RESPONSES TO COMMENTS PRESENTED IN AN AUGUST 30, 1994 FAX FROM KIRK WINGES OF MCCULLEY, FRICK AND GILMAN TO JIM SOUTHERLAND

COMMENT	RESPONSE
1. Relationship between moisture and emissions: It is not clear why there is such a poor relationship between moisture and emissions. Water with chemical suppressants is being used to control the emissions and one would assume that the results of the testing should demonstrate a relationship between moisture and emissions. In the correlation matrix on page 71 in both the PM-10 and TSP matrix moisture shows the least correlation with emissions. Related to this issue, there is no description in the report as to what was considered uncontrolled emission testing and what was considered controlled emission testing, for example, number of water truck passes, description of chemical suppressant being used, period road not watered, etc.	1. As noted in response to TRC's comments, we are preparing a new appendix to provide additional discussion on moisture content. In addition, the main body of the report is being revised to better (a) distinguish between watered and uncontrolled tests and (b) describe the control efficiency values observed.
- -	- -
EPA's response does not fully answer DEQ's comment. DEQ's major point in several related comments is that incorporating the moisture content into the emission factor equation will make it difficult to use in a regulatory application. The new information provided in Appendix C to the report, along with the text changes do help to answer DEQ's comment to some degree. However, EPA/MRI needs to take the response one step further. **The historical use of these emission factors in the regulatory environment is that an emission rate was calculated and a control factor applied. It seems possible, based on the data provided, for MRI to establish two factors: (1) a moisture content which is inherent to the soils which includes climatic influences and nature of the soils of the roads at the Cordero mine (an uncontrolled moisture content) and (2) the amount the moisture content of the soils is increased by the application of water to the ground. Clearly, this latter factor is influenced by temperature and wind speed and other factors present during the time of each individual test, and may need to be corrected. The point is that with such information, we could obtain a basic understanding of the amount of moisture in the soils naturally, the climatic factors which affect moisture and how much the watering helped to increase this moisture content. Then a regulatory agency, such as the DEQ, could give guidance to the applicant as to how much water is enough to control the road to a level acceptable from an ambient air quality perspective. Without this information, it will be difficult to assess the effectiveness of a watering program. The information added in the Appendix C does not answer this question.**	**MRI agrees that a better understanding of how road moisture levels are affected by meteorology and water addition would be of considerable use. An existing road watering model[3] provides a good beginning.** **Although current program sources (in terms of both time and money) would not permit this type of study at the present, a substantial data base could be assembled at relatively low cost. MRI suggests that the type of study recommended in the comment be undertaken after more samples (preferably spanning the calendar year) have been collected. Although one could use only the data collected at Cordero, a more thorough set of data would be expected to yield better estimates.**

COMMENT	RESPONSE
2. TSP PM 10 model relationship and variables: It is reported the TSP model based solely on the regression would result in a model including silt, weight and speeds. To maintain similarity between the models the TSP model was forced to resemble the PM-10 model. Reviewing the correlation matrix for TSP and PM-10, there appears to be little difference in the relationship between emissions and the above listed variables. What would a PM-10 model look like based on the silt, weight and speeds as initially suggested for the TSP model?	2. We recognize that the AP 42 Chapter 11 update (performed [illegible] with this program) provided us insight in this matter. In the update, we discussed the problem that, when different forms of emission factors are used, PM10 emission estimates could be numerically greater than corresponding TSP levels. Using similar model forms avoids this problem, even when emission factor models are used far outside the range of applicability. In reply to the specific question asked, the following table provides log-linear regression results when the TSP and PM10 data are fitted to (a) a silt-speed-weight model and (b) a silt-moisture model. r^2 for TSP model: "Silt, speed, weight" model 0.749; "Silt, moisture" model 0.673 PM10 model: "Silt, speed, weight" model 0.583; "Silt, moisture" model 0.511 Exponents in TSP model / PM10 model "Silt, speed, weight" model Silt: 0.875 / 0.775 Speed: 1.582 / 0.584 Weight: 0.611 / 0.237 "Silt, moisture" model Silt: 0.971 / 0.827 Moisture: -0.114 / -0.223 As one can see, the TSP and PM10 versions of a silt, speed and weight model would have very different powers for speed and weight. On the other hand, the second set of exponents indicates that the TSP data are far more amenable to being fitted to the same silt-moisture form used for PM10.
3. Moisture: Use of moisture in the emission factor to predict future emission on a short term and annual basis will be difficult. Previous factors have used variables such as silt content, # of wheels, speeds, etc., for an uncontrolled emission factor. Then control efficiency for a particular type of control is applied for the controlled emission rate. Water and chemical dust suppressants are used to control emissions from haul roads. I am not sure how the proposed factor would be used in regulatory application. How will one assume or determine a moisture content for a controlled road for a future mine? If one is conducting a study on existing roads over a particular time frame to determine emission rates and would measure moisture and silt content over the same time frame, I can see where the proposed emission factor may work. I do not see it working for projecting future emissions given moisture as direct input in place of a control efficiency. For use in determine annual emissions a climatic factor of some type must be built into the factor. The data taken at Cordero was during the driest season of the year. - **As noted above, EPA's response to DEQ's question does not adequately answer the important issue of the use of such a correction parameter in a regulatory application. The analogy with silt is not a good one. For the most part, silt content of the road is not something the mine consciously controls, at least not without substantial effort in road construction. Water content is something the mines do regularly affect with the watering program. Guidance needs to be provided to make this emission factor useful in the regulatory environment.**	3. As noted above, we are revising the report to enhance the discussion on moisture content, control efficiency observed, etc. We do not see that there is a great difference between being required to estimate moisture content rather than silt loading at a proposed mine. The general approach will remain using data from existing mines to project likely values at the proposed facility. The model presented in the report does have a distinct advantage over the current factors in that it can provide better definition of seasonal variations in emissions. (Substantial interest in this issue was expressed at the March 1992 meeting in Gillette.) Admittedly, there is a need to "track" moisture through grab samples; however, these are far easier samples to obtain and analyze than those needed for other emission factors currently in use. - **MRI agrees that additional guidance is needed; however, MRI also believes that additional moisture-tracking information should be collected. As noted in the response to 1, a more complete set of data would certainly be preferred. The point is made in the original response that this type information is relatively easy to collect and analyze.**

COMMENT	RESPONSE
4. Relationship with the old data set: There was considerable discussion comparing the new data set with the old data set. The old data set consisted of data taken from the Cordero mine in Wyoming and mines in two other states. There evidently was no consideration given to only looking at the old data set taken specifically at Cordero.	4. As was the case with TRC comments, we are not entirely sure what the reviewer means by the "old" data set. None of the data currently supporting AP-42 Tables 8.24-1,-2 were collected at Cordero. If, on the other hand, the reviewer means the emission factors measured in the EDS study, that comparison is on pages 73-74 of the report. As discussed in the report, the old EDS expression (based on testing at Cordero) fit the new data set relatively well. However, the comparison with the AP-42 Section 8.24 data set was not nearly as favorable.
5. Control efficiency: There is no discussion in the report as to control efficiency of the water and chemical suppressant application to the roads. As discussed in item 1, the testing program listed controlled and uncontrolled testing. No relationships were derived for control efficiency and as previously stated there is no information on what was considered controlled and uncontrolled. As discussed in item 3, if one determines an emission factor based on variables other than moisture, the data must be analyzed for determination of control efficiency. Use of moisture in the proposed emission equation apparently negated the need for this type of review and analysis. - **The same point applies to this response.** [i.e., that raised in item 3 above, which reads "As noted above, EPA's response to DEQ's question does not adequately answer the important issue of the use of such a correction parameter in a regulatory application. The analogy with silt is not a good one. For the most part, silt content of the road is not something the mine consciously controls, at least not without substantial effort in road construction. Water content is something the mines do regularly affect with the watering program. Guidance needs to be provided to make this emission factor useful in the regulatory environment."]	5. Please see response to items 1 and 3 above. - **As expressed in the other responses, MRI strongly believes in the value of additional guidance based on a suitable data base.**
6. Scraper emission tests: I do not believe any conclusions can be base on two tests. Further work should be done in this area.	6. We agree that much more work should be done for scraper emissions (not only in the context of surface mining but also general construction).[2]

References

1. Muleski, G. E. and B. Henk. Review and Update of Miscellaneous Sources in Chapter 11, AP-42. Assignment 44, EPA Contract 68-D0-0123. April 1993.

2. Henk, B. and G. E. Muleski. Background Document for AP-42 Section 11.2.4, Heavy Construction Operations. Draft. Work Assignment 44, EPA Contract 68-D0-0123. April 1993.

3. U. S. Environmental Protection Agency. Control of Open Fugitive Dust Sources. EPA-450/3-88-008. Research Triangle Park, NC.

RESPONSE TO COMMENTS IN TRC REPORT DATED SEPTEMBER 15, 1993

RESPONSES TO COMMENTS PRESENTED IN AN AUGUST 30, 1994 FAX FROM KIRK WINGES OF MCCULLEY, FRICK AND GILMAN TO JIM SOUTHERLAND

COMMENT	RESPONSE
2.1[1] Both 3 and 10 have been given as the silt content normalization factor, which is correct and why?	2.1 Both expressions are numerically correct in the context where they appear. The decision to revise the silt term denominator from 10 to 3 was made late in the report preparation process; we simply overlooked making the change in the cross-validation section. The recommended factor does indeed use the divisor of 3, and the cross-validation section will be revised in the final version of the report.
Why was logarithmic regression used instead of linear regression? It appears that better correlations can be obtained with linear regressions.	The choice of log-linear[2] regression is very much consistent with the data involved, in that the dependent and most of the independent variables appear to be far more log-normally distributed than normally distributed. Figures 1 through 8 compare normal probability plots for both 1) raw (i.e., untransformed) and 2) log-transformed data for all variables in correlation matrix, namely PM10 emission factor TSP emission factor silt content silt loading moisture content mean vehicle weight mean vehicle speed mean number of wheels per vehicle The figures include both sets of haul truck data in Appendix B to the report: SET = 0.000 refers to the "old" data, namely that supporting AP-42 Table 8.24-1,-2. SET = 1.000 refers to the new data, namely, that collected during the study Both emission factors, the silt and moisture contents, and the silt loading are far better characterized in terms of a log-normal rather than a normal distribution. This can be seen from the figures by observing whether the main portion of either the untransformed or the log-transformed data are more linear in the plot. Furthermore, normal and log-normal distributions appear to fit the vehicle-related variables equally well. Because standard tests of significance assume normal parent populations, regression of log-transformed data is far more appropriate than regression of untransformed values.

[1] Comments and responses are referenced by section number within the TRC report.

[2] Throughout this response, "log" refers to the natural logarithm.

COMMENT	RESPONSE
2.2 While it makes sense that a emission factor would be dependent on moisture content, the data do not support this conclusion. Even the log-transform of moisture content accounts for only a small amount of variation in either PM10 or TSP emission factor. If there is no obvious relationship between watering and moisture content, then there is no basis for judgement of control and no basis for inclusion of a weakly correlated variable such as moisture content in the emission factor.	2.2 A computerized stepwise linear regression of log transformed data was used to develop an emission factor model, and there was certainly no attempt to force moisture content to enter the regression. As one would expect from the correlation matrix (page 78 of the draft final report) silt content entered on the first step, and moisture content entered on the second step. Thereafter, no other variables entered. Comments made that the inclusion of moisture cannot be justified appear to overlook a key feature of stepwise regression. The matrix on page 78 presents only correlations between the original variables. On the other hand, once stepwise regression has begun, new quantities -- namely residuals -- must be taken into account. It may be instructive to consider the first two steps in stepwise regression in following general way. Regression with two independent variables may be viewed as a series of two simple (i.e., one independent variable) regressions. In the case of the haul trucks, simple log-linear regression of the PM10 emission factor against silt leads to a first result of log (predicted ef) = 0.32 + 0.82 * log(silt) The (log) residuals for this model are equal to the difference log (observed ef) - log (predicted ef) The second step regresses the (log) residuals against one of the remaining candidate independent variables. The correlation matrix is shown below:

	LRESID	LMOIST	LSL	LMPH	LTONS	LWHEELS
LRESID	1.000					
LMOIST	-0.301	1.000				
LSL	0.102	0.038	1.000			
LMPH	0.112	-0.400	0.238	1.000		
LTONS	0.038	0.248	0.247	-0.464	1.000	
LWHEELS	0.025	-0.042	0.252	-0.353	0.753	1.000

Because residuals are most highly correlated with moisture, it is no surprise that moisture content enters on the next step.

As a final remark, regression analysis requires "correction terms" to be essentially independent of one another. As noted on page 77 of the report, there is a very low degree of interdependence between silt and moisture contents.

We are adding an appendix to the report to provide additional discussion on moisture. In addition, the main body of the report is being revised to better (a) distinguish between watered and uncontrolled tests and (b) describe the control efficiency values observed.

COMMENT	RESPONSE
2.3 The measured silt contents in this data are significantly lower than that of previous studies. Nevertheless, the seven test runs above 5% dominate the relationship; this is a statistical weakness in the data set.	2.3 We are not sure what exactly TRC means by "old" data here. In our draft report, "old" data refer to the data base currently supporting AP-42 Tables 8.24 1, and -2. (Those values are included in Appendix B of the draft). None of those data were collected at the Cordero mine. It is possible that TRC is referring to either data collected during the EDS study[1] or perhaps the values used in their 1991 report[2] for the WY DEQ. Tables 4-5 and 4-7 of the latter study give the following: Silt Content (%) / Silt Loading (g/m^2) Coal haulage: 9.5 / 65 Overburden haulage: 6.5 / 65 In our draft final report, we have the following values: Silt Content (%) / Silt Loading (g/m^2) Coal haulage Site 1: 4.1 / 35 1B: 2.5 / 5.5 2: 3.0 / 8.0 All coal: 3.0 / 13 Overburden Site 4: 8.8 / 64 There is no discernible difference between the overburden values. While the new coal road values are lower, this does not strike us as particularly surprising. The permanent coal haul roads have been treated with water/surfactant for several years and are well compacted and maintained. For these reasons, we would suspect that the amount of loose material in all size fractions would be (on average) lower now than in the past. TRC is correct in surmising that the highest silt contents would "dominate" <u>if</u> arithmetic regression is used. Figures 3 and 4 in the TRC report show that point. Note, however, that log-linear regression does not suffer that limitation. In effect, the log-transformation effectively "spreads out" the data, which would be seen had TRC elected to use fully logarithmic plots in their Figures 3 and 4. Please see earlier discussions of log-linear regression.

COMMENT	RESPONSE
2.4 TRC believes that combining multiple sites has weakened the study's database and has led to a less than satisfactory emission factor. - **EPA's[3] response seems to fail to understand the point TRC was making. TRC's comment suggests that each test site exhibited a different emission behavior, and the separate emission factors for each site might be appropriate. Then guidance could be provided to the user to allow him/her to select which site best represents the haul road being modeled. As an example, consider the case of sealed and unsealed storage tanks of some volatile liquid. If half the tanks in the test are unsealed and emit at a rage of 100 pounds per hour, while the other half are sealed and emit a 0 pounds per hour, combining the data sets would mean that on the average, the tanks emit at 50 pounds per hour. It would be far better to report separate emission factors for sealed and unsealed tanks, so that the user could select the emission factor which most closely matched his source.** **EPA's response and the plots seem to make this point, rather than diffusing the point. By combining the data sets, the difference in performance at site 1B and site 4 is lost.**	2.4 It is important to keep in mind that a goal of any emission factor is to accurately estimate emission levels when no measurements are available. As a result, we believe that a "stronger" model will result when results from different sites are combined. (This assumes, of course, that differences in underlying source conditions do not preclude combinations.) The situation is certainly analogous to combining results from different plants or mines to develop more widely applicable emission factors. Figures 9 and 10 present a series of box plots for the PM10 emission factors versus test sites. (Note that statistics here are for the log-transformed data, in keeping with the earlier discussion about log-normal distributions.) The 95% confidence intervals indicate that there is no significant differences between (a) uncontrolled tests over the 4 sites or (b) watered tests over three sites. On the other hand, there is far more indication of a significant difference between watered and unwatered tests at the same site. - **The analogy of the different storage tanks is an interesting one. However, to continue the analogy: Does one know beforehand that 50 of the tanks are sealed and the other 50 are unsealed? Or does one know only that there are 100 tanks in all?** **One can easily point to several differences between the permanent coal haul roads and the overburden route (Site 4). For example, because the Site 4 road will not be used as long or as extensively, the road is not as well constructed or as well maintained as the permanent haul roads. Furthermore, because the Site 4 road is not "on the way" to other points in the mine, almost all the traffic at Site 4 consists of haul trucks. Thus, one can easily expect, for example, that Site 4 would have a higher silt fraction and a heavier average vehicle weight than the permanent coal haul roads. However, is there an a priori reason to suspect that the two types of roads have different mechanisms for dust generation?** **MRI agrees that data bases should not be forced together if there is compelling evidence that the underlying source mechanisms are not the same. However, in the absence of (a) a priori knowledge that the sources are different and (b) empirical data that show a significant difference that cannot be "explained" through the use of other variables, then MRI believes that the decision to combine sources is correct.**
2.5 Given that there were no changes at the Cordero mine, why are the silt content (old data versus new data) and more importantly silt loading (old data versus new data) so different? The silt contents for the mine's haul roads are not much different from the old data to the new data, but silt loadings are. TRC suspects that a change in sample collection methods for silt loading is the primary difference.	2.5 We agree that testing at more than one mine would have led to "stronger" model. Once again, we are unsure to what "old" data TRC is referring. (Please see response to section 2.3) There has been no change in sampling procedures; that is to say, the new samples were collected and analyzed in the same way as the old data in Appendix B of the report. However, because the original PEDCo/MRI test report used the term "loading" in two senses, our draft version report mistakenly identified total loading as silt loading in Appendix B. Appendix B and affected figures in the main body of the report have been corrected. Even after correction, however, silt loading still differs between the old and new data sets at the 5% significance level.

[3] Material shown in **bold** is either drawn from or responds to a second set of comments presented in an August 30, 1994 fax from Kirk Winges of McCulley, Frick and Gilman to Jim Southerland of the US EPA.

COMMENT	RESPONSE
2.6 What effect does wind angle have on the emission factor? Without correction this could affect the emission factor up to 41.4%.	2.6 The report did not include a correction for mean wind direction. No corrections had been made to any of the data supporting AP-42 Table 8.24-1, -2. As noted in the SoRI collaborative study of exposure profiling[3], not correcting for wind angle is fairly standard practice. In fact, although they employed cosine correction in the EDS study, TRC dropped the correction when describing MEDUSA sampler in the first phase[4] and did not correct during the second phase[5] of the SoRI collaborative study. We currently are reviewing the wind angle data. Although we have not fully QA'd the data at the time of this writing, the preliminary mean correction term using TRC's cosine expression is approximately 1.20 (on an arithmetic basis) and 1.18 (on a geometric averaging basis). To respond on a more fundamental level, it is important to note that the cosine correction proposed by TRC applies to (a) concentration downwind from (b) a uniformly emitting line source. In the context of testing a line source, however, mass flux rather than concentration is at issue in establishing an appropriate wind angle correction. Even more importantly, traffic on an industrial road is far too low to represent the road as a steady, uniformly emitting line source. A far better representation would view the source as a series of discrete moving point sources, and for this representation, it is not at all clear that the cosine correction applies. As the plume is released, dispersion occurs in all three cartestian coordinate directions. Only dispersion in the direction parallel to the plume centerline would be negligible. Depending on the direction a vehicle is traveling, an oblique wind would appear to dilute or "concentrate" the plume mass seen by the samplers. Correction for each plume depends upon the magnitude and direction of the wind relative to vehicle velocity vector. In other words, if two vehicles passed in opposite directions at the same time, one plume would be concetrated and the other diluted. The cosine correction cannot distinguish between those two cases.
- **We do not agree with EPA's response to this point. EPA states that "traffic on an industrial road is far too low to represent the road as a steady, uniformly emitting line source," but that is precisely what EPA assumes it to be in the equations of Section 2.3.1 and 2.3.2. Regardless of whether the vehicle's motion vector affects the dispersion of an individual truck pass, the equations used by EPA assume the emissions to have occurred continuously over the time the sampling occurred and the winds are perpendicular. Cosine correction is appropriate by the way EPA used these measured concentrations. Only the perpendicular component of the wind speed in the equation at the bottom of page 16 should be used.**	- The expressions in Section 2.3.1 and 2.3.2 are not based on any assumption of continuous emissions but rather rely on average conditions during the test period. In other words, concentration at a given height is certainly not assumed constant through the period, but is known to very strongly, in a cyclic manner, with the passage of each plume cross the sampler. The sample mass is collected over several plumes to form an integrated average. When the net average is multiplied by the test duration, the result represents a total mass attributed to the source, i.e., the passage of a given number of plumes (or vehicles).

COMMENT	RESPONSE
2.7 Setting the exposure at ground level equal to the exposure at the one meter height is counterintuitive. What happens at the ground level, in theory, is that the concentration approaches its maximum centerline value directly downwind of the emissions release (the "centerline" concentration) while the wind speed approaches zero. The exposure, which is the multiplicative product of wind speed and concentration, must go to zero. Again, without evidence to the contrary, it is counterintuitive that the exposure would be set to the exposure value at the one meter height. A similar problem may occur near the top of the concentration profile.	2.7 The SoRI collaborative study[3] also examined a wide variety of vertical integration schemes. Differences were found to range from 2% to 12%, with an average difference of about 4%. SoRI concluded that different methods of integration will usually have little effect on the results.
2.8 Applying the new emission factor to the old data set showed that almost all data points are greatly overpredicted. This inability of the new emission factor to match the old data sets leads to a dilemma. If the new emission factor can't match the old data, it loses its connection and validation for more than one mine. On the other hand, if the new emission factor is valid, the old data set must be discarded.	2.8 Because the regression used log-transformed data, TRC Figures 10 and 11 would be more meaningful had logarithmic scales been used. We used the nonparametric "runs" test to check log-residuals for randomness, and found a tendency for the new PM10 emission model to underestimate measured emissions for high silt fractions (or equivalently high observed emissions). We will expand this discussion in revised report. The box plots on page 58 of the draft report show that the source conditions -- especially mean vehicle weight and silt loading -- underlying the old and new data sets are quite different. There is certainly no argument that haul trucks are far heavier now than 10 or 15 years ago. Furthermore, as response 2.3 discussed, present-day silt loadings could well be expected to be lower now than past. Given the differences in underlying source conditions, the failure of the new equation to predict old data is neither particularly surprising nor damning. Quite simply, the two data sets were drawn from a parent population that has changed over time.

COMMENT	RESPONSE
2.9 The usefulness of the data has been compromised by testing at four different haul road sites and combining the results. The resulting equation contains two new independent variables -- silt and moisture -- but the purported correlation with moisture is non-existent.	2.9 MRI strongly agrees that a better model would have resulted had time and money permitted testing at more mines. The decision was made early on to focus on sources that have been identified [2,6] as major contributors to PM emission inventories at surface coal mines. Our planning studies[7,8] -- including the emission factor summary that TRC's Denver office reviewed -- discussed how conditions such as "typical" haul truck capacity had changed. Sampling plans were made to obtain as much information as possible given the time and budget constraints. MRI disagrees with TRC's contention that results from different test sites should be considered separately. Rather than developing an emission factor to provide an excellent fit to measured data, the goal is to provide a tool that is broadly applicable for estimating emissions when measurements are unavailable. Combining the test results provided a broader base upon which a factor could be built.
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As with the response to TRC Comment 2.4 above, EPA seems to fail to understand the point of the comment. It is recognized and agreed that the desire of emission factor development is to develop emission factors which are broadly representative, but the question is whether there are underlying relationships in the data which are lost when things are overly averaged or combined. Are there factors about Site 1B that would make the emissions marked less than those at site 4? If so, what are those factors, and has the user been presented with a way to account for those differences at his own mine, or are the conditions at the Cordero Mine so different from his mine that none of the sites are representative?	**Please see the expanded response given in 2.4 above. MRI believes that the use of correction parameters (such as silt content) in a predictive emission factor equation represents a much more tractable approach to account for differences between mines and roads, when such an emission factor is meant to be broadly applicable to a range of source conditions. The purpose of the emission testing at Cordero was not to develop specific emission factors for specific road segments.**

COMMENT	RESPONSE
3.1 The PM10 multiplier of 0.36 based on these limited tests of light and medium duty traffic is not supported. There are now only three tests in which PM10 was explicitly measured and the range of prediction is 0.976 to 3.35 times the observed. This clearly shows overprediction. - The three data points for light- and medium-duty traffic are too few to be entirely useful, yet EPA seems to be using them to justify the use of Section 11.2.1 emission factors, even though they don't agree very well. In the model protocol, Section 11.2.1 is proposed for these sources in all three emission factor sets. Somewhere it should be pointed out these are not supported by the current emission testing, and that, while too few emission tests have been performed to develop a new factor, the test data which are available suggest the source is overpredicted.	3.1 As discussed earlier, sampling plans were made to obtain as much valuable information as possible given the time and budget constraints. Soon after Section 8.24 first appeared in AP-42, some have raised doubts about emission factor for general vehicle traffic, primarily for the atypical dependence on moisture. During planning phases[7], there were independent data against which the Section 8.24 model could be evaluated. The background report[7] recommended that the Section 11.2.1 unpaved road factor replace the Section 8.24 light- and medium-duty emission factor. TRC's statement should be clarified. There are now three tests of light- and medium-duty traffic at surface coal mines in which PM10 was explicitly measured. The admittedly few light-duty tests were conducted to determine if the AP-42 Section 11.2.1 factors provide sufficiently accurate estimates for light and medium-duty traffic at mines. There was no intention to use these tests to revise the AP 42 Section 11.2.1 particle size multipliers. Those multipliers were were developed from many tests in several industries. - The recommendation was made on the basis of examining how well emission factors in the combined (i.e., old and new) data sets were estimated by the generic unpaved road model. This is shown at the bottom of page 79 in January 17, 1994 report. This point could be elaborated in the final version of the report.
3.2 With only two tests, TRC feels that no conclusion can be drawn concerning scrapers.	3.2 Scrapers were not singled out for intensive study because we believe that "typical" source conditions had not changed to any extent close to that for haul trucks. MRI strongly agrees that much more work should be done for this source (not only in the context of surface mining but also general construction).[9]
3.3 There are six other factors from the old study which should be tested in sufficient detail to arrive at highly correlatable factors for PM10.	3.3 As noted earlier, sampling plans were made to address the most important needs within the time and budget constraints. We agree that the other sources should be reevaluated, especially in terms of their predictive accuracy when applied to indepenedent data and their applicability to other mines. Our planning studies[7,8] -- based on earlier investigations[2,6] of the emission factor/dispersion modeling methodology as well as our observations on what currently constitutes "typical" operations -- indicated that haul trucks are the source to be investigated first.
4.0 The data support a PM10/TSP much smaller than the 35% used previously. The average ratio at 100 meters is 18%.	4.0 We are unsure to what "100 meter downwind" data TRC is referring. The number of samples suggests that they mean the exposure profiling tests, which are conducted at nominal 5m distance downwind. In any event, we agree that a PM10/TSP ratio of about 20% is appropriate for haul truck emissions (as evidenced by the ratio of "k" values in Table 19) as well as for the light- and medium-duty traffic emissions measured as part of the study. However, the three light- and medium-duty ratios do not provide a defensible basis to effectively halve the generic size multiplier for use at surface coal mines. In response to the last paragraph in TRC's Section 4.0, we will provide more text than is currently on page 15 about how TSP emission factors were obtained. Furthermore, we are including in the revised report a new table of "raw" (i.e., measured) concentrations for all the samplers, both upwind and downwind.

COMMENT	RESPONSE
5.0 The saturation sampling did not provide any useful data. Negative sample weights make that obvious. Tests at off-site locations show relatively low concentrations of both PM10 and TSP values and well below standard. These data should be of specific use during the model comparison phase of the study. Wind direction data would be helpful in the modeling. These need to be reported.	5.0 A side study was added to the field program during the August 31, 1993 meeting between EPA, WMA, Wyoming DEQ and MRI. This expanded operation of Cordero's hi-vol ambient monitoring network from 1-day-in-6 to as close to 1-day-in-2 as practical. Furthermore, limited "saturation sampling" was undertaken late in the field program to obtain practical experience with those devices. We are requesting the meteorological record from Inter-Mountain Laboratories in support of the hi-vol data for later phases in the study. (Please note that we do not expect to include the met record as part of the revised report.) The saturation samplers did indeed provide no useful quantitative information; nevertheless, the problems found during this check-out assisted in planning for later phases.

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TECHNICAL REPORT DATA

(Please read Instructions on reverse before completing)

1. REPORT NO. EPA-454/R-95-010	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Surface Coal Mine Emission Factor Study: Test Report		5. REPORT DATE January 1994 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) G.E. Muleski, G. Garmen, C. Cowherd		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Midwest Research Institute 425 Volker Boulevard Kansas City, MO 64110		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-D2-0159
12. SPONSORING AGENCY NAME AND ADDRESS Emission Factor and Inventory Group Emissions, Monitoring, and Analysis Division Office of Air Quality Planning and Standards U.S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final Report 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Technical Representative: Dennis Shipman

16. ABSTRACT

This report presents the results of an emissions sampling program to measure airborne particulate matter released from the activities conducted at open pit coal mines in the western United States. The principal objective of this study was to compare field measurements against available emission factors for surface coal mines and to revise the factors as necessary. The field measurements were conducted during the fall of 1992 at the Cordero surface coal mine in the Powder River Basin of Wyoming. A total of 36 PM-10 emission tests, distributed over various sources and five test sites, was performed. The report presents the sampling methodology used, the emission measurement results, the ambient monitoring results, the results of the reexamination of current emission factors, and recommended emission factor models for haul truck travel, light-duty vehicle travel and scraper travel on unpaved roads.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Surface Coal Mines Fugitive Dust		

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(Report)* Unclassified	21. NO. OF PAGES 165
	20. SECURITY CLASS *(Page)* Unclassified	22. PRICE

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