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Iron and Steel Plant Open Source Fugitive Emission Evaluation

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Iron and Steel Plant Open Source Fugitive Emission Evaluation

by

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PREFACE

This report was prepared for the Environmental Protection Agency's Industrial Environmental Research Laboratory under EPA Contract No. 68-02-2609, Work Assignment No. 3. Mr. Robert V. Hendriks, Metallurgical Processes Branch, was the requestor of this work.

The work was performed in the Environmental and Materials Sciences Division of Midwest Research Institute. Dr. Chatten Cowherd served as task manager and was the principal author of this report. Mr. Russel Bohn was responsible for source testing activities utilizing the exposure profiling technique. Mr. Thomas Cuscino coordinated the moisture sampling study and assisted in the wind erosion measurements. Mrs. Mary Ann Grelinger and Mrs. Christine Maxwell were responsible for emission data reduction. Mr. Reed Hodgin performed data analysis for the moisture parameter study.

Dr. Dennis Lane of Kansas University also contributed to the moisture parameter study. Dr. Dale Gillette of the National Center for Atomspheric Research directed the operation of the NCAR wind tunnel.

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SUMMARY AND CONCLUSIONS

This report presents the results of a field testing program aimed at increasing the reliability of emission factors for open dust sources within the integrated iron and steel industry. The predominant factor limiting the quality assurance ratings of the emission factor equations for open dust sources that were previously developed by MRI was the restricted number of test measurements in relation to the number of correction parameters appearing in each equation. Based on statistical analysis of source contributions and the reliability of previously developed emission factors, a source testing plan was developed.

Specifically, the following tests were performed at three integrated iron and steel plants:

* Eighteen tests of vehicular traffic on untreated, unpaved roads.

* Two tests of vehicular traffic on treated unpaved roads.

* Six tests of vehicular traffic on paved roads.

* Five tests of storage pile stacking.

The primary tool for quantification of dust emissions from the above sources was the MRI exposure profiler. Other equipment used in the testing included cascade impactors with cyclone precollectors for particle sizing, high-volume air samplers for determining upwind and downwind particulate concentrations, and recording wind instruments used to determine mean wind speed and direction for adjusting the MRI exposure profiler to isokinetic sampling conditions.

For all of the emission tests, samples of the emitting materials were collected for laboratory analysis to determine properties which affect the emission rates. Unpaved and paved roads were sampled by removing loose material (by means of vacuuming and/or broom sweeping) from lateral strips of road surface extending across the traveled portion. Storage piles were sampled to a depth exceeding the size of the largest aggregate pieces. Pertinent equipment parameters (vehicle weight and speed, stacker drop distance) were also recorded during each test.

In addition, 12 tests of wind erosion emissions were performed utilizing a portable wind tunnel with a specially designed isokinetic sampling system. Eight tests were performed on the upper flat surface of an inactive coal storage pile--three tests of one section of undisturbed (crusted) surface and five tests of a disturbed section. This was followed by two tests of the flat ground surface (undisturbed) adjacent to a dolomite storage pile and two tests of disturbed prairie soil in the same area. Both mass emission rates and particle size distributions were measured as a function of tunnel wind velocity.

This study also addressed a special problem related to the determination of storage pile surface moisture for aggregate materials. Surface moisture is known to affect the rate of wind erosion of exposed materials. Because of the high degree of variability of surface moisture in response to daily evaporation cycles, as well as to precipitation events and mechanical disturbances, it is desirable to develop empirical relationships for daily and seasonal average surface moisture values as a function of meteorological conditions and properties of stored aggregate materials.

Figure SC-1 presents the revised emissions factor equations developed in this study for traffic entrained dust from unpaved roads, traffic-entrained dust from paved roads and storage pile formation by means of a translating conveyor stacker. These factors describe emissions of particles smaller than 30 μm in Stokes diameter.

Based on an expanded data set of 24 tests, the revised MRI emission factor equation for traffic-entrained dust from unpaved roads predicts measured emission factors with precision factor* of 1.48 as compared to a precision factor of 1.66 for the unrevised equation. The addition of a correction term related to the average number of wheels per vehicle reduced the mean prediction error, as suggested by the clear tendency of the unrevised equation to underpredict measured emission factors when the test road was traveled by a substantial portion of 10- and 18-wheel vehicles rather than 4- and 6-wheel vehicles.

Approximately 35% of measured road dust emissions in the suspended particulate size range (particles smaller than 30 μm in diameter) consist of fine particles (particles smaller than 5 μm in diameter) which have the potential for transport over distances greater than a few kilometers from the source. This fine particle fraction appears to be independent of average vehicle weight and road surface composition.

* The precision factor (f) is defined such that the 95% confidence interval for a predicted emission factor value (P) extends from P/f to Pf.

OPEN DUST SOURCE:	Vehicular Traffic on Unpaved Roads	Vehicular Traffic on Paved Road	Storage Pile Formation by Means of Conveyor Stacker
QA RATING:	B for Dry Conditions C for Annual Average Conditions	B for Normal Urban Traffic C for Industrial Plant Traffic	B
EMISSION FACTOR – METRIC:	$EF = 1.7 \left(\frac{s}{12}\right)\left(\frac{S}{48}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{d}{365}\right)$ kg/veh-km	$EF = 0.13\ I \left(\frac{4}{n}\right)\left(\frac{s}{10}\right)\left(\frac{L}{280}\right)\left(\frac{W}{2.7}\right)^{0.7}$ kg/veh-km	$EF = 0.00090 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{2.2}\right)\left(\frac{H}{3}\right)}{\left(\frac{M}{2}\right)^2}$ kg/tonne
EMISSION FACTOR – NON-METRIC:	$EF = 5.9 \left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{d}{365}\right)$ lb/veh-mi	$EF = 0.090\ I \left(\frac{4}{n}\right)\left(\frac{s}{10}\right)\left(\frac{L}{1000}\right)\left(\frac{W}{3}\right)^{0.7}$ lb/veh-mi	$EF = 0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{H}{10}\right)}{\left(\frac{M}{2}\right)^2}$ lb/ton
SYMBOLS AND UNITS	(metric / non-metric) EF = suspended particulate emissions: kg/veh-km / lb/veh-mi s = silt content of road surface material: % / % S = average vehicle speed: km/hr / mph w = average number of wheels per vehicle: – / – W = average vehicle weight: tonnes / tons d = dry days per year: – / –	(metric / non-metric) EF = suspended particulate emissions: kg/veh-km / lb/veh-mi I = industrial road augmentation factor: – / – n = number of traffic lanes: – / – s = silt content of road surface material: % / % L = surface dust loading on traveled portion of road: kg/km / lb/mi W = average vehicle weight: tonnes / tons	(metric / non-metric) EF = suspended particulate emissions: kg/tonne of material transferred / lb/ton of material transferred s = silt content of aggregate: % / % M = moisture content of aggregate: % / % U = mean wind speed: m/sec / mph H = drop height: m / ft

Figure SC-1 - Revised MRI Emissions Factor Equations.

Limited testing of chemical dust suppressants for industrial unpaved roads indicates a high initial control efficiency (exceeding 90%) which decreases by more than 10% with the passage of 200 to 300 vehicles. Consistent with the emission factor equation, the lowering of emissions is reflected by the reduced silt content of the road surface material after the application of chemical dust suppressants. Additional testing is needed to better quantify the performance of road dust suppressants. Testing is also needed to verify and/or refine the emission factor adjustment term which accounts for climatic mitigation.

The expanded test data set for traffic-generated dust from paved roads indicates that the unrevised MRI emission factor equation consistently underpredicts emissions (by up to a factor of 7) for industrial paved roads. This is thought to be due to the additional dust generation from unpaved areas adjacent to the paved surface. Incorporation of emission factor correction terms which account for emissions from unpaved shoulders and for the number of traffic lanes, improves the precision factor from 14.1 to 3.31.

Modification of the MRI emission factor equation for continuous drop operations (translating conveyor stacker) by the addition of a linear correction term involving drop distance aids in improvidng the predictive capability of the equation. However, predictive errors remain significant, which indicates effects of complex physical phenomena not accounted for in the emission factor equation.

The results of the wind erosion testing indicate that natural surface crusts are very effective in mitigating suspended dust emissions. In addition, test data show that a given surface has a finite potential for erosion prior to additional mechanical disturbance. Erosion rates increase with wind velocity and decrease with erosion time.

Based on the results of the testing program to determine moisture levels in storage pile surface aggregate, it was found that daily moisture decreases from an early morning maximum to an afternoon minimum, the rate depending on the prevailing evaporation forces and the amount of fines in the stored aggregate. Daily average storage pile moisture was found to be strongly related to weighted precipitation over the previous 4 days. Active piles were less sensitive than dormant piles to precipitation because of the turnover of stored material.

It is recommended that an emission inventory handbook be developed for open dust sources that would provide guidance on determining emission factor correction parameters, source extent values, and control efficiencies, both natural and anthropogenic. This would aid in minimizing inventory errors associated with all factors which enter into emission rate calculations.

It is also recommended that road dust controls be studied. Although the emission factor equation for this major source has been reliable in dealing with a wide range of uncontrolled source conditions, little is known about the mitigative effects of natural controls and common industrial control practices such as watering. By studying watering effectiveness, optimization parameters for this control measure could be developed.

Significant information on the dynamics of wind erosion from storage piles and bare ground areas has been developed in this study. Observed phenomena associated with protective natural crusting and erosion potential have not been incorporated into emission factor expressions that are commonly used to estimate dust emissions from wind erosion. More investigation is needed to define these phenomena.

SECTION 1.0

INTRODUCTION

Iron- and steel-making processes, which are characteristically batch or semicontinuous operations, generate substantial quantities of fugitive (nonducted) emissions at numerous points in the process cycle. There are numerous materials handling steps in the storage and preparation of raw materials and in the disposal of process wastes. Additionally, fugitive emissions escape from reactor vessels during charging, process heating, and tapping.

Fugitive emissions in the iron and steel industry can be generally divided into two classes--process fugitive emissions and open dust source fugitive emissions. Process fugitive emissions include uncaptured particulates and gases that are generated by steel-making furnaces, sinter machines, and metal forming and finishing equipment, and that are discharged to the atmosphere through building ventilation systems. Open dust sources of fugitive emissions include such sources as raw material storage piles, from which emissions are generated by the forces of wind and machinery acting on exposed aggregate materials.

In a recent study of fugitive emissions from integrated iron and steel plants, Midwest Research Institute determined that open dust sources (specifically, vehicular traffic on unpaved and paved roads and storage pile activities) ranked with steel-making furnaces and sinter machines as sources which emit the largest quantities of fine and suspended particulate, taking into account typically applied control measures. [1] It became evident that open dust sources should occupy a prime position in control strategy development for fugitive particulate emissions within integrated iron and steel plants. Moreover, preliminary analysis of promising control options for both process sources of fugitive emissions and open dust sources indicated that control of open dust sources has a highly favorable cost-effectiveness ratio for particulate.

The technical soundness of these conclusions and the foundation for more detailed investigation rest on the availability of reliable particulate emission factors and particle size distributions for the sources under consideration. In turn, fugitive emissions are especially difficult to characterize for the following reasons:

1. Emission rates have a high degree of temporal variability.

2. Emissions are discharged from a wide variety of source configurations.

3. Emissions are comprised of a wide range of particle sizes, including coarse particles which deposit immediately adjacent to the source.

The scheme for quantification of emission factors must effectively deal with these complications.

Since 1972, MRI has been engaged in a series of field testing programs to develop emission factors for open dust sources associated with agriculture and industry. To provide for the requirement that the emission factors would be applicable on a national basis, at the outset MRI analyzed the physical principles of fugitive dust generation to ascertain the parameters which would cause emissions to vary from one location to another. These parameters were found to be grouped into three categories:

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

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

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

By constructing the emission factors as mathematical equations with multiplicative correction terms, the factors developed by MRI became applicable to a range of source conditions limited only by the extent of experimental verification.[2,3,4]

The use of the silt content as a measure of the dust generation potential of a material acted on by the forces of wind or machinery was an important step in extending the applicability of the emission factor equations to the wide variety of aggregate materials of industrial importance. The upper size limit of silt particles (75 μm in diameter) is the smallest particle size for which size analysis by dry sieving is practical, and this particle size is also a reasonable upper limit for particulates which can become airborne. Analyses of atmospheric samples of fugitive dust indicate a consistency in size distribution so that particles in specific size ranges exhibit fairly constant mass ratios.[2,3]

In order to quantify source-specific emission factors, MRI developed the "exposure profiling" technique, which uses the isokinetic profiling concept that is the basis for conventional source testing.[5/] Exposure profiling consists of the direct measurement of the passage of airborne pollutant immediately downwind of the source by means of simultaneous multipoint sampling over the effective cross section of the fugitive emissions plume. This technique uses a mass-balance calculation scheme similar to EPA Method 5 stack testing rather than requiring indirect calculation through the application of a generalized atmospheric dispersion model.

The emission factors developed by MRI have been made specific to particles smaller than 30 μm in Stokes diameter, so that emissions may be related to ambient concentrations of total suspended particulate. The upper size limit of 30 μm for suspended particulate is the approximate effective cutoff diameter for capture of fugitive dust by a standard high volume particulate sampler (based on a typical particle density of 2 to 2.5 g/cm).[2/] It should be noted, however, that analysis of parameters affecting the atmospheric transport of fugitive dust indicates that only the portion smaller than about 5 μm in diameter will be transported over distances greater than 5 to 10 km from the source.[6/]

In 1977, as noted above, MRI performed field testing of open dust sources at two integrated iron and steel plants (designated as Plants A and E) in order to extend the applicability of the previously developed emissions factor equations to open dust sources in the iron and steel industry.[1/] The sources tested were: (a) light-duty vehicular traffic on unpaved roads; (b) heavy-duty vehicular traffic on unpaved roads; (c) mixed vehicular traffic on paved roads; (d) mobile stacking of lump iron ore; (e) mobile stacking of pelletized iron ore; and (f) load-out of processed slag into a truck with a front-end loader. These sources involved materials handling equipment of a scale significantly larger than had been tested previously. Criteria used in choosing the above sources for testing included the relative importance of sources as determined from plant surveys, the amenability of sources to accurate testing, and the accessibility of sources for testing within the selected iron and steel plants.

This report presents the results of a follow-up investigation aimed at increasing the reliability of emission factors for open dust sources within integrated iron and steel plants. As indicated in Table 1-1, the predominant factor limiting the quality assurance ratings (Figure 1-1) of the emission factor equations previously developed by MRI for open dust sources is the restricted number of test measurements in relation to the number of correction parameters appearing in each equation.

TABLE 1-1. EMISSION FACTOR QUALITY ASSURANCE LIMITATIONS
(Effective March 1978)

Source category	Quality assurance rating	Test data limitations
Vehicular Traffic on Unpaved Roads - Dry Conditions	B	Insufficient number of tests
Vehicular Traffic on Unpaved Roads - Annual Conditions	C	Insufficient number of tests; limited to dry surfaces
Vehicular Traffic on Paved Roads - Normal Urban Traffic	B	Insufficient number of tests
Vehicular Traffic on Paved Roads - Industrial Plant Traffic	C	Insufficient number of tests; probable effect of dust resuspension from underbodies
Storage Pile Formation by Means of Translating Conveyor Stacker	B	Insufficient number of tests
Transfer of Aggregate from Loader to Truck	B	Insufficient number of tests
Vehicular Traffic Around Storage Piles	C	Insufficient number of tests; questionable measurement accuracy
Wind Erosion from Storage Piles	C	Insufficient number of tests; questionable measurement accuracy
Wind Erosion of Exposed Areas	C	Insufficient number of tests; limited to dry uncrusted surfaces

MRI

QUALITY ASSURANCE RATING SCHEME

A = FORMULATION BASED ON STATISTICALLY REPRESENTATIVE NUMBER OF ACCURATE FIELD MEASUREMENTS (EMISSIONS, METEOROLOGY AND PROCESS DATA) SPANNING EXPECTED PARAMETER RANGES

B = FORMULATION BASED ON LIMITED NUMBER OF ACCURATE FIELD MEASUREMENTS

C = FORMULATION OR SPECIFIC VALUE BASED ON LIMITED NUMBER OF MEASUREMENTS OF UNDETERMINED ACCURACY

— OR —

EXTRAPOLATION OF B-RATED DATA FROM SIMILAR PROCESSES

D = ESTIMATE MADE BY KNOWLEDGEABLE PERSONNEL

E = ASSUMED VALUE

Figure 1-1. Quality assurance (QA) rating scheme for emission factors.

In addition, this study addresses a special problem related to the determination of aggregate material surface moisture which affects the rate of wind erosion of exposed materials. Because of the high degree of variability of storage pile surface moisture in response to daily evaporation cycles, as well as to precipitation events and mechanical disturbances, it is desirable to develop empirical relationships for daily and seasonal average surface moisture values as a function of meteorological conditions and materials properties.

This report is organized by subject area as follows:

- Section 2 presents the statistical plan used to select source types and conditions for testing.
- Section 3 describes source testing procedures and results of exposure profiling of emissions from (a) vehicular traffic on unpaved roads; (b) vehicular traffic on paved roads, and (c) storage pile stacking.
- Section 4 describes procedures and results of wind erosion testing utilizing a portable wind tunnel rather than the exposure profiling apparatus.
- Section 5 addresses the refinement of previously developed emission factor equations through the incorporation of data presented in Sections 3 and 4, and assesses the reliability of refined emission factors.
- Section 6 describes the procedures and results of field data collection and analysis to develop empirical relationships for unbound moisture in storage pile surface materials.
- Section 7 outlines additional research needs.

Metric units with some non-metric equivalents are used in this report. The word ton always refers to short ton (abbreviated "T"), which is equivalent to 2,000 lb. The word tonne always refers to the metric tonne (abbreviated "t"), which is equivalent to 2,200 lb. An English-to-metric conversion table follows Section 9.

SECTION 2.0

SELECTION OF SOURCES AND TEST CONDITIONS

This section presents the statistical plan for selection of sources and test conditions. The objective of the statistical analysis was to find the optimal distribution of tests over generic source categories such that maximum precision in the estimated total emissions from open dust sources within integrated iron and steel plants would be achieved. Weighting factors are assigned to each source category by balancing (a) relative source contributions to total particulate emissions and (b) precisions of the previously developed emission factor equations, as described below.

2.1 Emission Contributions of Open Dust Sources

This section presents the methodology used to estimate nationwide emission contributions of open dust sources within integrated iron and steel plants. For this purpose, sources were grouped by similarity of physical mechanisms for dust generation. The following generic source categories were considered in this test plan:

- Vehicular Traffic on Unpaved Surfaces

  Unpaved roads
  Storage pile maintenance

- Vehicular Traffic on Paved Surfaces

- Batch Drop Operations

  Loaders
  Railcars
  Trucks
  Gantry/clamshell buckets

- Continuous Drop Operations

  Stackers
  Conveyor transfer stations
  Bucket wheel barge unloading

- Wind Erosion

  Storage piles
  Exposed areas

Table 2-1 lists the predictive emission factor equations previously developed for each source category.[1/]

The following subsections detail the procedure used to derive the emission estimate for each generic source category.

2.1.1 Vehicular Traffic

Emission factors for light, medium, and heavy duty traffic on unpaved roads were calculated using the emission factor equations in Table 2-1. The values of the correction parameters were based on averages from four open dust source surveys previously performed by MRI.[1/] The emission factors were then multiplied by the average source extent (vehicle miles traveled) which were calculated from the open dust surveys. Finally, it was assumed that there were 50 major plants in the nation producing the emission rate calculated for the average plant.

The emission factor for paved roads was calculated as the average of two tests performed by MRI at an iron and steel plant.[1/] The emission factor was then multiplied by the average source extent (vehicle miles traveled) calculated from the open dust surveys. Finally, the emission rate for paved road traffic at the average plant was multiplied by 50, in order to extrapolate to nationwide emissions.

The emission factor used for storage pile maintenance was developed from the emission factors calculated for four plants previously surveyed. Separate weighted emission factors were determined for pellets and coal. The weighted emission factors were multiplied by the 1976 nationwide tonnage of these materials received at iron and steel plants. Finally, the summed emission rate for pellets and coal was linearly scaled by the ratio of all aggregate materials received to the sum of coal and pellets received. In this manner, the total nationwide emission rate for pile maintenance and other traffic associated with storage of all aggregate material was calculated.

2.1.2 Batch and Continuous Drop Operations

The following assumptions were used in calculating emissions for the batch and continuous drop categories:

1. Fifty percent of the aggregate material received in the average plant arrives by barge and 50% by rail.

TABLE 2-1. FUGITIVE DUST EMISSION FACTORS EXPERIMENTALLY DETERMINED BY MRI--NONMETRIC UNITS[a/]

Source category	Measure of extent	Emission factor[b/] (lb/unit of source extent)	Correction parameters
1. Vehicular Traffic on Unpaved Roads	Vehicle-Miles Traveled	$5.9 \left(\frac{s}{12}\right) \left(\frac{S}{30}\right) \left(\frac{W}{3}\right)^{0.8} \left(\frac{d}{365}\right)$	s = Material Silt Content (%)
2. Vehicular Traffic on Paved Roads	Vehicle-Miles Traveled	$0.45 \left(\frac{s}{10}\right) \left(\frac{L}{5,000}\right) \left(\frac{W}{3}\right)^{0.8}$	S = Average Vehicle Speed (mph); W = Average Vehicle Weight (tons)
3. Batch Load-In (e.g., front-end loader, railcar dump)	Tons of Material Loaded in	$0.0018 \frac{\left(\frac{s}{5}\right) \left(\frac{U}{5}\right)}{\left(\frac{M}{2}\right)^2 \left(\frac{Y}{6}\right)}$	L = Surface Dust Loading on Traveled Portion of Road (lb/mile)
4. Continuous Load-In (e.g., stacker, transfer station)	Tons of Material Loaded in	$0.0018 \frac{\left(\frac{s}{5}\right) \left(\frac{U}{5}\right)}{\left(\frac{M}{2}\right)^2}$	U = Average Wind Speed (mph); M = Material Unbound Moisture Content (%); Y = Dumping Device Capacity (yd^3)
5. Active Storage Pile Maintenance ant Traffic	Tons of Material Put Through Storage	$0.10\ K \left(\frac{s}{1.5}\right) \left(\frac{d}{235}\right)$	K = Activity Correction (= 1.0 for tested sand and gravel operations)[c/]
6. Active Storage Pile Wind Erosion	Tons of Material Put Through Storage	$0.05 \left(\frac{s}{1.5}\right) \left(\frac{d}{235}\right) \left(\frac{f}{15}\right) \left(\frac{D}{90}\right)$	d = Number of Dry Days Per Year; f = Percentage of Time Wind Speed Exceeds 12 mph at height of 1.0 ft
7. Batch Load-Out	Tons of Material Loaded out	$0.0018 \frac{\left(\frac{s}{5}\right) \left(\frac{U}{5}\right)}{\left(\frac{M}{2}\right)^2 \left(\frac{Y}{6}\right)}$	D = Duration of Material Storage (days)
8. Wind Erosion of Exposed Areas	Acre-Years of Exposed Land	$3,400 \frac{\left(\frac{e}{50}\right) \left(\frac{s}{15}\right) \left(\frac{f}{25}\right)}{\left(\frac{P-E}{50}\right)^2}$	e = Surface Erodibility (tons/acre/year); P-E = Thornthwaites Precipitation-Evaporation Index

a/ MRI emission factor equations were formerly presented only in nonmetric units.

b/ Annual average emissions of dust particles smaller than 30 μm in diameter based on particle density of 2.5 g/cm^3.

2. The 50% arriving by rail is batch unloaded.

3. Of the 50% arriving by barge, half is batch unloaded (gantry/clamshell) and half is continuously unloaded (bucket wheel).

4. All aggregate passes through two transfer stations in its lifetime at the average iron and steel plant.

5. Railcars have 100 tons capacity and haul aggregate with an average density of 2.5 g/cm^3.

6. The average clamshell is 20 yd^3 in volume.

7. The average truck has 50 tons capacity and hauls aggregate with an average density of 2.5 g/cm^3.

8. The averages of the silts and moistures measured during the previous open dust surveys of four plants are representative nationwide values.

9. The loading into storage piles of all aggregate is apportioned as follows: 10% dropped by truck, 10% dropped by loader, and 80% dropped by stacker.

The two aggregates selected as representative of all aggregate materials were coal and iron-bearing pellets. These particular materials were selected for two reasons: (a) they represent over 50% of the total aggregate stored at iron and steel plants; and (b) more data are available on the silt and moisture of these materials than other aggregate materials stored at iron and steel plants.

The silt and moisture measurements obtained during the open dust surveys of the four plants surveyed were averaged in an attempt to obtain representative nationwide values. For coal, the average silt and moisture percentages were 4.4 and 2.8, respectively; and for pellets, the average silt and moisture percentages were 8.6 and 1.1, respectively.

Based on the above assumptions and the average silt and moisture values, 1976 nationwide emission rates for coal and pellet batch and continuous drop sources were calculated. The sum of these emission rates was then scaled linearly by the ratio of total aggregate receipts to the sum of coal and pellet receipts. In this fashion, the emission rates for total aggregate batch drop and continuous drop were calculated.

2.1.3 Wind Erosion

The emission factors for wind erosion from pellet and coal piles were weighted averages of emission factors calculated for four previously surveyed plants. The weighting of each plant emission factor reflected the mass of the material located at each plant.

The emission rates for coal and pellets were calculated by multiplying the emission factors by the 1976 nationwide receipts at iron and steel plants. The total emission rate for wind erosion from all aggregate piles was calculated by linearly scaling the sum of the emission rates for coal and pellets by the ratio of the total aggregate receipts to the sum of the coal and pellet receipts.

The emission factor for wind erosion of bare areas was calculated as a weighted average of the emission factors for the four previously surveyed plants. The plant emission factors were weighted by source extent (acres exposed).

The emission rate for the average plant was calculated by multiplying the weighted average emission factor by the arithmetic average source extent observed at the four previously surveyed plants. Finally, the nationwide emission rate was obtained by multiplying the emission rate for the average plant by 50, which is the number of major plants estimated to exist in the country.

Table 2-2 gives the uncontrolled and the controlled 1976 suspended particulate emission rates for the open dust source categories. The typical control efficiencies are estimates of current practice, as presented in the previous MRI report.[1] The right-hand column shows the percent contribution of each generic category to the nationwide dust emissions from open dust sources within integrated iron and steel plants.

2.2 Distribution of Source Tests

This section describes the statistical methodology used to determine the optimal distribution of 42 source tests over the five generic source categories of open dust sources such that maximum precision is achieved in estimating the total emissions from open dust sources. It was estimated that 42 tests (including laboratory tests of wind erosion) could be performed within the funding limit of this program.

The total controlled emission rate or inventory (I) is the sum of contributions from five sources, namely:

TABLE 2-2. GENERIC SOURCE CONTRIBUTIONS TO SUSPENDED PARTICULATE EMISSIONS

Source	Estimated typical control efficiency (%)	1976 Nationwide suspended particulate emission rate: Uncontrolled (tons/yr)	Uncontrolled (tonnes/yr)	Controlled (tons/yr)	Controlled (tonnes/yr)	Percent of total controlled emissions
• Vehicular traffic on unpaved surfaces						65
Unpaved roads	50	48,800	44,300	24,400	22,100	
Storage pile maintenance	40	12,600	11,400	7,600	6,890	
• Vehicular traffic on paved surfaces	50	15,000	13,600	7,500	6,800	15
• Batch drop operations						1
Loaders	0	100	91	100	91	
Railcars	0	110	100	110	100	
Trucks	0	43	39	43	39	
Gantry/clamshell	0	120	109	120	109	
• Continuous drop operations						5
Stackers	40	1,270	1,150	760	690	
Conveyor transfer stations	50	3,170	2,880	1,580	1,430	
Bucket wheels	0	400	363	400	363	
• Wind erosion						14
Storage piles	40	8,500	7,710	5,100	4,630	
Exposed areas	40	3,000	2,720	1,800	1,630	
				49,513		

X1 = Vehicular traffic on unpaved surfaces; this source has an approximate weight W1 = 0.65;

X2 = Vehicular traffic on paved surfaces, W2 = 0.15;

X3 = Batch drop operations, W3 = 0.01;

X4 = Continuous drop operations, W4 = 0.05;

X5 = Wind erosion, W5 = 0.14.

Also, each X is the product of three components: e = emission factor, S = source extent, C = (complement of) control efficiency. All three of these components have an uncertainty about them, but this "sampling error" can be approximated from prior work,* as given in Table 2-3.

However, only the emission factors are sampled in the testing program; the errors in S and C are irreducible. This means that the precision of I has a lower bound that cannot be reduced by increasing the sample size of emission factor determinations.

Given a total sample size n, it must be determined how many tests to execute on each source category, i.e., how to efficiently allocate the sample. The objective, of course, is to maximize the precision in total emission factor. This is a standard problem in sampling theory, and the resulting rule is:

$$n_i = \frac{W_i \sqrt{\text{var}\,(X_i)}}{\sum_{i=1}^{5} W_i \sqrt{\text{var}\,(X_i)}} \qquad \text{(the Neyman allocation)}$$

* It is assumed in these calculations that e and S are distributed log-normally and C is distributed binomially. In other words, an e or S precision is known as "a factor of _____" while a C precision is known as "± _____%."

TABLE 2-3. ESTIMATED PRECISIONS OF AVAILABLE EMISSION RATE INPUT PARAMETERS

Source category	Emission factor precision*	Source extent precision*	Range of typical control efficiency	
			Conservative	Optimistic
X1. Vehicular traffic on unpaved surfaces	Factor of 1.5	Factor of 1.5	50 ± 25%	50 ± 12.5%
X2. Vehicular traffic on paved surfaces	Factor of 3	Factor of 1.5	50 ± 25%	50 ± 12.5%
X3. Batch drop operations	Factor of 2	Factor of 1.5	0 (constant)	0 (constant)
X4. Continuous drop operations	Factor of 3	Factor of 1.5	50 ± 25%	50 ± 12.5%
X5. Wind erosion	Factor of 5	Factor of 1.5	40 ± 20%	40 ± 10%

* 95% confidence level.

$$\text{Controlled emission rate} = \text{Source extent} \times \text{Emission factor} \times \left(1 - \begin{array}{c}\text{Fractional}\\ \text{control}\\ \text{efficiency}\end{array}\right)$$

The Neyman allocation for the proposed experiment yields:

Source	Ideal % of Total Sample Size	Proposed Sample Size
X1	36.8%	15
X2	23.0%	9
X3	1.0%	0
X4	7.7%	6
X5	31.5%	12
		42

In the project we are constrained to run tests in sets of three, and also to run a minimum of six tests per source.

The entire set of 42 tests thus allocated should estimate the plantwide emission factor to within $\pm$ 11% (with 95% confidence), i.e., an average emission factor will be determined to within a factor of about 1.1.

Unfortunately, the uncertainty in I will still reflect the uncertainties in S and C, even though the emission factor precision has been markedly improved. The precision (standard deviation) of a triple product $X_i = e_i S_i C_i$ follows a rms rule* which means, loosely speaking, that the precision of X is determined by its "weakest link."

Table 2-4 illustrates these considerations explicitly. In 4a, the expected precision for each source and the total emission rate are shown based on 42 emission factor tests. In 4b, comparable results are shown under the assumption of perfect emission factor values, i.e., the irreducible uncertainty in I due to uncertainties in S and C. For illustrative purposes, 4c displays hypothetical precisions attainable if S and C were known constants.

It is clear from Table 2-4 (by comparison of 4a and 4b) that increasing the number of emission factor tests to infinity will allow only a slight improvement in the source-specific and overall emission rate precisions. This indicates the necessity for improving techniques used to determine source extent and for quantifying actual control efficiencies of commonly used emission control techniques. Current uncertainty in control efficiency estimates is the limiting factor in developing precise emission rate values. The precision values presented in 4c are those achievable after the current testing program, based on perfectly known source extents and control efficiencies.

* rel var (X1·X2·X3) $\cong \sum_{i=1}^{3}$ rel var (X_i) iff X_i independent.

TABLE 2-4. EXPECTED PRECISIONS IN EMISSION RATES[a]

4a. Given n=42 tests for emission factors

Source	Precision a	Precision b
X1	± 67.7%	± 52.1%
X2	± 97.5%	± 87.3%
X3	-	-
X4	± 110.3%[b]	± 101.5%[b]
X5	± 113.1%[b]	± 104.5%[b]
Total	± 80.7%	± 67.2%

4b. Given perfectly known emission factors (n=∞)

Source	Precision a	Precision b
X1	± 64.4%	± 47.6%
X2	± 64.4%	± 47.6%
X3	± 40.5%	± 40.5%
X4	± 64.4%	± 47.6%
X5	± 64.4%	± 47.6%
Total	± 64.2%	± 47.5%

4c. Given perfectly known source extents and control efficiencies (n=42)

Source	Precision[c]	
X1	± 10.5%	Factor of 1.11
X2	± 36.6%	1.44
X3	-	-
X4	± 44.8%	1.57
X5	± 46.5%	1.59
Total	± 11.0%	

a/ 95% confidence interval as a % of the estimated value (± 2 cv). Precision "a" is with a conservative estimate of C uncertainty, while Precision "b" uses a more optimistic guess.

b/ Of course the minimum possible value physically is zero.

c/ The errors in particular emission factors are asymmetric, e.g., "a factor of 2" rather than ± 100%, etc. However, the total (or average) of error is asymptotically symmetric, because it arises as a sum of five sources.

2.3 Source Test Conditions

This section describes the rationale for selection of conditions under which open dust sources were to be tested. Table 2-5 lists the physical parameters which enter into the mechanisms for generation of airborne dust from each generic source category. These parameters may be used to adjust emissions estimates to properties of the materials being disturbed, the equipment involved, and the meteorological conditions. Quantified parameters are those which appear in the previously developed emission factor equations, as given in Table 2-1.

Table 2-6 lists the proposed conditions under which sources were to be tested according to the distribution of tests given on page 10. Test conditions were selected based on the following:

1. Known or suspected importance of each parameter.

2. Parameter controllability.

3. Normal range of variation in each parameter across the steel industry.

4. Typical values of parameters which are not highly variable across the industry.

In short, parameter selection was made to maximize the applicability of the emission factor equations to source conditions which are representative of the industry.

Although a total of 44 tests were performed pursuant to the plan outlined in this section, adjustments in the mix of test conditions were necessary as dictated by the availability of sources amenable to testing within the industry. In addition, it was not always possible to test under ideal wind and moisture conditions. A detailed explanation of actual test conditions is presented in Sections 3 and 4.

TABLE 2-5. EMISSION FACTOR CORRECTION PARAMETERS FOR OPEN DUST SOURCES

Source category	Correction parameters: Quantified	Correction parameters: Unquantified
Vehicular traffic on unpaved surfaces	Surface silt content Vehicle speed a/ Vehicle weight a/	Surface loading Surface moisture content Particle density b/
Vehicular traffic on paved surfaces	Surface silt content c/ Surface loading c/	Vehicle weight a/ Vehicle speed a/ Surface moisture content Particle density b/
Batch drop operations	Silt content b/ Moisture content Wind speed Loader capacity a/	Particle density b/
Continuous drop operations	Silt content b/ Moisture content Wind speed	Drop distance a/ Belt width a/ Particle density b/
Wind erosion of storage piles and exposed areas	Surface erodibility b/ Surface silt content b/ Wind speed Surface moisture content	Particle density b/

a/ Controllable through equipment selection.
b/ Controllable through material selection.
c/ May be tied to vehicle weight and/or speed.

TABLE 2-6. SOURCE TEST CONDITIONS

I. Vehicular Traffic on Unpaved Roads (Exposure Profiling)

A. Sampling locations (three roads)

(1) Slag haulage road with heavy-duty traffic
(2) Representative unpaved road with mixed traffic (dirt-surfaced)
(3) Representative unpaved road with mixed traffic (slag-surfaced)

B. Distribution of tests (15 total)

(1) Three tests - 15 passes of heavy-duty trucks on slag haulage road
(2a) Three tests - 15 passes of vehicle mix on representative road
(2b) Three tests - 15 passes of heavy-duty vehicles on representative road
(2c) Three tests - 15 passes of medium-duty vehicles on representative road
(3) Three tests - 15 passes of vehicle mix on second representative road

C. Special conditions

(1) Use normal plant traffic and vehicle mix
(2) Test only dry, untreated road surfaces
(3) Restrict testing to periods of moderate winds (2 to 7 m/sec) of constant mean direction
(4) Locate sampling equipment about 5 m from edge of road

II. Vehicular Traffic on Paved Roads (Exposure Profiling)

A. Sampling locations (three roads)

(1) Representative paved road with light surface dust loading (< 300 kg/km)
(2) Representative paved road with medium surface dust loading (300 to 1,500 kg/km)
(3) Representative paved road with heavy surface dust loading (> 1,500 kg/km)

TABLE 2-6. (Continued)

B. Distribution of tests (nine total)

Nine tests - 100 passes of vehicle mix on each test road (three tests per road)

C. Special conditions

(1) Use normal plant traffic and vehicle mix
(2) Test only dry road surfaces that have not been cleaned for at least one week
(3) Restrict testing to periods of moderate winds (2 to 7 m/sec) of constant mean direction
(4) Locate sampling equipment about 5 m from edge of road

III. Continuous Drop Operation - Storage Pile Stacking

A. Sampling locations (ore bedding area)

(1) Translating stacker for iron ore pellets
(2) Translating stacker for lump iron ore
(3) Alternative: translating stacker for coal

B. Distribution of test (six total)

(1) Three tests - 15 passes of pellet stacker
(2) Three tests - 15 passes of lump ore stacker

C. Special conditions

(1) Tests to begin when new pile is being formed
(2) Test only dry materials
(3) Restrict testing to periods of moderate winds (2 to 7 m/sec) of constant mean direction
(4) Locate sampling equipment along edge of pile area

IV. Wind Erosion

A. Sampling locations

Field site (ore bedding area and coal storage area) to which NCAR* portable wind tunnel may be transported

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* National Center for Atmospheric Research (Dr. Dale Gillette).

TABLE 2-6. (Continued)

B. Distribution of tests (12 total)

(1) Six tests - iron ore erosion at three wind speeds (two tests per speed)

(2) Six tests - coal erosion at three wind speeds (two tests per speed)

C. Special conditions

(1) Horizontal surface of test materials required to facilitate wind tunnel testing

(2) Testing under dry surface conditions ($<$ 1% moisture in aggregate)

SECTION 3.0

SOURCE TESTING BY EXPOSURE PROFILING

This section describes the program of field testing using the exposure profiling method to develop additional emission factor data for open dust sources. Specifically, the following field tests were performed at three integrated iron and steel plants:

- Eighteen tests of vehicular traffic on untreated, unpaved roads.
- Two tests of vehicular traffic on treated unpaved roads.
- Six tests of vehicular traffic on paved roads.
- Five tests of storage pile stacking.

Table 3-1 specifies the kinds and frequencies of field measurements that were conducted during each run. "Composite" samples denote a set of single samples taken from several locations in the area; "integrated" samples are those taken at one location for the duration of the run.

3.1 Sampling Equipment

The primary tool for quantification of emission rate was the MRI exposure profiler, which was developed under EPA Contract No. 68-02-0619.[2/] The profiler (Figure 3-1) consists of a portable tower (4 to 6 m height) supporting an array of sampling heads. Each sampling head is operated as an isokinetic exposure sampler directing passage of the flow stream through a settling chamber (trapping particles larger than about 50 μm in diameter) and then upward through a standard 8 in. by 10 in. glass fiber filter positioned horizontally. Sampling intakes were pointed into the wind, and sampling velocity of each intake was adjusted to match the local mean wind speed, as determined prior to each test. Throughout each test, wind speed was monitored by recording anemometers at two heights, and the vertical wind speed profile was determined by assuming a logarithmic distribution.

TABLE 3-1. FIELD MEASUREMENTS

Test Parameter	Units	Sampling Mode	Measurement Method
1. Meteorology			
a. Wind speed	m/sec	Continuous	Recording instrument at "background" station; sensors at reference height
b. Wind direction	deg	Continuous	
c. Cloud cover	%	Single	Visual observation
d. Temperature	°C	Single	Sling psychrometer
e. Relative humidity	%	Single	Sling psychrometer
2. Storage Piles			
a. Material type	--	Composite	Determined by plant personnel
b. Moisture content	% moisture	Single	Oven drying
c. Dust texture	% silt	Composite	Dry sieving
d. Material throughput	tonnes	--	Determined by plant personnel
3. Road Surfaces			
a. Pavement type	--	Composite	Observation (photographs)
b. Surface condition	--	Composite	Observation
c. Dust loading	g/m^2	Multiple	Dry vacuuming
d. Dust texture	% silt	Multiple	Dry sieving
4. Vehicular Traffic			
a. Mix	--	Multiple	Observation (car, truck, number of axles, etc.)
b. Count	--	Cumulative	Automatic counters
5. Suspended Dust			
a. Exposure (versus height)	mg/cm^2	Integrated	Isokinetic high-volume filtration (MRI method)
b. Mass size distribution	µm	Integrated	High-volume cascade impaction
c. Downwind concentration	$\mu g/m^3$	Integrated	High-volume filtration (EPA method)
d. Background concentration	$\mu g/m^3$	Integrated	High-volume filtration (EPA method)
e. Duration of sampling	min	Cumulative	Timing

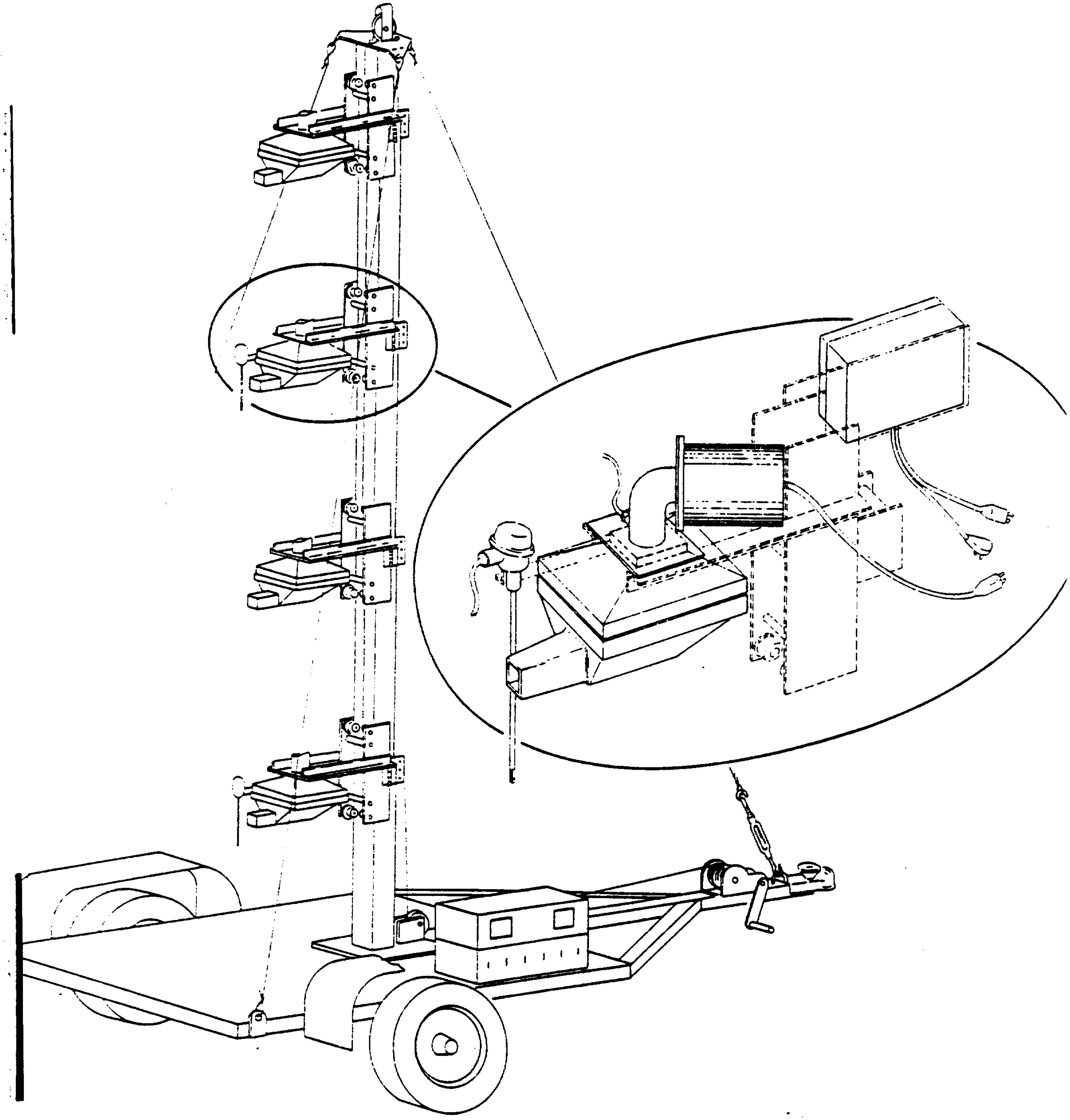


Figure 3-1. MRI exposure profiler.

Sampling time was sufficient to provide sufficient particulate mass and to average over several units of cyclic fluctuation in the emission rate, e.g., vehicle passes on an unpaved road. The first condition was easily met because of the proximity of the sampling grid to the source.

In addition to airborne dust passage (exposure), fugitive dust parameters that were measured included suspended dust concentration and particle size distribution. Conventional high-volume filtration units were operated upwind and downwind of the test source.

A Sierra Instruments high-volume parallel-slot cascade impactor with a 34 m^3/hr (20 cfm) flow controller was used to measure particle size distribution along side of the exposure profiler. The impactor unit was equipped with a Sierra cyclone preseparator to remove coarse particles which otherwise would tend to bounce off the glass fiber impaction substrates, causing fine particle measurement bias. The cyclone sampling intake was directed into the wind, resulting in isokinetic sampling for a wind speed of 5 mph.

In order to determine the properties of aggregate materials being disturbed by the action of machinery or wind, representative samples of the materials were obtained for analysis in the laboratory. Unpaved and paved roads were sampled by vacuuming and broom sweeping to remove loose material from lateral strips of road surface extending across the traveled portion. Storage piles were sampled to a depth exceeding the size of the largest aggregate pieces.

3.2 Sample Handling and Analysis

To prevent dust losses, the collected samples of dust emissions were carefully transferred at the end of each run to protective containers within the MRI instrument van. High-volume filters from the MRI exposure profiler and from standard high-volume units, and impaction substrates were folded and placed in individual envelopes. Dust that collected on the interior surfaces of each exposure probe was rinsed with distilled water into separate glass jars. Dust was transferred from the cyclone precollector in a similar manner.

Dust samples from the field tests were returned to MRI and analyzed gravimetrically in the laboratory. Glass fiber filters and impaction substrates were conditioned at constant temperature and relative humidity for 24 hr prior to weighing, the same conditioning procedure used before taring. Water washes from the exposure profiler intakes and the cyclone precollectors were filtered after which the tared filters were dried, conditioned at constant humidity, and reweighed.

Samples of road dust and storage pile materials were dried to determine moisture content and screened to determine the weight fraction passing a 200-mesh screen, which gives the silt content. A conventional shaker was used for this purpose. That portion of the material passing through the 200-mesh screen was analyzed to determine the density of potentially suspendable particles.

Table 3-2 gives the site parameters for the field tests conducted. The following section describes the locations of the sampling instruments at each test site and presents the results of the testing.

3.3 Results for Vehicular Traffic on Unpaved Roads

As indicated in Table 3-2, 21 tests of dust emissions from vehicular traffic on unpaved roads were performed--18 tests of untreated roads and 3 tests of a 100-m road segment treated with Coherex® applied at 10% strength in water. Arrangements for the application of Coherex® were made by plant personnel as part of an internal study of dust suppressants. The results of Test Series G-1 to G-9 will not be reported because unanticipated static charge problems created unreliable tare weights for the high-purity glass fiber filters used for those tests. Figures 3-2 through 3-4 show the locations of sampling instruments relative to the test road segments.

In addition to the silt content of the road surface material, the emission factor equation (Figure 2-1) requires data on vehicle speed and weight, averaged over the vehicle passes (approximately 50) accumulated during a test. During each test, the speeds of vehicles passing the sampling station were estimated by timing vehicles over a known travel distance. Estimates of vehicle weights were obtained from plant personnel. In some tests, the vehicle passes sampled were dominated by controlled test vehicles traveling at preselected speeds.

Table 3-3 lists, for each run, the individual point values of exposure exposure (net mass per sampling intake area) within the fugitive dust plume as measured by the exposure profiling equipment. Also given are the point values of filter exposure consisting only of particulate collected by the filter following the settling chamber. Finally, the integrated exposure value is given for each run.

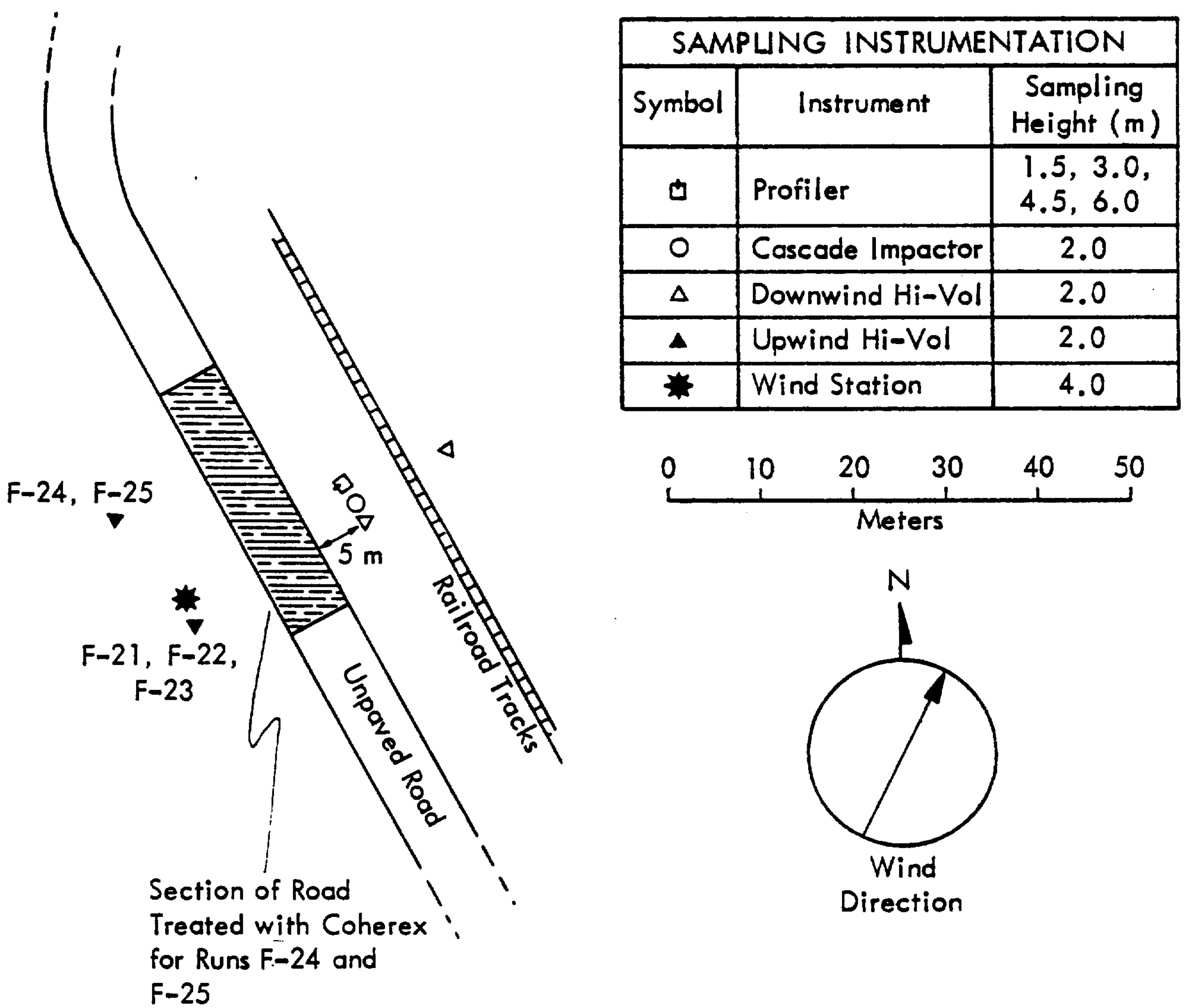
Table 3-4 compares particulate concentrations measured by the upwind hi-vol and by three types of downwind samplers (exposure profiling head, standard hi-vol, and high-volume cascade impactor) located 5 m from the test road and near the vertical center of the plume at a height of 2 m above ground. For the interpolated profiler concentrations, both nonisokinetic and isokinetic values are given. Also indicated are hi-vol concentrations measured at distances further downwind.

TABLE 3-2. EXPOSURE PROFILING TEST SITE PARAMETERS

Source	Run	Date	Start time	Exposure sampling duration (min)	No. of vehicle passes or weight transferred	Meteorology: Ambient air temperature (°C)	(°F)	Mean wind speed[a/] (m/sec)	(mph)
Unpaved Roads (crushed slag)	G-1	6/20/78	1126	44	50	28	82	-	-
	G-2	6/20/78	1252	42	40	30	86	2	4
	G-3	6/20/78	1417	43	30	30	86	1	3
	G-4	6/21/78	1107	25	42	22	71	-	-
	G-5	6/21/78	1515	36	41	25	77	2	5
	G-6	6/21/78	1604	17	177	25	77	2	5
	G-7	6/22/78	1348	14	26	25	77	4	9
	G-8	6/22/78	1440	14	32	26	79	4.5	10
	G-9	6/22/78	1507	14	28	26	78	3	7
Unpaved Roads (dirt/crushed slag)	F-21	8/ 1/78	1028	32	40	26	79	2	4
	F-22	8/ 1/78	1117	12	50	31	87	1	3
	F-23	8/ 1/78	1142	33	68	31	87	2	4
Unpaved Roads (Coherex treated dirt/ crushed slag)	F-24	8/ 2/78	1045	30	123	28	83	2	4
	F-25	8/ 2/78	1305	23	100	32	89	2	4
	F-26	8/ 2/78	Rained Out						
Unpaved Roads (crushed slag)	G-27	8/ 7/78	1257	60	74	27	80	2	5
	G-28	8/ 7/78	1409	25	52	24	75	2	5
	G-29	8/ 7/78	1444	27	78	24	76	2	5
	G-30	8/ 8/78	1016	40	46	26	78	6.3	14
	G-31	8/ 8/78	1112	38	57	29	84	4.5	10
	G-32	8/ 8/78	1316	40	68	32	89	5.4	12
Paved Roads (light surface dust loading)	F-13	7/18/78	1159	83	88	29	85	2	4
	F-14	7/18/78	1350	60	123	33	92	2	4
	F-15	7/18/78	1509	51	47	31	88	1	2
Paved Roads (moderate surface dust loading)	F-16	7/19/78	1344	36	66	32	90	1	3
	F-17	7/19/78	1438	34	61	32	90	1	3
	F-18	7/19/78	1531	82	96	34	93	1	3
Iron Pellet Stacking	H-10	6/29/78	1011	17	672 t (741 T)	28	82	0.5-1	1-2
	H-11	6/29/78	1125	14	183 t (202 T)	30	86	2	4
	H-12	6/29/78	1226	8	374 t (412 T)	30	86	3	6
Coal Stacking	F-19	7/20/78	1250	57	121 t (133 T)	34	93	1	3
	F-20[b/]	7/20/78	1407	15	0 t (0 T)	36	96	1	3

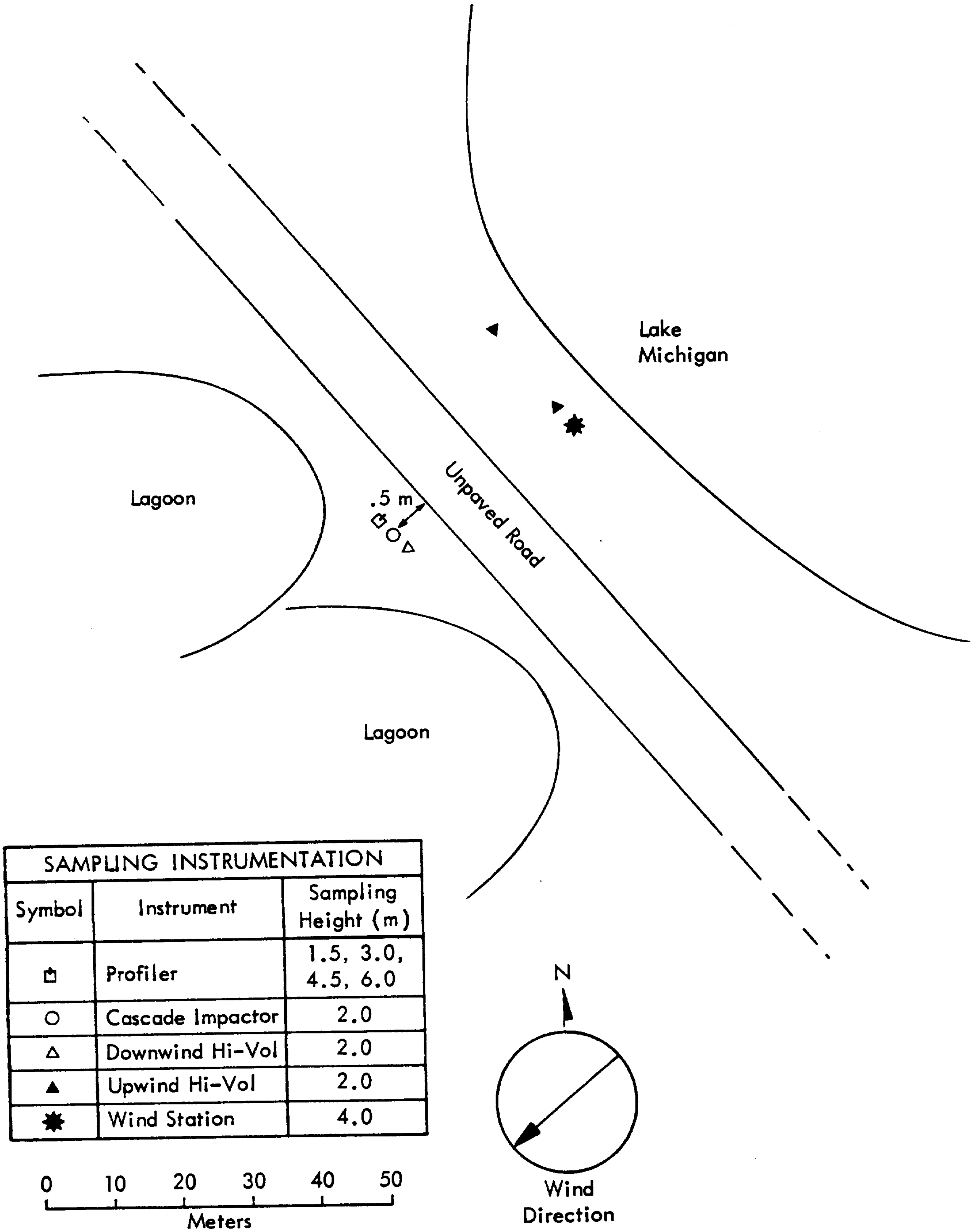
a/ Measured at 1.5 and 4.5 m above ground.

b/ Background test; no coal stacked.



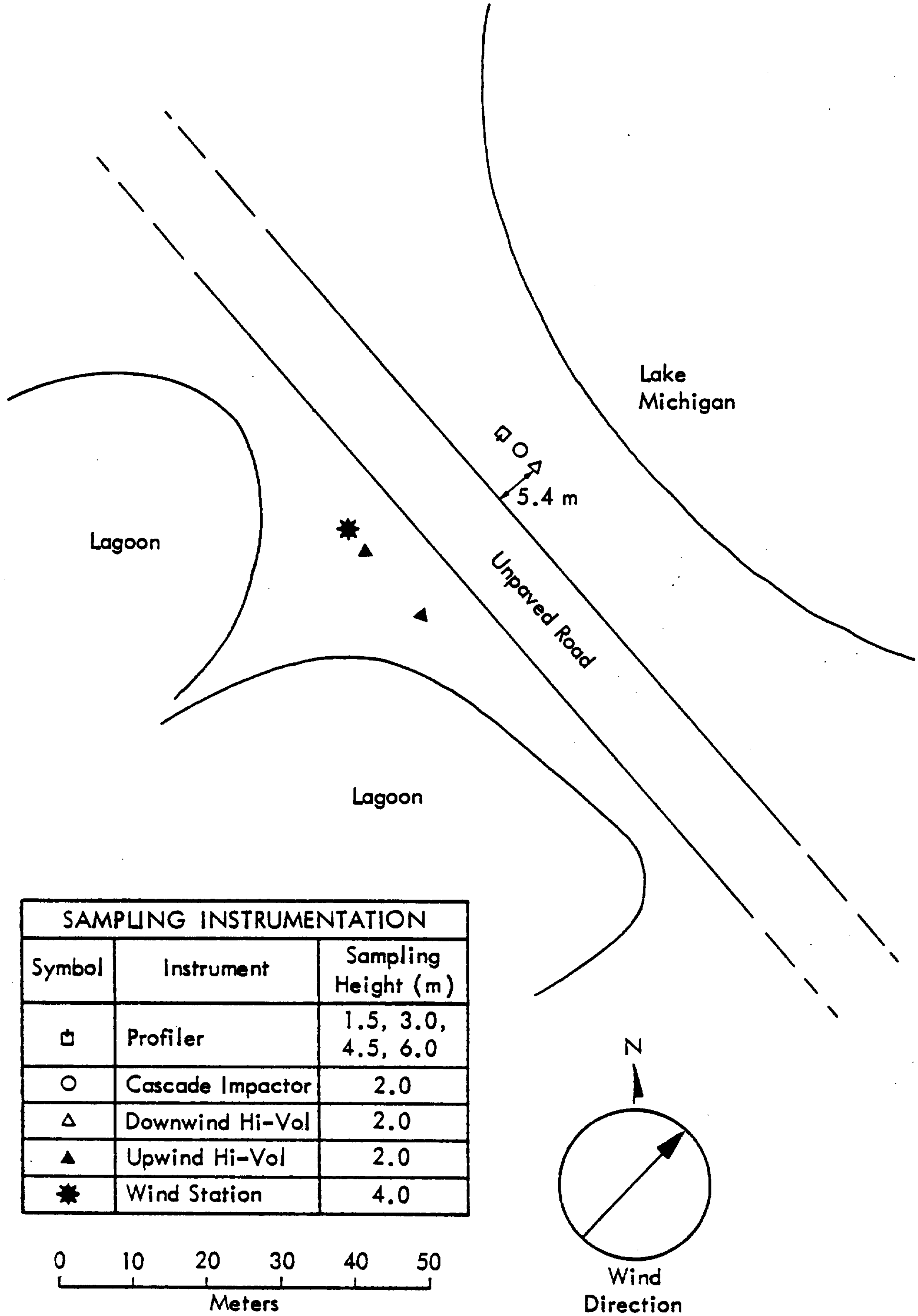
SAMPLING INSTRUMENTATION		
Symbol	Instrument	Sampling Height (m)
⌂	Profiler	1.5, 3.0, 4.5, 6.0
○	Cascade Impactor	2.0
△	Downwind Hi-Vol	2.0
▲	Upwind Hi-Vol	2.0
✸	Wind Station	4.0

Figure 3-2. Sampling equipment layout for Runs F-21 through F-26.



SAMPLING INSTRUMENTATION		
Symbol	Instrument	Sampling Height (m)
⛋	Profiler	1.5, 3.0, 4.5, 6.0
○	Cascade Impactor	2.0
△	Downwind Hi-Vol	2.0
▲	Upwind Hi-Vol	2.0
✸	Wind Station	4.0

Figure 3-3. Sampling equipment layout for Runs G-27 through G-29.



SAMPLING INSTRUMENTATION		
Symbol	Instrument	Sampling Height (m)
□	Profiler	1.5, 3.0, 4.5, 6.0
○	Cascade Impactor	2.0
△	Downwind Hi-Vol	2.0
▲	Upwind Hi-Vol	2.0
✸	Wind Station	4.0

Figure 3-4. Sampling equipment layout for Runs G-30 through G-32.

TABLE 3-3. PLUME SAMPLING DATA--UNPAVED ROADS

Run	Sampling height (m)	Sampling rate (m^3/hr)	Sampling rate (cfm)	Total exposure (mg/cm^2)	Filter exposure (mg/cm^2)	Integrated filter exposure (kg/km)	Integrated filter exposure (lb/mi)
F-21	1.5	27	16	1.36	0.79	34.7	123
	3.0	29	17	0.69	0.39		
	4.5	27	16	0.32	0.17		
	6.0	26	15	0.38	0.18		
F-22	1.5	27	16	1.02	0.60	27.7	98.3
	3.0	29	17	0.79	0.47		
	4.5	27	16	0.45	0.24		
	6.0	26	15	0.37	0.17		
F-23	1.5	27	16	1.59	1.01	47.4	168
	3.0	29	17	1.14	0.72		
	4.5	27	16	0.77	0.45		
	6.0	26	15	0.61	0.34		
F-24	1.5	27	16	0.067	0.048	3.35	11.9
	3.0	29	17	0.041	0.039		
	4.5	27	16	0.048	0.032		
	6.0	26	15	0.047	0.031		
F-25	1.5	27	16	0.34	0.20	10.0	35.5
	3.0	29	17	0.26	0.13		
	4.5	27	16	0.11	0.08		
	6.0	26	15	0.24	0.12		
G-27	1.5	27	16	8.66	4.69	254	901
	3.0	27	16	9.29	5.12		
	4.5	NA	NA	NA	NA		
	6.0	26	15	1.84	1.07		
G-28	1.5	27	16	4.48	2.26	110	391
	3.0	27	16	3.02	1.60		
	4.5	NA	NA	NA	NA		
	6.0	26	15	1.24	0.77		

TABLE 3-3 (Continued)

Run	Sampling height (m)	Sampling rate (m^3/hr)	(cfm)	Total exposure (mg/cm^2)	Filter exposure (mg/cm^2)	Integrated filter exposure (kg/km)	(lb/mi)
G-29	1.5	27	16	6.05	3 37	134	475
	3.0	27	16	3.22	1.83		
	4.5	NA	NA	NA	NA		
	6.0	26	15	0.74	0.05		
G-30	1.5	39	23	5.47	1.98	89.3	317
	3.0	43	25	3.81	1.64		
	4.5	85	50	2.12	0.91		
	6.0	44	26	1.02	0.42		
G-31	1.5	39	23	4.09	1.71	68.8	244
	3.0	43	25	2.20	0.96		
	4.5	85	50	1.91	1.01		
	6.0	44	26	0.50	0.26		
G-32	1.5	39	23	10.5	5.06	238	845
	3.0	43	25	7.9	3.68		
	4.5	85	50	NA	NA		
	6.0	44	26	2.5	1.39		

TABLE 3-4. SUSPENDED PARTICULATE CONCENTRATION AND EXPOSURE MEASUREMENTS--UNPAVED ROADS

	Particulate concentration ($\mu g/m^3$) at 2 m above ground						
		Downwind					
		Profiler a,b/			Standard hi-vol		
Run	Upwind background	Non-isokinetic	Isokinetic	Cascade impactor b/	5 m	20 m	50 m
F-21	925	2,920	3,590	2,990	2,140	1,330	-
F-22	925	5,330	7,410	4,820	4,390	1,800	-
F-23	925	3,320	3,980	c/	3,260	1,610	-
F-24	498	537	618	866	629	452	-
F-25	433	1,175	1,330	1,200	782	641	-
G-27	50	8,470	9,740	12,300	10,100	-	-
G-28	50	9,180	10,470	6,980	7,040	-	-
G-29	50	10,900	13,600	11,400	9,570	-	-
G-30	1,165	5,930	5,210	6,400	3,840	-	-
G-31	1,165	4,720	4,860	5,270	4,060	-	-
G-32	764	10,100	10,100	12,300	8,190	-	-

a/ Interpolated from 1.5 m and 3.0 m concentrations.

b/ Positioned at 5 m downwind.

c/ Invalid data; improperly sequenced stages.

Table 3-5 summarizes the particle sizing data for the unpaved road tests. Particle size is expressed as Stokes diameter based on actual density of silt-size particles. In addition to data from the cascade impactor measurements, Table 3-5 also gives the average percent of the exposure measurement consisting of filter catch weighted by the individual exposure values for each run.

Table 3-6 gives the wind speed and intake velocity used to calculate the average isokinetic ratio for each run. Also presented are isokinetic correction factors for exposure and concentration, calculated from the particle size data and isokinetic ratio values for each run according to the procedure delineated in Appendix A.

Table 3-7 presents the isokinetic emission factors for suspended particulates, particles smaller than 30 μm in Stokes diameter, and for fine particulates, particles smaller than 5 μm in Stokes diameter. Also indicated in Table 3-7 are vehicle and site parameters which are believed to have a significant effect on observed emission rates.

An example emission factor calculation based on data for Run G-29 is given in Appendix A.

3.4 Vehicular Traffic on Paved Roads

As indicated in Table 3-2, six tests of dust emissions from vehicular traffic on paved roads were performed. Figures 3-5 and 3-6 show the locations of sampling instruments relative to the test road segments.

In addition to the silt loading on the road surface material, the emission factor equation (Table 2-1) requires data on the number of traffic lanes and the vehicle weight averaged over the vehicle passes (approximately 50) accumulated during a test. Estimates of vehicle weights were obtained from plant personnel. In some tests, the vehicle passes sampled were dominated by controlled test vehicles traveling at preselected speeds.

Table 3-8 lists the individual point values of exposure (net mass per sampling intake area) within the fugitive dust plume as measured by the exposure profiling equipment for each run. Also given are the point values of filter exposure consisting only of particulate collected by the filter following the settling chamber. Finally, the integrated exposure value is given for each run.

TABLE 3-5. PARTICLE SIZE DATA--UNPAVED ROADS (Density = 3 g/cm^3)[a/]

Run	Cascade impactor					Profiler
	Mass median diameter (μm)	Percent < 30 μm	Percent < 5 μm	Ratio[b/]	Percent >50 μm	Weighted average % captured on the filter
F-21	10.0	74	34	0.46	17	55
F-22	11	72	31	0.43	18.5	56
F-23[c/]	-	-	-	-	-	56
F-24	8.2	83	36	0.44	10	74
F-25[d/]	-	-	-	-	-	57
G-27	17	61	26	0.43	29	55
G-28	22	56	33	0.59	34	53
G-29	20	59	21	0.36	29	57
G-30	38	45	17	0.38	45	39
G-31	26	53	22	0.42	37	44
G-32	21	59	21	0.36	30	49

a/ Based upon previous MRI testing.[1/]

b/ Percent < 5 μm ÷ percent < 30 μm.

c/ Data invalid; improperly sequenced stages.

d/ Data invalid; insufficient substrate loadings.

TABLE 3-6. ISOKINETIC CORRECTION PARAMETERS--UNPAVED ROADS

	Wind speed				Intake velocity					Isokinetic correction factor	
	Ht = 1.5 m		Ht = 4.5 m		Ht = 1.5 m		Ht = 4.5 m				
Run	(cm/sec)	(fpm)	(cm/sec)	(fpm)	(cm/sec)	(fpm)	(cm/sec)	(fpm)	Isokinetic ratio[a]	Exposure	Concentration
F-21	134	263	210	414	293	576	293	576	1.79	0.725	1.23
F-22	99.1	195	185	365	293	576	293	576	2.27	0.679	1.39
F-23	144	283	226	445	293	576	293	576	1.66	0.760[b]	1.20[b]
F-24	142	279	202	398	293	576	293	576	1.76	0.677	1.15
F-25	170	335	197	387	293	576	293	576	1.60	0.707[c]	1.13[c]
G-27	198	389	260	512	293	576	293	576	1.30	0.896	1.15
G-28	210	414	266	524	293	576	d/	-	1.39	0.892	1.14
G-29	183	360	238	468	293	576	d/	-	1.60	0.874	1.25
G-30	541	1,065	702	1,381	420	827	d/	-	0.777	1.05	0.878
G-31	408	803	514	1,012	420	827	d/	-	1.03	0.981	1.03
G-32	452	890	597	1,175	420	827	d/	-	0.929	1.0	1.0

a/ Intake velocity ÷ wind speed.

b/ Based on averages of particle size data from Runs F-21 and F-22.

c/ Based on particle size data from Run F-24.

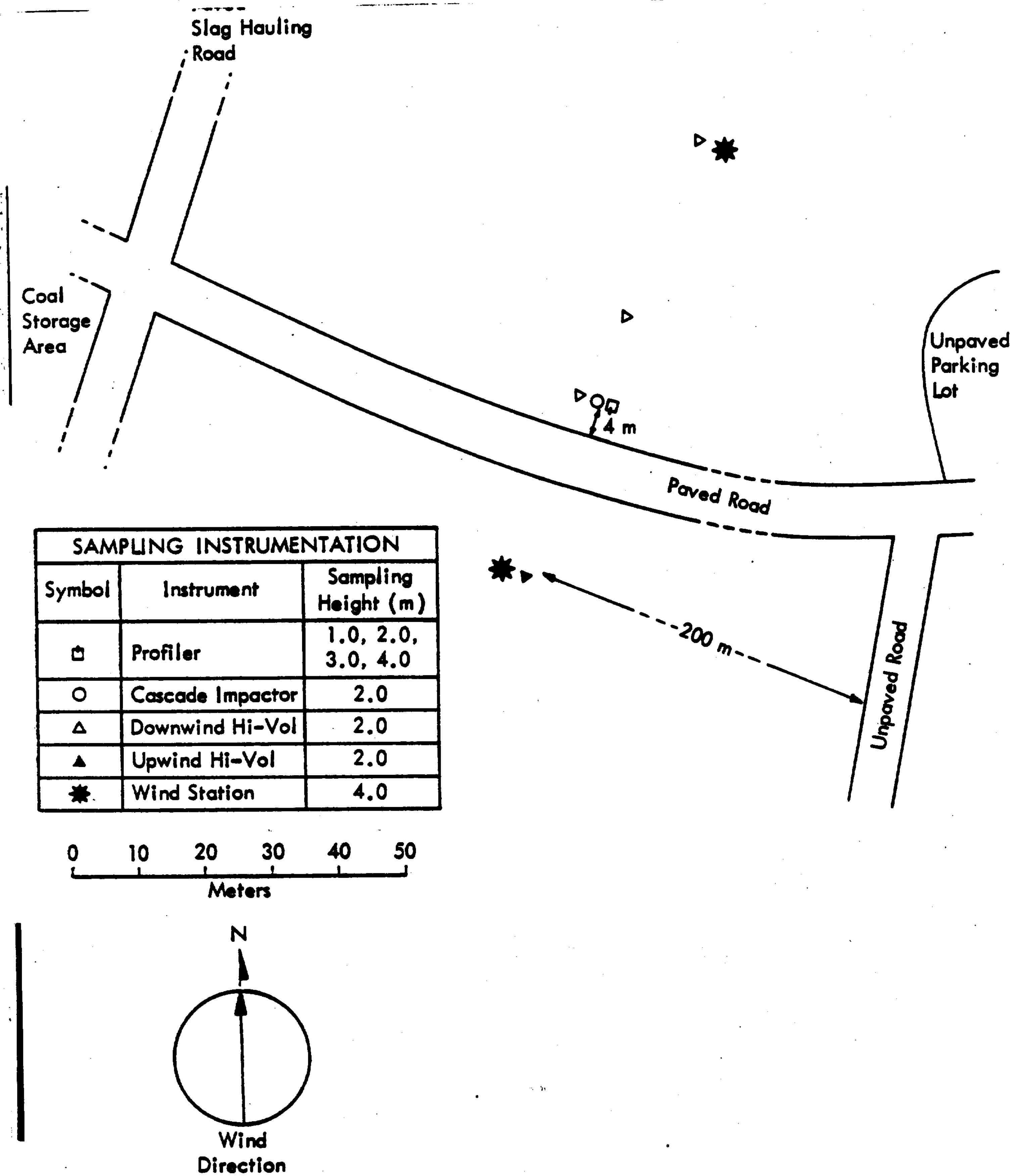
d/ Flow controller not functioning properly.

TABLE 3-7. EMISSION FACTORS AND ADJUSTMENT PARAMETERS--UNPAVED ROADS

Run	Road surface material: Type	Road surface material: Silt (%)	Mean vehicle speed (km/hr)	Mean vehicle speed (mph)	Mean vehicle weight (tonnes)	Mean vehicle weight (tons)	Mean number of wheels per vehicle pass	Suspended particulate emission factor (kg/VKT)	Suspended particulate emission factor (lb/VMT)	Fine particulate emission factor (kg/VKT)	Fine particulate emission factor (lb/VMT)
F-21	Dirt/crushed slag	9.0	24	15	3	3	4	0.85	3.0	0.29	1.0
F-22		9.0	24	15	3	3	4	0.48	1.7	0.15	0.53
F-23		9.0	24	15	4	4	4	0.65	2.3	0.21a/	0.75a/
F-24	Coherex treated dirt/ crushed slag	0.03	24	15	3	3	4	0.021	0.073	0.0076	0.026
F-25		0.02	24	15	3	3	4	0.101	0.36	0.036b/	0.13b/
F-26			← Rained Out →								
G-27	Crushed slag	5.3	35	22	15	17	11	3.4	12.0	0.88	3.1
G-28		5.3	37	23	11	12	10	2.0	7.2	0.66	2.4
G-29		5.3	39	24	8	9	8	1.6	5.6	0.34	1.2
G-30		4.3	40	25	13	14	9	2.5	8.7	0.43	1.5
G-31		4.3	47	29	7	8	6	1.4	5.1	0.31	1.1
G-32		4.3	35	22	27	30	13	4.5	16.0	0.95	3.4

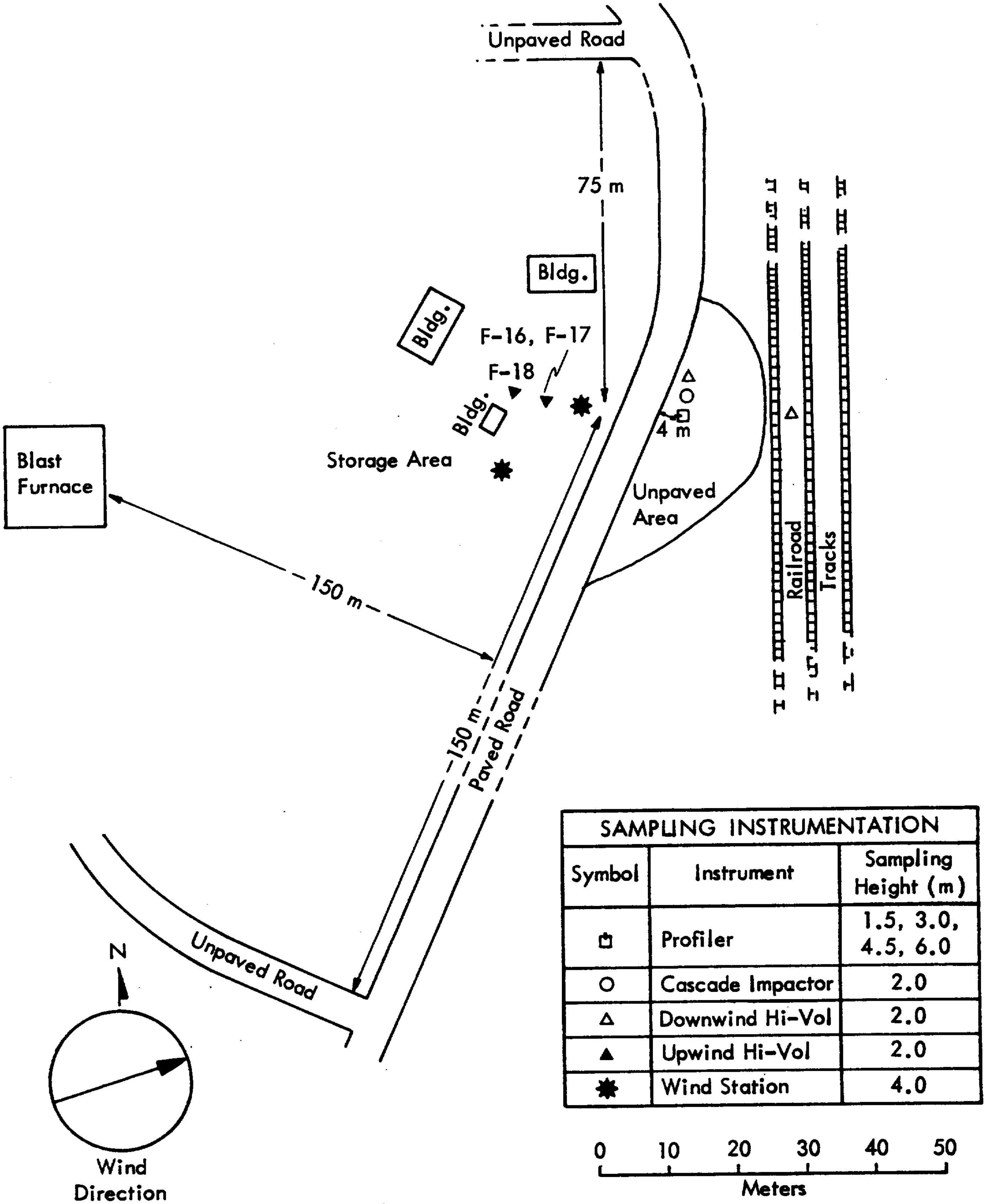
a/ Based on averages of particle size data from Runs F-21 and F-22.

b/ Based on particle size data from Run F-24.



SAMPLING INSTRUMENTATION		
Symbol	Instrument	Sampling Height (m)
⌂	Profiler	1.0, 2.0, 3.0, 4.0
○	Cascade Impactor	2.0
△	Downwind Hi-Vol	2.0
▲	Upwind Hi-Vol	2.0
✸	Wind Station	4.0

Figure 3-5. Sampling equipment layout for Runs F-13 through F-15.



SAMPLING INSTRUMENTATION		
Symbol	Instrument	Sampling Height (m)
□	Profiler	1.5, 3.0, 4.5, 6.0
○	Cascade Impactor	2.0
△	Downwind Hi-Vol	2.0
▲	Upwind Hi-Vol	2.0
✸	Wind Station	4.0

Figure 3-6. Sampling equipment layout for Runs F-16 through F-18.

TABLE 3-8. PLUME SAMPLING DATA--PAVED ROADS

Run	Sampling height (m)	Sampling rate (m³/hr)	Sampling rate (cfm)	Total exposure (mg/cm²)	Filter exposure (mg/cm²)	Integrated filter exposure (kg/km)	Integrated filter exposure (lb/mi)
F-13	1.0	24	14	0.60	0.24	10.5	37.2
	2.0	27	16	0.36	0.17		
	3.0	24	14	0.38	0.16		
	4.0	22	13	0.32	0.16		
F-14	1.0	22	13	0.31	0.18	6.14	21.8
	2.0	27	16	0.20	0.12		
	3.0	24	14	0.13	0.10		
	4.0	22	13	0.11	0.08		
F-15	1.0	22	13	0.20	0.12	4.14	14.7
	2.0	27	16	0.05	0.04		
	3.0	24	14	0.02	0.02		
	4.0	22	13	0.15	0.07		
F-16	1.5	27	16	2.19	1.57	68.8	244
	3.0	29	17	1.60	1.09		
	4.5	27	16	0.99	0.66		
	6.0	26	15	0.42	0.33		
F-17	1.5	27	16	1.70	1.29	58.9	209
	3.0	29	17	1.44	0.98		
	4.5	27	16	0.87	0.60		
	6.0	26	15	0.37	0.27		
F-18	1.5	27	16	0.44	0.30	18.9	67.0
	3.0	29	17	0.40	0.29		
	4.5	27	16	0.31	0.23		
	6.0	26	15	0.28	0.20		

Table 3-9 compares particulate concentrations measured by the upwind hi-vol and by three types of downwind samplers (exposure profiling head, standard hi-vol, and high-volume cascade impactor) located 5 m from the test road and near the vertical center of the plume at a height of 2 m above ground. For the interpolated profiler concentrations, both nonisokinetic and isokinetic values are given. Also indicated are hi-vol concentrations measured at distances further downwind.

Table 3-10 summarizes the particle sizing data for the paved road tests. Particle size is expressed as Stokes diameter based on actual density of silt-size particles. In addition to data from the cascade impactor measurements, Table 3-10 also gives for each run the average percent of the exposure measurement consisting of filter catch, weighted by the individual exposure values.

Table 3-11 gives the wind speed and intake velocity used to calculate the average isokinetic ratio for each run. Also presented are isokinetic correction factors for exposure and concentration, calculated from the particle size data and isokinetic ratio values for each run according to the procedure delineated in Appendix A.

Table 3-12 presents the isokinetic emission factors for suspended particulates, particles smaller than 30 μm in Stokes diameter, and for fine particulates, particles smaller than 5 μm in Stokes diameter. Also indicated in Table 3-12 are and site parameters which are believed to have a significant effect on observed emission rates.

An example emission factor calculation based on data for Run F-18 is given in Appendix A.

3.5 Storage Pile Stacking

As indicated in Table 3-2, four tests of dust emissions from storage pile formation by means of a mobile conveyor stacker were performed, three tests of iron pellet stacking and one test of coal stacking. For each test, the stacking arm was passed back and forth in front of the profiler so that the sampler configuration was the same as that used for roads (moving point source configuration). Figures 3-7 and 3-8 show the locations of sampling instruments relative to the stacking strips.

Table 3-13 lists the individual point values of exposure (net mass per sampling intake area) within the fugitive dust plume as measured by the exposure profiling equipment for each run. Also given are the point values of filter exposure consisting only of particulate collected by the filter following the settling chamber. Finally, the integrated exposure value is given for each run.

TABLE 3-9. SUSPENDED PARTICULATE CONCENTRATION AND EXPOSURE MEASUREMENTS--PAVED ROADS

	Particulate Concentration ($\mu g/m^3$) at 2 m Above Ground						
		Downwind					
	Upwind	Profiler[a]		Cascade	Standard Hi-vol		
Run	Background	Non-Isokinetic	Isokinetic	Impactor	5 m	20 m	50 m
F-13	134	383	433	429	201	288	211
F-14	134	327	327	323	279	234	176
F-15	134	195	310	360	243	81	181
F-16	1,520	4,620[a]	6,840	3,900	2,850[b]	1,700	-
F-17	1,520	4,170[a]	7,590	8,130	3,760[b]	1,470	-
F-18	920	1,170[a]	1,540	1,180	722[b]	-	-

a/ Interpolated from 1.5 m and 3.0 m concentrations.
b/ 3 m downwind.

TABLE 3-10. PARTICLE SIZE DATA--PAVED ROADS (Density = 3 g/cm^3)[a/]

Run	Cascade impactor: Mass median diameter (μm)	Cascade impactor: Percent < 30 μm	Cascade impactor: Percent < 5 μm	Cascade impactor: Ratio[b/]	Cascade impactor: Percent > 50 μm	Profiler: Weighted average % captured on the filter
F-13	14	69	27	0.39	21	44
F-14	4.3	97	56	0.58	0.9	65
F-15[c/]	—	—	—	—	—	66
F-16	12.5	68	31	0.46	23	71
F-17	50	41	14	0.34	50	72
F-18	9.0	78	36	0.46	15	72

a/ Based upon previous MRI testing.[1/]

b/ Percent < 5 μm ÷ percent < 30 μm.

c/ Data invalid; insufficient substrate loadings.

TABLE 3-11. ISOKINETIC CORRECTION PARAMETERS--PAVED ROADS

Run	Wind speed				Intake velocity				Isokinetic ratio[a]	Isokinetic correction factor	
	Ht = 1.5 m		Ht = 4.5 m		Ht = 1.5 m		Ht = 4.5 m				
	(cm/sec)	(fpm)	(cm/sec)	(fpm)	(cm/sec)	(fpm)	(cm/sec)	(fpm)		Exposure	Concentration
F-13	174[b]	343[b]	222[c]	437[c]	256[b]	503[b]	256[c]	503[c]	1.31	0.873	1.13
F-14	148[b]	291[b]	219[c]	432[c]	237[b]	467[b]	256[c]	503[c]	1.38	0.744	1.00
F-15	62.5[b]	123[b]	65.5[c]	129[c]	237[b]	467[b]	256[c]	503[c]	3.85	0.412[d]	1.59[d]
F-16	113	223	160	315	293	576	293	576	2.21	1.16	1.48
F-17	116	228	170	334	293	576	293	576	2.13	0.887	1.82
F-18	119	234	163	320	293	576	293	576	2.13	0.633	1.32

a/ Intake velocity ÷ wind speed.

b/ At 1.0-m height.

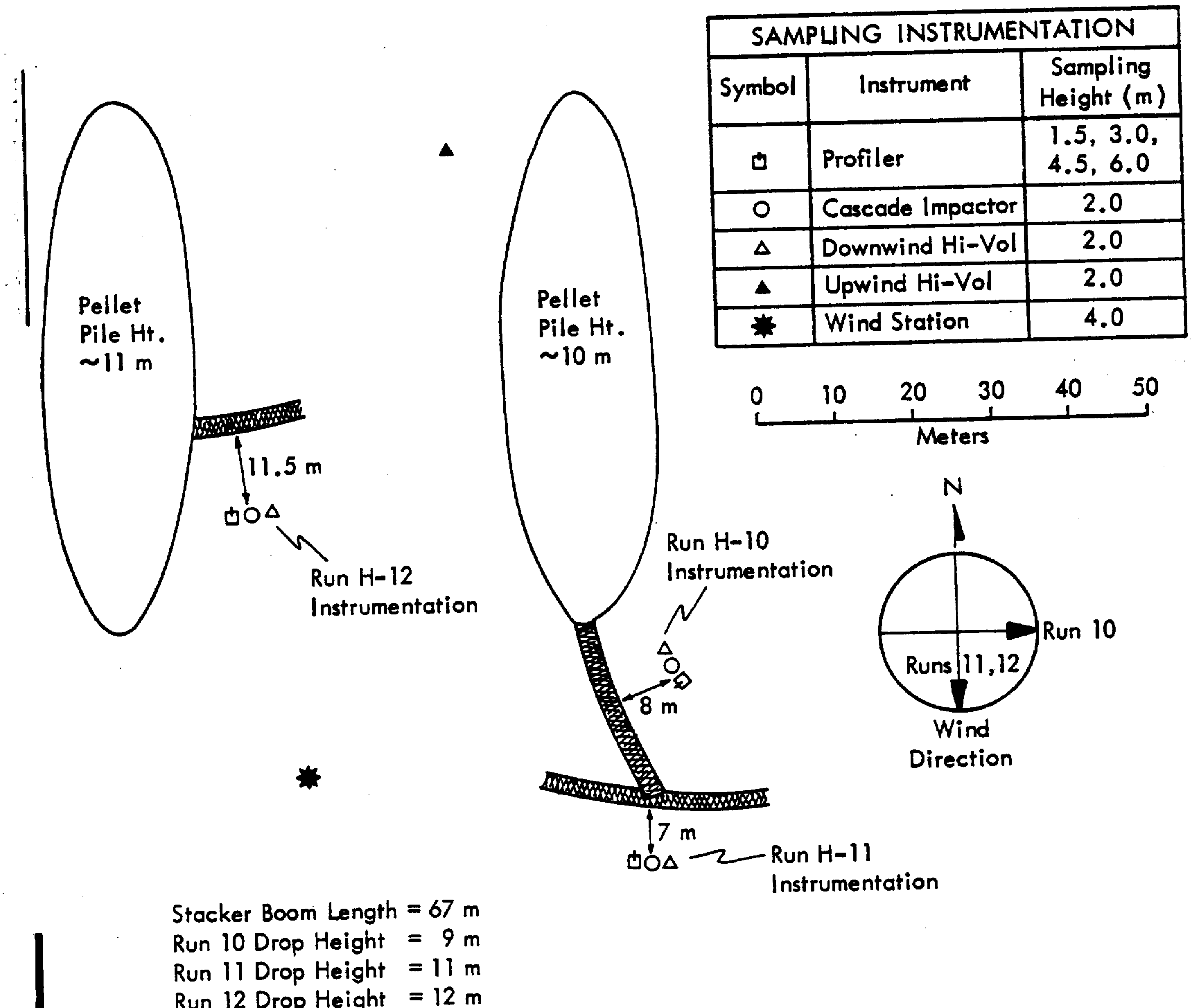
c/ At 3.0-m height.

d/ Based on averages of particle size data from Runs F-13 and F-14.

TABLE 3-12. EMISSION FACTORS AND ADJUSTMENT PARAMETERS--PAVED ROADS

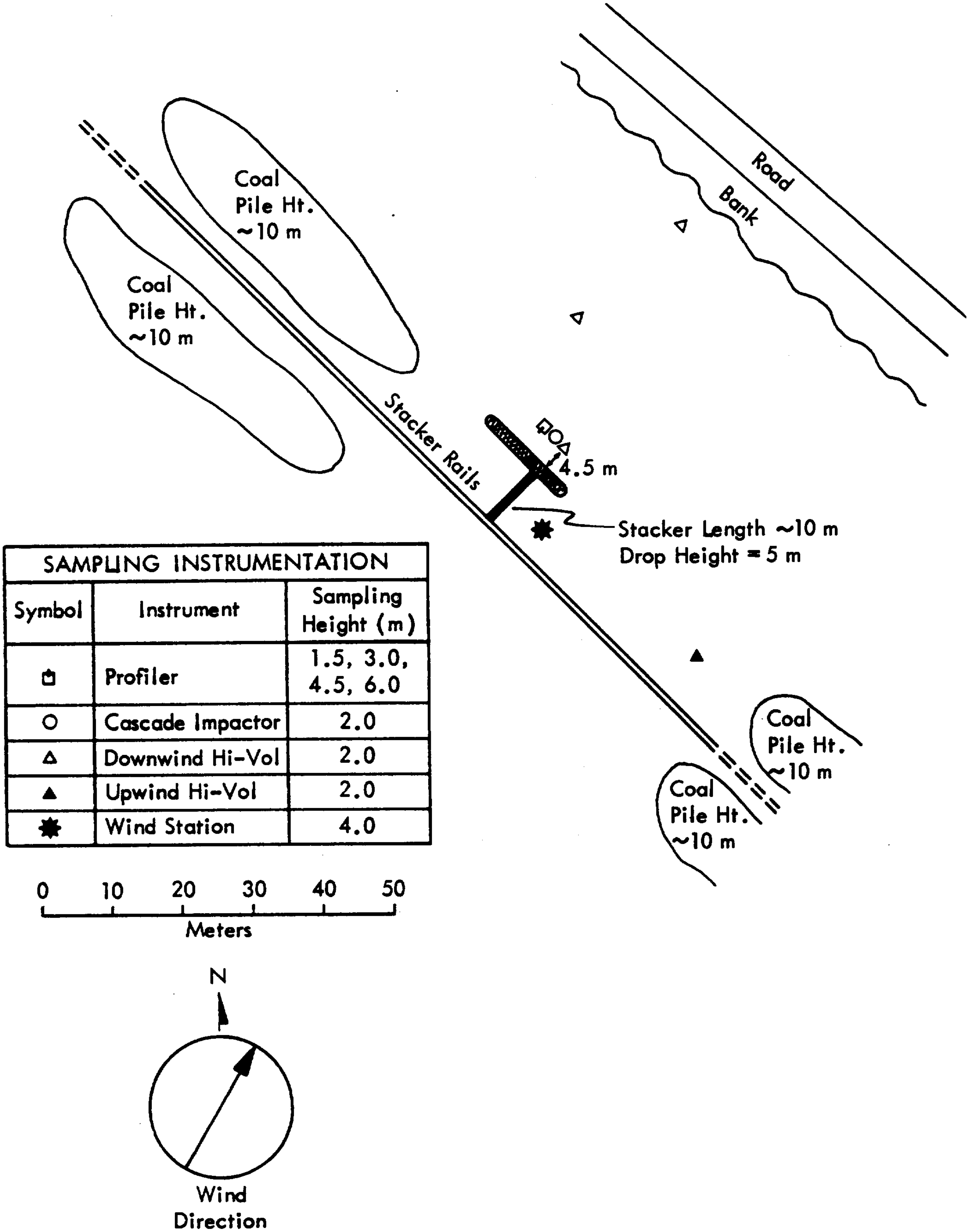
Run	Road surface material: Silt (%)	Loading (kg/km)	Loading (lb/mi)	Mean vehicle speed (mph)	Mean vehicle weight (tonnes)	Mean vehicle weight (tons)	Mean number of wheels per vehicle pass	Suspended particulate emission factor (kg/VKT)	Suspended particulate emission factor (lb/VMT)	Fine particulate emission factor (kg/VKT)	Fine particulate emission factor (lb/VMT)
F-13	13.2	57.2	203	-	7	8	-	0.16	0.58	0.043	0.16
F-14	13.2	57.2	203	-	5	5	-	0.056	0.20	0.031	0.11
F-15	13.2	57.2	203	-	5	5	-	0.045	0.16	0.019[a]	0.066[a]
F-16	6.8	627	2,225	-	12	13	-	0.70	2.5	0.22	0.78
F-17	6.8	627	2,225	-	11	12	-	0.48	1.7	0.067	0.24
F-18	6.8	627	2,225	-	5	5	-	0.14	0.48	0.050	0.17

a/ Based on averages of particle size data from Runs F-13 and F-14.



SAMPLING INSTRUMENTATION		
Symbol	Instrument	Sampling Height (m)
⍓	Profiler	1.5, 3.0, 4.5, 6.0
○	Cascade Impactor	2.0
△	Downwind Hi-Vol	2.0
▲	Upwind Hi-Vol	2.0
✸	Wind Station	4.0

Figure 3-7. Sampling equipment layout for Runs H-10 through H-12.



SAMPLING INSTRUMENTATION		
Symbol	Instrument	Sampling Height (m)
□	Profiler	1.5, 3.0, 4.5, 6.0
○	Cascade Impactor	2.0
△	Downwind Hi-Vol	2.0
▲	Upwind Hi-Vol	2.0
✸	Wind Station	4.0

Figure 3-8. Sampling equipment layout for Runs F-19 and F-20.

TABLE 3-13. PLUME SAMPLING DATA--STORAGE PILE STACKING

Run	Sampling height (m)	Sampling rate (m^3/hr)	Sampling rate (cfm)	Total exposure (mg/cm^2)	Filter exposure (mg/cm^2)	Integrated filter exposure (kg/km)	Integrated filter exposure (lb/mi)
H-10	1.5	26	15	12.1	2.43	89.9	319
	3.0	24	14	5.88	1.43		
	4.5	24	14	3.18	0.89		
	6.0	22	13	4.13	2.56		
H-11	1.5	26	15	0.92	0.42	25.6	90.8
	3.0	24	14	0.74	0.62		
	4.5	24	14	0.50	0.46		
	6.0	22	13	0.10	0.09		
H-12	1.5	26	15	3.45	1.88	56.9	202
	3.0	24	14	1.15	0.35		
	4.5	24	14	1.11	0.80		
	6.0	22	13	1.82	1.59		
F-19	1.5	27	16	0.82	0.42	18.5	65.6
	3.0	31	18	0.34	0.21		
	4.5	27	16	0.35	0.19		
	6.0	26	15	0.27	0.15		
F-20[a]	1.5	29	17	0.23	0.095	5.44	19.3
	3.0	29	17	0.19	0.084		
	4.5	27	16	0.24	0.062		
	6.0	26	15	0.21	0.062		

a/ Background run only.

Table 3-14 compares particulate concentrations measured by the upwind hi-vol and by three types of downwind samplers (exposure profiling head, standard hi-vol, and high-volume cascade impactor) located 5 m from the test road and near the vertical center of the plume at a height of 2 m above ground. For the interpolated profiler concentrations, both nonisokinetic and isokinetic values are given. Also indicated are hi-vol concentrations measured at distances further downwind.

Table 3-15 summarizes the particle sizing data for the storage pile stacking tests. Particle size is expressed as Stokes diameter based on actual density of silt-size particles. In addition to data from the cascade impactor measurements, Table 3-15 also gives the average percent of the exposure measurement consisting of filter catch, weighted by the individual exposure values for each run.

Table 3-16 gives wind speed and intake velocity used to calculate the average isokinetic ratio for each run. Also presented are isokinetic correction factors for exposure and concentration, calculated from the particle size data and isokinetic ratio values for each run according to the procedure delineated in Appendix A.

Table 3-17 presents the isokinetic emission factors for suspended particulates, particles smaller than 30 μm in Stokes diameter, and for fine particulates, particles smaller than 5 μm in Stokes diameter. Also indicated in Table 3-17 are vehicle site parameters which are believed to have a significant effect on observed emission rates.

An example emission factor calculation based on data for Run H-12 is given in Appendix A.

TABLE 3-14. SUSPENDED PARTICULATE CONCENTRATION AND EXPOSURE MEASUREMENTS--STORAGE PILE STACKING

Run	Particulate concentration ($\mu g/m^3$) at 2 m above ground						
		Downwind					
	Upwind	Profiler[a]		Cascade	Standard Hi-vol		
	background	Non-isokinetic	Isokinetic	impactor	5m	20m	50m
H-10	670	36,900	150,000[b]	39,700	11,400	-	-
H-11	700	4,580	5,360	4,860	3,990	-	-
H-12	800	21,600	25,300	13,400	8,560	-	-
F-19	630	1,280	2,620	2,500	452	636	500
F-20[c]	630	1,400	-	-	1,110	606	528

a/ Interpolated from 1.5 m and 3.0 m concentrations.

b/ Suspect because of large isokinetic ratio.

c/ Background run only.

TABLE 3-15. PARTICLE SIZE DATA--STORAGE PILE STACKING

Run	Particle Density (g/cm^3)a/	Cascade Impactor					Profiler
		Mass Median Diameter (μm)	Percent < 30 μm	Percent < 5 μm	Ratio b/	Percent >50 μm	Weighted Average % Captured on the Filter
H-10	4.9	96	21	5	0.24	72	29
H-11 c/	4.9	-	-	-	-	-	71
H-12	4.9	11.4	75	30	0.40	15.5	61
F-19	1.4	63	35	8.2	0.23	55	55
F-20 d/	1.4	17	69	14	0.20	17.5	35

a/ Based on coal densities from Handbook of Chemistry and Physics, 53rd Ed., CRC Press, 1972-1973.

b/ Percent < 5 μm ÷ percent < 30 μm.

c/ Data invalid; insufficient substrate loadings.

d/ Background run only.

TABLE 3-16. ISOKINETIC CORRECTION PARAMETERS--STORAGE PILE STACKING

	Wind speed				Intake velocity					Isokinetic correction factor	
	Ht = 1.5 m		Ht = 4.5 m		Ht = 1.5 m		Ht = 4.5 m				
Run	(cm/sec)	(fpm)	(cm/sec)	(fpm)	(cm/sec)	(fpm)	(cm/sec)	(fpm)	Isokinetic ratio[a]	Exposure	Concentration
H-10	58.9	116	58.9	116	274	540	238	468	4.34	0.937	4.07
H-11	183	360	157	310	274	540	238	468	1.50	0.777[b]	1.17[b]
H-12	221	436	302	594	274	540	238	468	1.01	0.777	1.17
F-19	71.6	141	194	382	293	576	293	576	2.80	0.928	2.05
F-20	77.2	152	172	339	311	612	293	576	2.86	-	-

a/ Intake velocity ÷ wind speed.

b/ Based on particle size data from Run H-12.

TABLE 3-17. EMISSION FACTORS AND ADJUSTMENT PARAMETERS--STORAGE PILE STACKING

Run	Aggregate material			Number of stacker passes	Stacker velocity		Stacking rate		Drop distance (m)	Mean wind speed		Suspended particulate emission factor		Fine particulate emission factor	
	Type	Silt (%)	Moisture (%)		(m/sec)	(mph)	(tonnes/hr)	(tons/hr)		(m/sec)	(mph)	(g/tonne)	(lb/ton)	(g/tonne)	(lb/ton)
H-10	Iron pellet	1.4	2.6	7	0.2	0.5	5,000	5,500	9	0.67	1.5	1.2	0.0023	0.060	0.00012
H-11		1.8	3.5	11	0.9	2.0	5,000	5,500	11	1.8	4.0	1.5	0.0029	0.45[a]	0.00087[a]
H-12		1.7	3.4	10[b]	0.2	0.5	5,000	5,500	12	2.7	6.0	1.2	0.0023	0.35	0.00069
F-19	Coal	5.9	4.8	30	0.2	0.5	1,100	1,200	5	1.3	3.0	0.070	0.00014	0.0056	0.000011

a/ Based on particle size data from Run H-12.

b/ Estimate.

SECTION 4.0

WIND EROSION TESTING

4.1 Sampling Equipment

For the measurement of dust emissions generated by wind erosion of storage piles, a portable wind tunnel developed by Dr. Dale Gillette was used.[7] The open-floored test section of the tunnel was placed directly on the surface to be tested (15 cm x 2.4 m), and the tunnel air flow was adjusted to predetermined velocities up to a nominal 27 m/sec (60 mph) as measured by a pitot tube at the downstream end of the test section.

An emissions sampling module was designed and fabricated by MRI for use with the pull-through wind tunnel in measuring particulate emissions and particle size distributions generated by wind erosion. As shown in Figure 4-1, the sampling module was located between the tunnel outlet hose and the fan inlet. The sampling train, which was operated at 34 m^3/hr (20 cfm), consisted of a tapered probe, cyclone precollector, parallel-slot cascade impactor, back-up filter, and high-volume motor. Interchangeable probe tips were sized for isokinetic sampling at cross-sectional average velocities of 7, 12, 17, and 27 m/sec within the tunnel test section.

4.2 Preliminary Testing

Prior to the development of the emissions sampling module, preliminary tests were conducted on crusted and disturbed surfaces of an inactive coal storage pile and nearby prairie soil within an integrated and steel plant. A test surface was disturbed, i.e., the thin crust was broken, by walking over it repeatedly with a twisting action.

The purposes of the preliminary tests were to determine the threshold velocities for wind erosion (minimum velocities at which wind erosion is initiated) and to gather other data needed for the design of the sampling module. The threshold velocity for a particular surface was determined by observing the onset of surface particle movement as the wind velocity was gradually increased. As indicated in Table 4-1, the surface crusts, especially for soil, were found to be very effective in protecting against wind erosion.

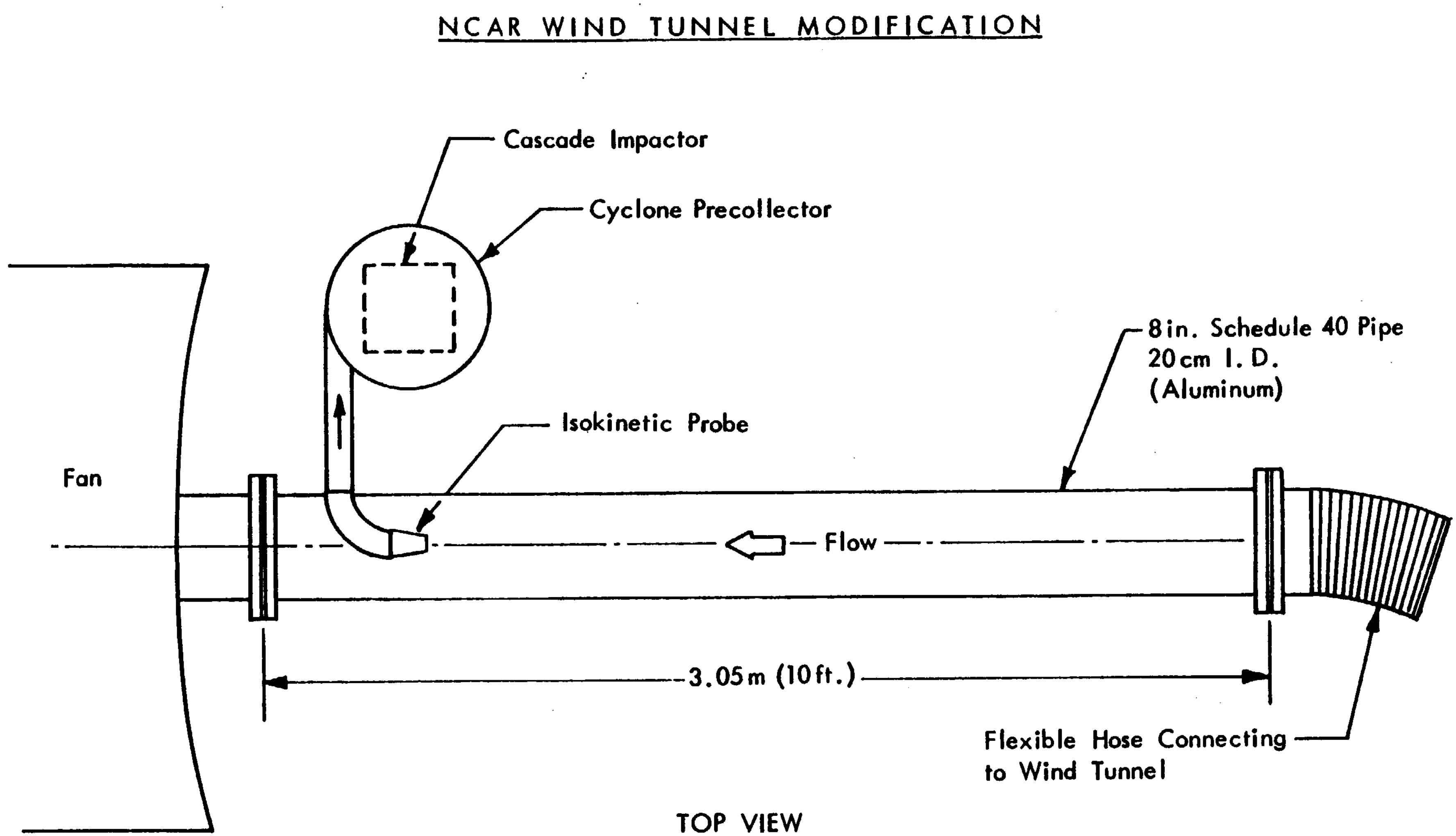


Figure 4-1. Emissions sampling module for portable wind tunnel.

TABLE 4-1. OBSERVED THRESHOLD VELOCITIES
(June 12, 1978)

Surface	Threshold friction velocity (cm/sec)		Approximate threshold tunnel centerline velocity[a]	
			(m/sec)	(mph)
	Test 1	Test 2		
Coal pile				
Undisturbed	128	137	13	30
Disturbed	96	93	8.9	20
Prairie soil				
Undisturbed	[b]	[b]	> 27	> 60
Disturbed	~ 25[c]	~ 25[c]	4.5	10

a/ Calculated assuming a roughness height = 0.1 cm.
b/ Unobserved within tunnel flow range.
c/ Only slight deflection on Pitot tube pressure gauge.

It was also observed during the preliminary tests that, at wind velocities substantially exceeding the threshold value for a test surface, the erosion rate decayed rapidly with time.

4.3 Emissions Testing Program

In the emissions testing program, 12 tests were performed. A total of eight tests were performed on the upper flat surface of an inactive coal storage pile--three tests of one section of undisturbed (crusted) surface, three tests of a disturbed section, and two tests of a second disturbed section. This was followed by two tests of the flat ground surface (undisturbed) adjacent to a dolomite storage pile and two tests of disturbed prairie soil in the same area where the preliminary tests were conducted.

In order to determine the quantity and textural properties of each material being eroded, samples of the materials were removed from an area adjacent to the test surface before each test and from the test surface subsequent to each test. The samples were obtained by manually sweeping the surface with a small broom. In the case of both of the disturbed surfaces (coal and soil), a consolidated sublayer was found within a depth of 1 to 2 cm below the original surface.

To prevent dust losses, the collected samples of dust emissions were carefully transferred at the end of each run, to protective containers within the MRI instrument van. High-volume filters and impaction substrates were folded and placed in individual envelopes. Dust that collected on the interior surfaces of the sampling probe was rinsed with distilled water into separate glass jars. Dust was transferred from the cyclone precollector in a similar manner.

Dust samples from the field tests were returned to MRI and analyzed gravimetrically in the laboratory. Glass fiber filters and impaction substrates were conditioned at constant temperature and relative humidity for 24 hr prior to weighing (the same conditioning procedure used before taring). Water washes from the sampling probe and cyclone precollector were filtered after which the tared filters were dried, conditioned at constant humidity, and reweighed.

Samples of surface materials were dried to determine moisture content and screened to determine the weight fraction passing a 200-mesh screen, which gives the silt content. A conventional shaker was used for this purpose.

Table 4-2 gives the wind erosion test site parameters. Note that at tunnel locations B, C, and D on the coal storage pile, experiments were conducted in succession at the same velocity to measure the decay in erosion rate.

Table 4-3 lists the sampling parameters for the wind erosion tests. For Runs C-1, C-2, and C-3, the incorrect probe tip size was used resulting in a low isokinetic ratio. For Run C-11, rapid clogging of the screen at the end of the diffuser section prevented the maintenance of the desired tunnel flow rate.

Table 4-4 summarizes the particle size data for the wind erosion tests. The small portion of material collected on the interior surface of the probe tip was disregarded in the particle size analysis. For runs having isokinetic ratio values less than 0.8, particle size distributions were adjusted according to the procedure outlined in Appendix A.

Table 4-5 presents data on the surface properties which are believed to have a significant effect on emission rate. Table 4-6 summarizes the wind erosion test results.

Figure 4-2 shows the dependence of the average erosion rate on cumulative erosion time for the coal pile tests. Each data point is labeled with the appropriate tunnel centerline wind velocity. As expected for a given erosion time, the average erosion rate is highly dependent on wind speed. It is also evident that the naturally formed surface dust was effective in reducing wind erosion.

Figure 4-2 also shows the decay of emission rate with cumulative erosion time for test surface B (undisturbed) and C (disturbed) at the indicated wind velocities. The areas under the lines shown represent the total quantity of suspended particulate generated as a function of erosion time. It should be noted that the tunnel centerline wind velocities used in these tests substantially exceeded the threshold values corresponding to the onset of wind erosion for uncrusted and crusted coal surfaces.

The results of the wind erosion testing indicate that natural surface crusts are very effective in mitigating suspended dust emissions. In addition, test data show that a given surface has a finite potential for erosion prior to mechanical disturbance. Erosion rates increase with wind velocity and decrease with erosion time.

TABLE 4-2. WIND EROSION TEST SITE PARAMETERS

Surface							Cross-sectional average velocity in test section		Ambient meteorology			
									Temperature		Relative humidity	Cloud cover
Type	Condition	Run	Date	Start time	Sampling duration	Tunnel location	(m/sec)	(mph)	(°C)	(°F)	(%)	(%)
Coal	Undisturbed	C-1	10/12/78	1629	10.0	A	16	35	22	71	45	0
Coal	Undisturbed	C-2	10/12/78	1717	5.0	B	25	56	-	-	-	-
Coal	Undisturbed	C-3	10/12/78	1745	9.25	B	25	56	-	-	-	-
Coal	Disturbed	C-4	10/13/78	1011	10.0	C	8.5	19	8.9	48	36	100
Coal	Disturbed	C-5	10/13/78	1043	2.0	C	16	36	-	-	-	-
Coal	Disturbed	C-6	10/13/78	1102	6.0	C	16	36	14	57	41	70
Coal	Disturbed	C-7	10/13/78	1212	1.5	D	19[a]	43[a]	-	-	-	50
Coal	Disturbed	C-8	10/13/78	1236	0.67	D	16[b]	35[b]	-	-	-	-
Dolomite	Undisturbed	C-9	10/13/78	1640	10.0	E	10	23	17	63	47	0
Dolomite	Undisturbed	C-10	10/13/78	1711	10.0	F	15	33	-	-	-	-
Prairie soil	Disturbed	C-11	10/13/78	1834	10.0	G	9.8	22	-	-	-	-
Prairie soil	Disturbed	C-12	10/13/78	1854	3.0	G	11	24	-	-	-	-

a/ Estimated average; velocity fell from initial value of 24 m/sec (54 mph) due to plugging of tunnel screen.

b/ Estimated value; plugging of tunnel screen prevented higher velocity.

TABLE 4-3. WIND EROSION SAMPLING PARAMETERS

Run	Wind tunnel test section			Sampling module						
	Cross-sectional average velocity		Flow rate	Probe tip		Velocity		Isokinetic ratio	Volume sampled (m^3)	Total mass collected (g)
	(m/sec)	(mph)	(m^3/hr)	Diameter (cm)	Area (cm^2)	Approach (cm/sec)	Inlet (cm/sec)			
C-1	15.6	35	1300	3.81	11.4	1400	828	0.594	5.66	0.8680
C-2	25.0	56	2090	5.08	20.3	2240	465	0.208	2.83	2.7565
C-3	25.0	56	2090	5.08	20.3	2240	465	0.208	5.23	0.2176
C-4	8.49	19	716	3.81	11.4	767	828	1.08	5.66	0.2995
C-5	16.1	36	1320	3.18	7.92	1420	1190	0.841	1.13	2.4418
C-6	16.1	36	1320	3.18	7.92	1420	1190	0.841	3.40	0.4106
C-7	19.2[a/]	43[a/]	1600[a/]	2.54	5.07	1720[a/]	1860	1.08[a/]	0.850	2.6867
C-8	15.6[a/]	35[a/]	1300[a/]	2.54	5.07	1400[a/]	1860	1.33[a/]	0.378	3.0931
C-9	10.3	23	853	3.81	11.4	913	828	0.907	5.66	0.3773
C-10	14.8	33	1230	3.18	7.92	1320	1190	0.904	5.66	4.2370
C-11	9.83	22	806	5.08	20.3	863	465	0.539	5.66	0.6034
C-12	10.7	24	893	3.81	11.4	956	828	0.866	1.08	8.1764

a/ Estimated value.

TABLE 4-4. PARTICLE SIZE DATA

Run	Surface type	Particle density (g/cm^3)[a]	Mass median diameter (µm)	Percent < 30 µm	Percent < 5 µm	Ratio[b]	Percent > 50 µm
C-1	Undisturbed coal	1.4	> 100	9.0	2.7	0.30	88
C-2	Undisturbed coal	1.4	> 100	5.5	1.4	0.25	92
C-3	Undisturbed coal	1.4	> 100	13	2.0	0.15	81
C-4	Disturbed coal	1.4	> 100	16	3.6	0.23	77
C-5	Disturbed coal	1.4	> 100	12	3.0	0.25	85
C-6	Disturbed coal	1.4	> 100	18	4.5	0.25	76
C-7	Disturbed coal	1.4	85	30	7.6	0.25	61
C-8	Disturbed coal	1.4	86	30	7.7	0.26	61
C-9	Undisturbed dolomite	2.5	95	32	11.5	0.36	60
C-10	Undisturbed dolomite	2.5	> 100	9.0	2.8	0.31	88
C-11	Disturbed prairie soil	1.8	97	29	7.8	0.27	62
C-12	Disturbed prairie soil	1.8	> 100	12	3.0	0.25	83

a/ Estimated values.

b/ Percent < 5 µm ÷ percent < 30 µm.

TABLE 4-5. PROPERTIES OF LOOSE SURFACE MATERIAL

Run	Surface type	Before erosion Loading (kg/m^2)	Before erosion Silt (%)	Before erosion Moisture (%)	After erosion Loading (kg/m^2)	After erosion Silt (%)	After erosion Moisture (%)
C-1	Undisturbed coal				-	-	-
C-2	Undisturbed coal	1,050	3.3	0.1	-	-	-
C-3	Undisturbed coal				19.4	-	-
C-4	Disturbed coal				-	-	-
C-5	Disturbed coal				-	-	-
C-6	Disturbed coal	2,180	6.5	0.9	2,220	5.2	0.6
C-7	Disturbed coal				-	-	-
C-8	Disturbed coal				1,790	7.4	0.5
C-9	Undisturbed dolomite	7,080	12.4	0.2	731	11.6	1.0
C-10	Undisturbed dolomite				2,550	8.8	0.5
C-11	Disturbed prairie soil	53,100	25.7	4.5	-	-	-
					-	-	-
C-12	Disturbed prairie soil				-	-	-

TABLE 4-6. WIND EROSION TEST RESULTS

Run	Surface type	Silt (%)	Moisture (%)	Cross-sectional average velocity in test section (mph)	Cross-sectional average velocity in test section (cm/sec)	Friction velocity (cm/sec)	Roughness height (cm)	Cumulative erosion time (min)	Suspended particulate emission factor (lb/sec/acre)	Suspended particulate emission factor (g/sec/m²)	Fine particulate emission factor (lb/sec/acre)	Fine particulate emission factor (g/sec/m²)
C-1	Undisturbed coal	3.3	0.1	35	15.6	109	0.01	10.0	1.1	0.12	0.27	0.030
C-2	Undisturbed coal	3.3	0.1	56	25.0	145	0.004	5.0	11.0	1.2	2.8	0.31
C-3	Undisturbed coal	3.3	0.1	56	25.0	145	0.004	14.3	0.47	0.053	0.12	0.013
C-4	Disturbed coal	5.8	0.7	19	8.49	53	0.003	10.0	0.21	0.023	0.051	0.0058
C-5	Disturbed coal	5.8	0.7	36	16.0	63	0.001	12.0	16.0	1.7	3.9	0.44
C-6	Disturbed coal	5.8	0.7	36	16.1	63	0.001	18.0	0.87	0.097	2.2	0.24
C-7	Disturbed coal	6.9	0.7	43	19.2	a/	a/	1.5	28.0	3.1	6.9	0.77
C-8	Disturbed coal	6.9	0.7	35	15.6	a/	a/	2.17	58.0	6.5	15.0	1.6
C-9	Undisturbed dolomite	12.0	0.6	23	10.3	53	0.003	10.0	0.31	0.035	0.077	0.0086
C-10	Undisturbed dolomite	10.6	0.4	33	14.8	186	0.19	10.0	5.0	0.56	1.3	0.14
C-11	Disturbed prairie soil	25.7	4.5	22	9.83	48	0.03	10.0	0.47	0.052	0.12	0.013
C-12	Disturbed prairie soil	25.7	4.5	24	10.7	33	0.0003	13.0	37.0	4.1	9.1	1.0

a/ Velocity profile not measured.

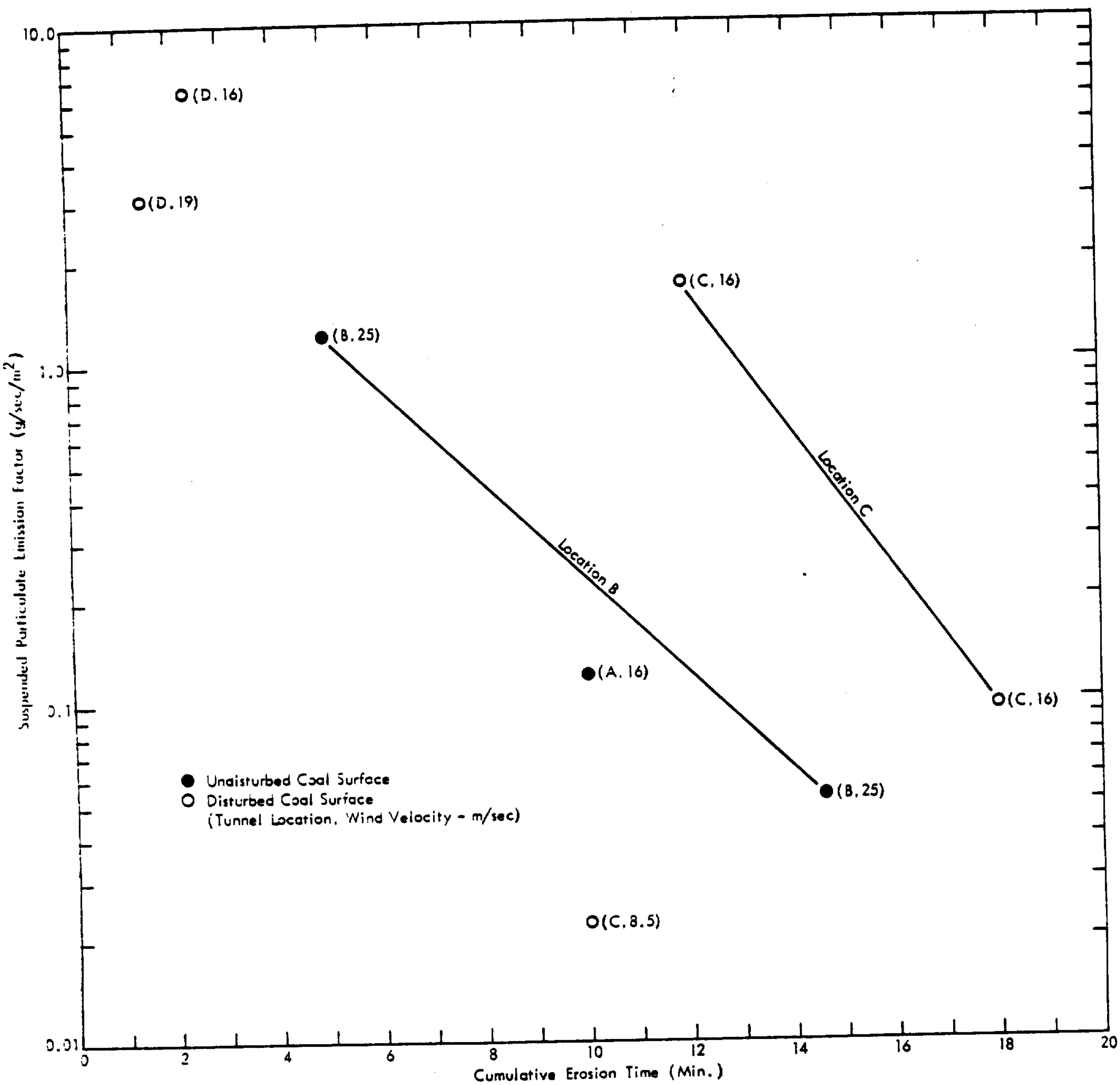


Figure 4-2. Average emission factor versus cumulative erosion time.

Additional test data are needed to define the relationship of dust emissions generated by wind erosion to the influencing parameters. These relationships, coupled with an analysis of wind flow patterns around basic storage pile configurations, would form the basis for improvement of existing emission factors.

SECTION 5.0

REFINEMENT OF EMISSION FACTOR EQUATIONS

This section presents refined emission factor equations for: (a) vehicular traffic on unpaved roads; (b) vehicular traffic on paved roads; (c) storage pile formation by continuous load-in or stacking; and (d) wind erosion of storage piles and bare ground areas. Refinements to previously developed equations have been adopted as necessary to extend the predictive capability of the equations to the expanded test data bases without loss in precision. In this way, the quality assurance (QA) ratings, as given in Figure 1-1, may be improved.

5.1 Vehicular Traffic on Unpaved Roads

Figure 5-1 shows the predictive emission factor equation for vehicular traffic on unpaved roads, as derived by multiple regression analysis of the test data shown in Table 5-1. The coefficient and the first two correction terms in Figure 5-1 are identical to the expression given in AP-42 as follows:

$$0.6\ (0.81\ s)\left(\frac{S}{30}\right)$$

which describes the emissions of particles smaller than 30 μm in Stokes diameter generated by light duty vehicles traveling on unpaved roads. The weight correction term in Figure 5-1 was developed on the basis of prior testing; however, the term was formerly raised to the 0.8 power.

Table 5-1 compares measured emissions with predicted emissions as calculated from the equation given in Figure 5-1. In addition to the test results presented in Section 3, the results of testing of traffic on haul roads at a taconite mine (Test Series I), which was performed as part of another study, have also been added to the data base. [8/] As shown in Figure 5-2, in the tests conducted on a previously inactive road (Runs I-1 through I-5), emissions approached the predicted values with successive tests. The test truck was loaded between Runs I-3 and I-4. Also,measured emissions for Runs I-7 and I-8 were significantly lower than predicted, presumably because of the considerable rainfall on the days prior to testing.

OPEN DUST SOURCE: Vehicular Traffic on Unpaved Roads
QA RATING: B for Dry Conditions
C for Annual Average Conditions

$$EF = 1.7 \left(\frac{s}{12}\right)\left(\frac{S}{48}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{d}{365}\right) \text{ kg/veh-km}$$

$$EF = 5.9 \left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{d}{365}\right) \text{ lb/veh-mi}$$

Determined by profiling of emissions from light-duty vehicles on gravel and dirt roads under dry conditions.

Estimated factor to account for mitigating effects of precipitation over period of one year.

Determined by profiling of emissions from medium- and heavy-duty vehicles on gravel and dirt roads under dry conditions.

	metric	non-metric
EF = suspended particulate emissions	kg/veh-km	lb/veh-mi
s = silt content of road surface material	%	%
S = average vehicle speed	km/hr	mph
w = average number of wheels per vehicle	–	–
W = average vehicle weight	tonnes	tons
d = dry days per year	–	–

Figure 5-1. Predictive emission factor equation for vehicular traffic on unpaved roads.

TABLE 5-1. PREDICTED VERSUS ACTUAL EMISSIONS (UNPAVED ROADS)

Run	Road surface: Type	Road surface: Silt (%)	Average vehicle speed (km/hr)	Average vehicle speed (mph)	Average vehicle weight (tonnes)	Average vehicle weight (tons)	Average No. of vehicle wheels	Emission factor a/: Predicted b/ (kg/VKT)	Emission factor a/: Predicted b/ (lb/VMT)	Emission factor a/: Actual (kg/VKT)	Emission factor a/: Actual (lb/VMT)	Predicted ÷ actual
R-1	Crushed Limestone	12	48	30	3	3	4.0	1.7	5.9	1.7	6.0	0.98
R-2		13	48	30	3	3	4.0	1.8	6.4	1.9	6.8	0.94
R-3		13	64	40	3	3	4.0	2.4	8.5	2.2	7.9	1.08
R-8	Dirt	20	48	30	3	3	4.5	2.9	10.4	2.3	8.1	1.29
R-10		5	64	40	3	3	4.0	0.93	3.3	1.1	3.9	0.85
R-13		68	48	30	3	3	4.0	9.3	33.0	9.0	32.0	1.03
A-14	Crushed slag	4.8	48	30	64	70	4.0	6.0	21.4	6.0	21.5	1.00
A-15		4.8	48	30	64	70	4.0	6.0	21.4	6.5	23.0	0.93
E-1	Dirt	8.7	23	14	31	34	9.4	4.7	16.7	3.8	13.6	1.23
E-2		8.7	26	16	31	34	8.3	5.1	18.0	3.4	12.2	1.47
E-3		8.7	26	16	21	23	6.4	3.4	12.0	4.1	14.5	0.83
F-21	Dirt/ crushed slag	9.0	24	15	3	3	4.0	0.62	2.2	0.84	3.0	0.73
F-22		9.0	24	15	3	3	4.0	0.62	2.2	0.48	1.7	1.29
F-23		9.0	24	15	4	4	4.1	0.76	2.7	0.65	2.3	1.19
F-24	Dirt/slag (Coherex®) c/	0.03	24	15	3	3	4.0	d/	d/	0.021	0.073	-
F-25		0.02	24	15	3	3	4.0	d/	d/	0.10	0.36	-
G-27	Crushed slag	5.3	35	22	15	17	11.0	3.0	10.7	3.4	12.0	0.89
G-28		5.3	37	23	11	12	9.5	2.3	8.1	2.0	7.2	1.13
G-29		5.3	39	24	8	9	7.8	1.8	6.3	1.6	5.6	1.12
G-30		4.3	40	25	13	14	8.5	2.1	7.5	2.4	8.7	0.87
G-31		4.3	47	29	7	8	6.2	1.4	6.1	1.4	5.1	0.99
G-32		4.3	35	22	27	30	13.0	3.9	14.0	4.5	16.0	0.88
I-1 e/	Crushed rock and glacial till	4.7	24	15	61	67	6.0	3.5	12.4	1.0	3.7	3.36
I-2		4.7	24	15	61	67	6.0	3.5	12.4	2.1	7.5	1.66
I-3		4.7	24	15	61	67	6.0	3.5	12.4	4.1	14.5	0.86
I-4		4.7	24	15	142	157	6.0	6.4	22.6	5.1	18.1	1.25
I-5		4.7	24	15	142	157	6.0	6.4	22.6	7.0	25.0	0.90
I-7 f/	Crushed rock (taconite/ waste)	6.1	22	13.5	107	118	6.0	6.1	21.6	3.3	11.6	1.86
I-8		6.1	22	13.5	106	117	6.0	6.1	21.5	3.3	11.6	1.85
I-9	Crushed rock (TREX) c/	1.3	21	13	100	110	6.0	d/	d/	0.56	2.0	-
I-10		1.5 g/	21	13	102	112	6.0	d/	d/	0.65	2.3	-
I-11		1.8	23	24	115	127	6.0	d/	d/	1.0	3.6	-

a/ Particles smaller than 30 µm in Stokes diameter, based on actual density of silt particles.

b/ Based on revised MRI emission factor equation.

c/ Tests performed on treated road (see text).

d/ Equation not applicable.

e/ Test Series I-1 through I-5 performed on previously inactive road.

f/ Tests performed on day following 2 days of rain totaling 1.13 in.

g/ Assumed value.

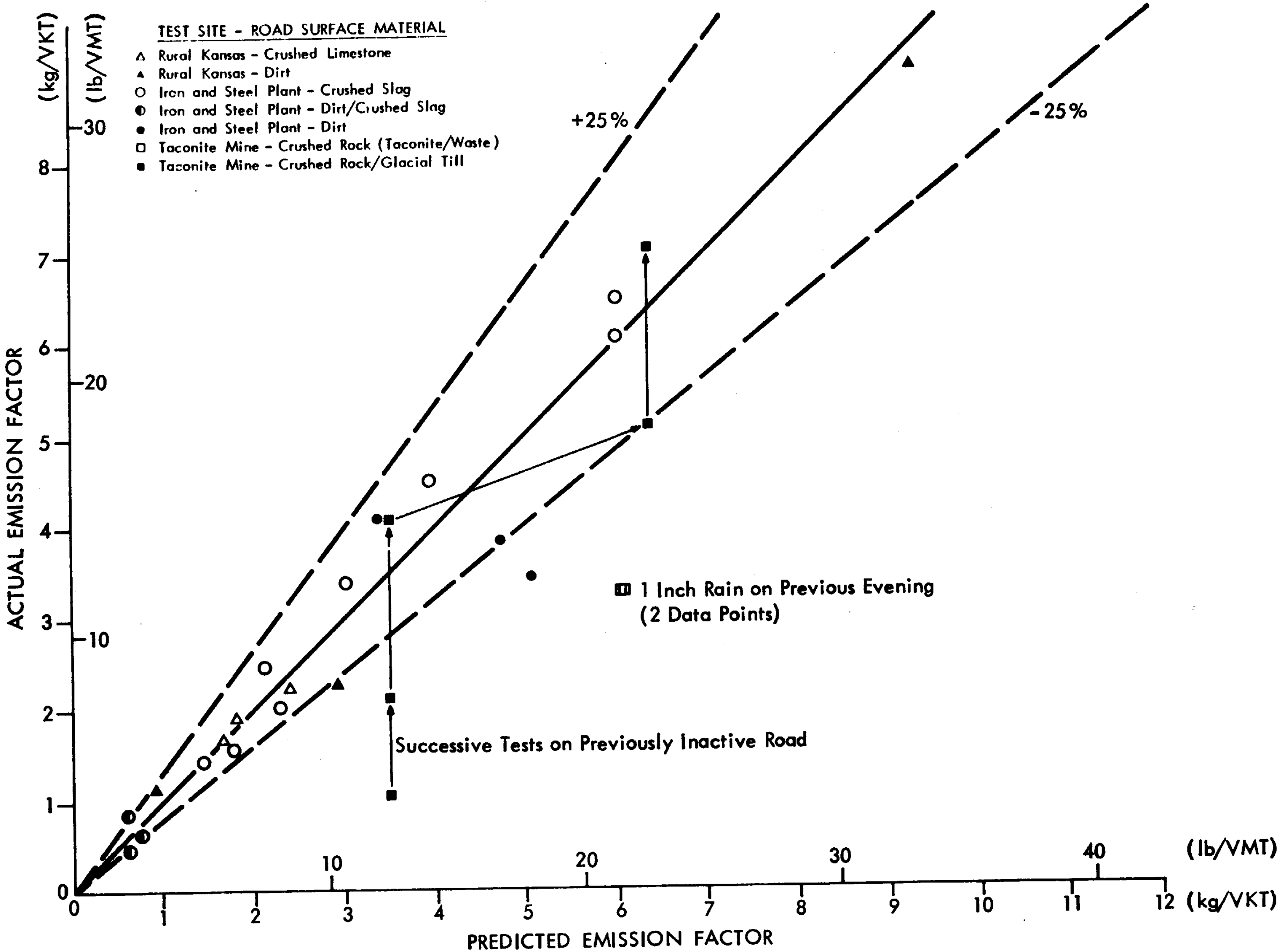


Figure 5-2. Comparison of predicted and actual emissions--untreated roads.

The wheel correction term appears in the emission factor equation for the first time. The need for this term was indicated by the fact that for Test Series E and G, the emission factor equation without a wheel correction term consistently underpredicted the measured factors. This appeared to be due to the effect of 10- and 18-wheel trucks, which comprised a substantial number of the passes in those tests. In all other test series, the vehicle mix was dominated by four- and six-wheel vehicles.

Excluding Test Series I except for Run Nos. I-3 and I-5, the revised emission factor equation presented in Figure 5-1 predicts actual test results with a precision factor of 1.48. By comparison, the precision factor for the unrevised equation from Table 2-1 is 1.66.

As indicated in Figure 5-3, there is no apparent relation between the fraction of the emissions consisting of fine particles and the average vehicle weight or the road surface composition. The average value is approximately 35% by weight.

As stated above, limited testing of the effects of a chemical dust suppressant was also conducted. Coherex® (a petroleum-based emulsion) was used to treat a dirt/slag surfaced service road traveled by light- and medium-duty vehicles at an integrated iron and steel plant. Coherex® was applied at 10% strength in water.

Figure 5-4 shows a plot of measured dust control efficiency as a function of the number of vehicle passes following application of the road dust suppressant. Control efficiency was calculated by comparing controlled emissions with uncontrolled emissions measured prior to road surface treatment. As indicated, the effectiveness of the road dust suppressant was initially high but began to decay with road usage. It should also be noted that the apparent performance of Coherex was negatively affected by tracking of material from the untreated road surface connected to the 100-ft treated segment.

Figure 5-4 also shows the results obtained from the similar testing of another chemical dust suppressant at a taconite mine. TREX (ammonium lignin sulfonate--a water soluble by-product of papermaking) was applied to the waste rock aggregate comprising the surface of a haul road. A 20 to 25% solution of TREX in water was sprayed on the road at a rate of 0.08 gal./sq yard of road surface.

Once again the effectiveness of the dust suppressant was found to be initially high, but decayed with road usage. According to taconite mine personnel, the binding effect of TREX can be partially restored by the addition of water to the road surface.

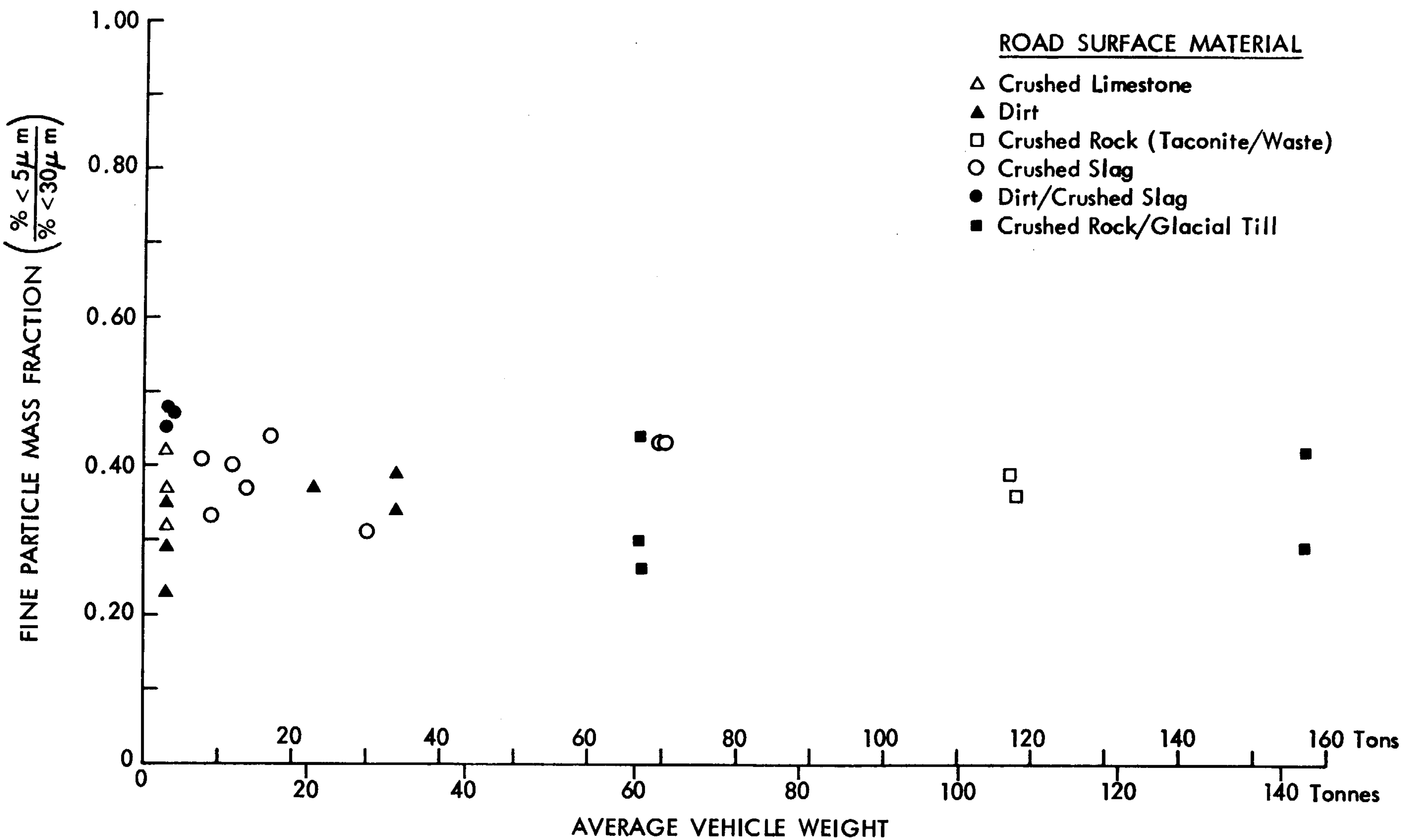


Figure 5-3. Fine particle fractions of TSP emissions.

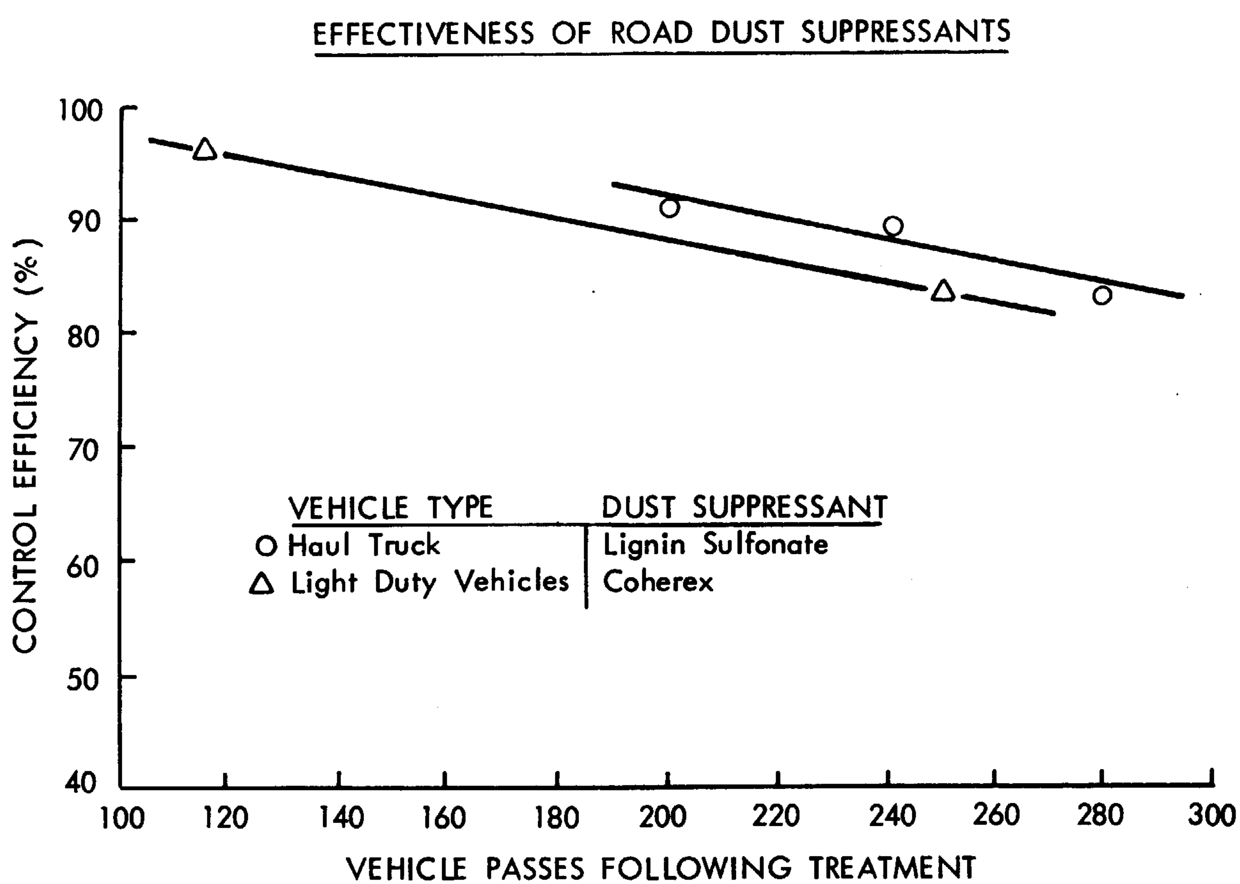


Figure 5-4. Effectiveness of road dust suppressants.

With regard to the effects of natural mitigation of road dust emissions, the final term in the emission factor equation for traffic on unpaved roads (Figure 5-1) is used to reduce emissions from dry conditions to annual average conditions. The simple assumption is made that emissions are negligible on days with measurable precipitation and are at a maximum on the rest of the days. Obviously, neither assumption is defendable alone; but there is a reasonable balancing effect. On the one hand, 0.01 in. of rain would have a negligible effect in reducing emissions on an otherwise dry, sunny day. On the other hand, even on dry days, emissions during early morning hours are reduced because of overnight condensation and upward migration of subsurface moisture; and on cloudy, humid days, road surface material tends to retain moisture. Further natural mitigation occurs because of snow cover and frozen surface conditions. In any case, further experimentation is needed to verify and refine this factor.

5.2 Vehicular Traffic on Paved Roads

Figure 5-5 shows the predictive emission factor formula for vehicular traffic on paved roads. As indicated, the coefficient and the first two correction terms were determined by field testing of emissions from traffic consisting primarily of light-duty vehicles on urban arterial roadways and on a test strip that was artificially loaded with surface dust in excess of normal levels. The vehicle weight correction term was added by analogy to the experimentally determined factor for unpaved roadways, and more testing is needed to confirm the validity of this correction term. The number of lanes comprising the traveled portion of the road and over which the surface dust loading is distributed was added as a correction term to account for the fact that emissions increase in proportion to surface dust loading.

The industrial road correction factor was added to the emission factor equation because measured emissions from medium-duty and heavy-duty vehicles traveling on paved roadways at both Plant E (tested previously) and plant F were substantially in excess of the predicted levels without such a correction term. There are several plausible explanations for the increase in dust emissions from paved roads within integrated iron and steel plants as compared to urban roads. Paved roads within integrated iron and steel plants are typically bordered by unpaved surfaces and there are no curbings to prevent traffic from traveling on these surfaces. Therefore, additional dust generation may result from:

1. Resuspension from vehicle underbodies of dust accumulated during travel over unpaved surfaces.

OPEN DUST SOURCE: Vehicular Traffic on Paved Roads
QA RATING: B for Normal Urban Traffic
C for Industrial Plant Traffic

$$EF = 0.026\, I \left(\frac{4}{n}\right)\left(\frac{s}{10}\right)\left(\frac{L}{280}\right)\left(\frac{W}{2.7}\right)^{0.7} \text{ kg/veh-km}$$

$$EF = 0.090\, I \left(\frac{4}{n}\right)\left(\frac{s}{10}\right)\left(\frac{L}{1000}\right)\left(\frac{W}{3}\right)^{0.7} \text{ lb/veh-mi}$$

Determined by profiling of emissions from traffic (mostly light-duty) on arterial roadways with values for s and L assumed.

Assumed by analogy to experimentally determined factor for unpaved roads.

Determined by profiling of emissions from industrial plant traffic yielding higher than predicted emissions, presumably due to resuspension of dust from vehicle underbodies and from unpaved road shoulders.

Determined by profiling of emissions from light-duty vehicles on roadway which was artificially loaded with known quantities of gravel fines and pulverized topsoil.

	metric	non-metric
EF = suspended particulate emissions	kg/veh-km	lb/veh-mi
I = industrial road augmentation factor (see text)	-	-
n = number of traffic lanes	-	-
s = silt content of road surface material	%	%
L = surface dust loading on traveled portion of road	kg/km	lb/mi
W = average vehicle weight	tonnes	tons

Figure 5-5. Predictive emission factor equation for vehicular traffic on paved roads.

2. Emissions from unpaved shoulders generated by the wakes of large vehicles.

3. Emissions from unpaved shoulders during passage of two large vehicles.

Also, there may be a wheel effect similar to that indicated for unpaved roads. Resuspension of dust from vehicle underbodies was visually evident at Plant E as the heavy-duty vehicles traveled from an unpaved area onto the paved roadway.

Quantification of these phenomena would require substantial additional testing with detailed analysis of site conditions and traffic patterns at test sites. For now, it is suggested that a multiplier of 7 be used with the emission factor equation when Item 1 above is readily observed and that a multiplier of 3.5 be used when the paved road (usually without curbs) is bordered by unpaved and unvegetated shoulders. These factors were determined by regression analysis of the test data for Plants E and F.

Table 5-2 compares measured emissions with predicted emissions as calculated from the equations given in Figure 5-5. The revised emission factor equation predicts actual test results with a precision factor of 3.31. This is a marked improvement over the precision factor of 14.1 associated with the unrevised equation from Table 2-1.

It should be noted that the emission factor for re-entrained dust from paved roadways contains no correction term for precipitation. Although emissions from wet pavement are reduced, increased carryover of surface material by vehicles occurs during wet periods, and emissions reach a maximum when the pavement dries. More testing would be helpful in analyzing the net effects of precipitation on re-entrained dust emissions.

5.3 Storage Pile Formation by Continuous Load-in (Stacking)

Figure 5-6 gives the predictive emission factor equation for storage pile formation (load-in) by means of a translating conveyor stacker. The equation was originally developed from the results of field testing of emissions from the stacking of pelletized and lump iron ore at Plant A.[1/] The effect of wind speed on emissions occurs presumably because of the increased atmospheric exposure of suspendable particles during the drop from the stacker to the pile.

TABLE 5-2. PREDICTED VERSUS ACTUAL EMISSIONS (PAVED ROADS)

Run	Type	Road surface dust: Loading excluding curbs[a] (kg/km)	Road surface dust: Loading excluding curbs[a] (lb/mile)	Road surface dust: No. of traffic lanes	Road surface dust: Silt (%)	I (industrial multiplier)	Average vehicle weight (tonnes)	Average vehicle weight (tons)	Emission factors[b]: Predicted[c] (kg/VKT)	Emission factors[b]: Predicted[c] (lb/VMT)	Emission factors[b]: Actual (kg/VKT)	Emission factors[b]: Actual (lb/VMT)	Predicted ÷ Actual
P-9	Pulverized topsoil[d]	1,990	7,060	4	45	1	3	3	0.82	2.9	1.0	3.7	0.78
P-10	Pulverized topsoil[d]	809	2,870	4	92	1	3	3	0.68	2.4	0.59	2.1	1.14
P-14	Gravel[d]	1,890	6,700	4	23	1	3	3	0.39	1.4	0.13	0.46	3.04
E-7	(Iron and steel) Plant E	225	800	2	5.1	7	6	7	0.26	0.93	0.21	0.76	1.22
E-8	(Iron and steel) Plant E	225	800	2	5.1	7	7	8	0.29	1.02	0.28	1.0	1.02
P-3, P-5, P-6	Urban arterial site 1[e]	45.1[f]	160[f]	4	10[f]	1	3	3	0.0039	0.014	0.0042	0.015	0.93
P-15, P-16	Urban arterial site 2[e]	42.0[f]	149[f]	4	10[f]	1	3	3	0.0037	0.013	0.0037	0.0130	1.00
F-13	Iron and steel plant	57.2	203	2	13.2	1	7	8	0.096	0.34	0.16	0.58	0.59
F-14	Iron and steel plant	57.2	203	2	13.2	1	5	5	0.068	0.24	0.056	0.20	1.20
F-15	Iron and steel plant	57.2	203	2	13.2	1	5	5	0.068	0.24	0.045	0.16	1.50
F-16	Iron and steel plant	629	2,230	2	6.8	3.5	12	13	0.76	2.7	0.70	2.5	1.08
F-17	Iron and steel plant	629	2,230	2	6.8	3.5	11	12	0.70	2.5	0.48	1.7	1.47
F-18	Iron and steel plant	629	2,230	2	6.8	1	5	5	0.11	0.39	0.14	0.48	0.81

a/ Loading distributed over traveled portion of road, i.e., traffic lanes.

b/ Particles smaller than 30 μm in Stokes diameter based on actual density of silt particles.

c/ Based on revised MRI emission factor equation.

d/ Four-lane test roadway artificially loaded.

e/ Four-lane roadway with traffic count of about 10,000 vehicles per day, mostly light-duty.

f/ Estimated value.

OPEN DUST SOURCE: Storage Pile Formation by Means of Conveyor Stacker

QA RATING: B

$$EF = 0.00090 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{2.2}\right)\left(\frac{H}{3}\right)}{\left(\frac{M}{2}\right)^2} \text{ kg/tonne}$$

$$EF = 0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{H}{10}\right)}{\left(\frac{M}{2}\right)^2} \text{ lb/ton}$$

Determined by profiling of emissions from pile stacking of pelletized and lump iron ore and coal.

	metric	non-metric
EF = suspended particulate emissions	kg/tonne of material transferred	lb/ton of material transferred
s = silt content of aggregate	%	%
M = moisture content of aggregate	%	%
U = mean wind speed	m/sec	mph
H = drop height	m	ft

Figure 5-6. Predictive emission factor equation for storage pile formations by means of conveyor stacker.

An additional adjustment term containing drop distance has been added to the emission factor equation. It is assumed that emissions are proportional to drop distance, accounting for the additional energy released on impact and the greater time of exposure during the drop.

Table 5-3 compares measured emissions with predicted emissions as calculated from the equation given in Figure 5-6. The revised emission factor equation predicts actual test results with an improved precision. However, the sample size remains too small for meaningful statistical determination of the precision factor.

Addition of the drop distance correction term aids significantly in predicting the results of Runs H-10 through H-12 although a large discrepancy remains for the first two of these runs. This may be due to lack of representativeness of the pellet moisture values for these runs. The pellets stacked during these runs comprised the last portion of a barge shipment, and moisture variations may have been substantial if water had collected in the bottom of the ship hold. The pellets were observed to be unusually wet when the samples were taken.

TABLE 5-3. PREDICTED VERSUS ACTUAL EMISSIONS (LOAD-IN BY STACKER)

Run	Type	Aggregate Silt (%)	Aggregate Moisture (%)	Drop distance (m)	Wind speed (m/sec)	Wind speed (mph)	Emission factor[a] x 10^3 Predicted[b] (kg/tonne)	Emission factor[a] x 10^3 Predicted[b] (lb/ton)	Emission factor[a] x 10^3 Actual (kg/tonne)	Emission factor[a] x 10^3 Actual (lb/ton)	Predicted ÷ Actual
A-8	Iron ore pellets	4.8	0.64	3.0	1.0	2.3	3.9	7.8	1.1	2.3	3.39
A-10	Iron ore pellets	4.8	0.64	1.5	2.0	4.5	3.7	7.5	25.0	5.0	1.50
A-11	Lump iron ore	2.8	2.0[c]	4.5	0.8	1.8	0.27	0.54	0.26	0.53	1.02
A-12	Lump iron ore	11.9	4.3	3.0	0.8	1.8	0.16	0.33	0.19	0.38	0.87
A-13	Lump iron ore	19.1	4.3	3.5	1.0	2.2	0.38	0.76	0.12	0.25	3.04
H-10	Iron ore pellets	1.4	2.6	9.0	0.7	1.5	0.13	0.27	1.1	2.3	0.12
H-11	Iron ore pellets	1.8	3.5	11.0	1.8	4.0	0.31	0.62	1.4	2.9	0.21
H-12	Iron ore pellets	1.7	3.4	12.0	2.7	6.0	0.50	1.0	1.1	2.3	0.43
F-19	Coal	5.9	4.8	5.0	1.3	3.0	0.18	0.37	0.070	0.14	2.64

a/ Particles smaller than 30 μm in Stokes diameter based on an adjusted density of 2.5 g/cm^3; multiply emission factor values by 10^{-3} to obtain units given.

b/ Based on revised MRI emission factor equation.

c/ Estimated value.

SECTION 6.0

DEVELOPMENT OF STORAGE PILE SILT AND MOISTURE VALUES

This section describes a field study of the physical properties of aggregate materials which are known to affect the atmospheric dust emissions generated by exposed materials handling operations associated with adding material to or removing material from an open storage pile and by wind erosion of the exposed surface of the pile. Aggregate materials of interest are those which are stored in significant quantities within integrated iron and steel plants, specifically iron-bearing pellets, coal, iron ore, limestone and slag. The properties of concern are moisture content and texture (silt content and cloddiness).

The testing program focused on the moisture content of storage pile surface material because of the strong dependence (inverse square) of wind-generated dust emissions on moisture, and because of the highly variable nature of this parameter. Temporal variations in surface moisture content are a function of precipitation and evaporation rates during the time of exposure. Because available emission factors are based on field tests generally performed with dry materials, seasonal and annual emission estimates must be adjusted to higher moisture values reflective of various climatic and exposure conditions.

6.1 Testing Program

The field testing program was divided into two segments: an intensive short-term program entailing daily collection of one to three samples of dormant coal and iron pellet storage piles; and a longer term program of weekly sampling of coal and iron pellet storage piles, both dormant and active.

The 1-week program of intensive sampling was conducted by MRI at Armco, Inc., Middletown, Ohio. The purpose of the intensive program was to determine the diurnal variation of storage pile surface moisture.

The program of weekly sampling and analysis of coal and iron pellet-storage piles, extending over a period of 2 to 3 months, was conducted by personnel at three cooperating plants: Armco, Inc., Middletown, Ohio; Bethlehem Steel, Bethlehem, Pennsylvania; and Inland Steel, East Chicago, Indiana. The purpose of this extended sampling program was to gather data for use in developing a relationship between daily storage pile surface moisture, after normalization to remove the daytime portion of the diurnal moisture cycle, and precipitation/evaporation parameters.

The specific sampling program for each plant was formulated during a presurvey, taking into account: the materials stored at the plant, both live (active) storage and dead (inactive) storage; and the accessibility of the material for sampling, including the load-in and load-out streams. The materials of greatest interest were pellets and coal although iron ore, limestone, and other materials were also considered for sampling.

The procedures developed by MRI for sampling of aggregate storage piles and for silt and moisture analysis of collected samples are reproduced in Appendix B. Appropriate meteorological data for the sampling locations and periods were obtained by MRI from area weather stations.

6.2 Test Results--Intensive Study

Table 6-1 lists the results of the 1-week intensive field study conducted by MRI at Armco's Middletown works. No rainfall occurred during or within 4 days previous to the sampling period, and the sampling days exhibited similar meteorology.

The data in Table 6-1 may be used to determine the diurnal variation in surface moisture content for a precipitation-free period. During the summer months, an increase in pile surface moisture during nighttime hours may be expected due to condensation and/or diffusion of moisture from wetter material within the pile; however, during daytime hours, surface moisture normally decreases because of increased evaporation.

By averaging the moisture values for the morning, mid-day, and afternoon sampling times, the curves in Figure 6-1 may be constructed. The fact that the curve for Armco coal lies below the curve for Armco pellets indicates that coal has a greater capability than pellets for moisture retention. This is consistent with the substantially larger quantity of fines in crushed coal as compared to iron-bearing pellets.

The curves shown in Figure 6-2 for coal and pellets have been normalized to unit moisture at 1400 hours (2 p.m.). In this way, moisture values for sampling times between about 0930 hours and 1400 hours may be adjusted to the equivalent 1400 value. This allows potential correlation of "daily" moistures with precipitation events.

TABLE 6-1. SURFACE MOISTURE VARIATION IN DORMANT PILES AT ARMCO MIDDLETOWN WORKS

Material	Sampling date	Time (EDT)	Moisture content (%)	Relative Humidity (%)	Temperature (°C)	Temperature (°F)	Cloud cover (%)
Coal	7/17/78	1415	1.51	-	-	-	0
Coal	7/18/78	0930	2.89	-	-	-	0
Coal	7/18/78	1130	2.11	-	-	-	0
Coal	7/18/78	1415	1.62	55	30	86	20
Coal	7/19/78	0930	1.55	72	26	78	0
Coal	7/19/78	1100	1.67	54	30	86	0
Coal	7/19/78	1400	1.57	48	33	92	0
Coal	7/20/78	0930	1.27	72	27	81	0
Coal	7/20/78	1115	1.63	53	32	90	0
Coal	7/20/78	1315	1.12	48	36	97	5
Coal	7/21/78	0900	1.50	84	27	81	100
Pellets	7/17/78	1415	-	-	-	-	0
Pellets	7/18/78	1000	0.95	-	-	-	0
Pellets	7/18/78	1130	0.40	-	-	-	0
Pellets	7/18/78	1445	0.21	55	30	86	30
Pellets	7/19/78	0945	1.26	72	26	78	0
Pellets	7/19/78	1115	0.21	54	30	86	0
Pellets	7/19/78	1415	0.43	48	33	92	0
Pellets	7/20/78	0945	0.19	72	27	81	0
Pellets	7/20/78	1130	0.26	53	32	90	0
Pellets	7/20/78	1330	0.05	48	36	97	20
Pellets	7/21/78	0915	0.37	84	27	81	100

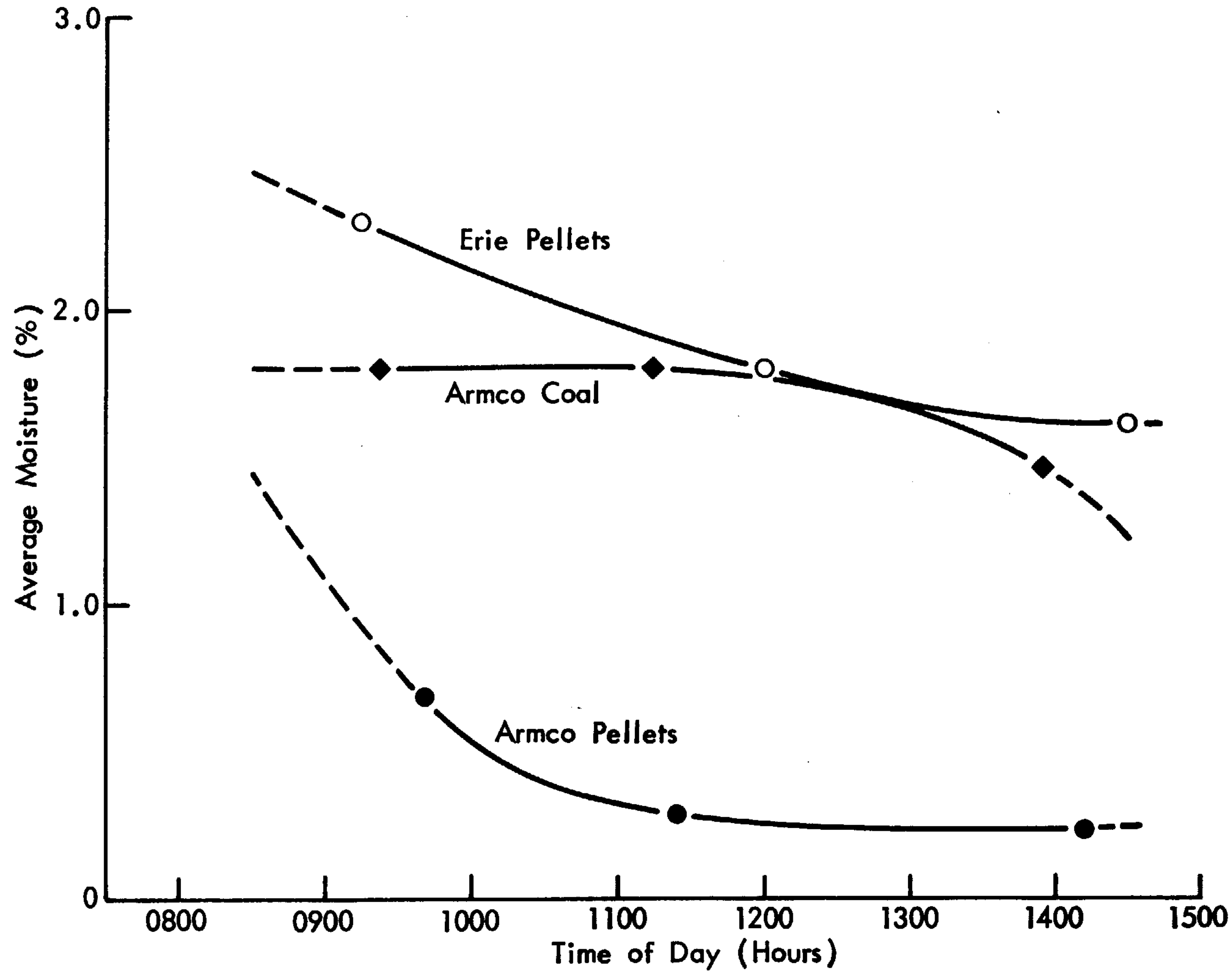


Figure 6-1. Observed storage pile moisture versus time of day.

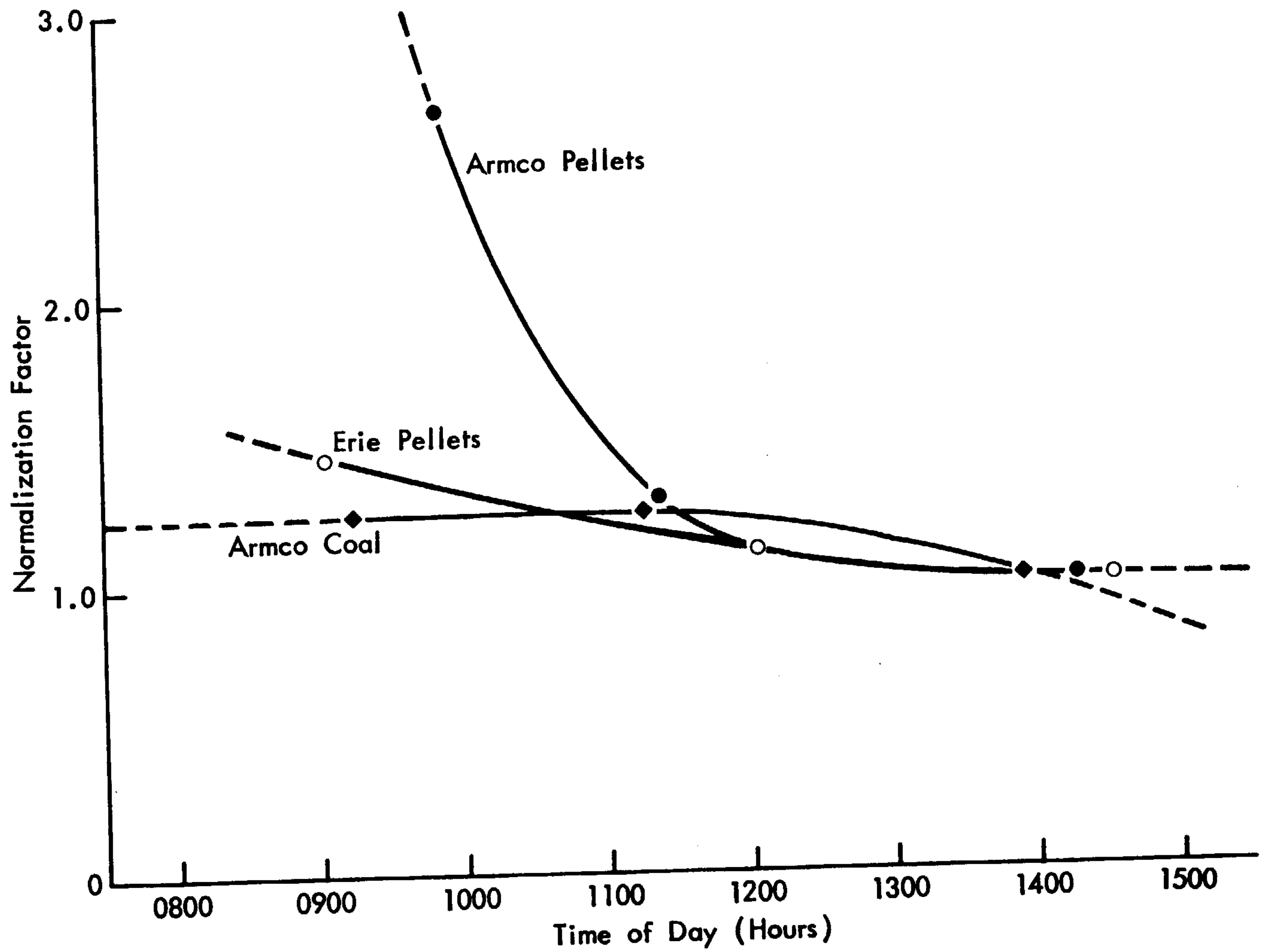


Figure 6-2. Storage pile moisture normalization factor (= 1.0 for 1400 hr LDT).

It should be emphasized that the normalization curves derived from the intensive study apply only to geographical locations and times of year which exhibit similar evaporative conditions. For example, the lower curve for Erie iron pellets in Figure 6-2 was derived from moisture measurements corresponding to a significantly lower daytime evaporation rate; thus, that curve shows a much smaller moisture decay rate.[8/]

6.3 Test Results--Extended Study

Tables 6-2 through 6-4 present the results of weekly storage pile sampling conducted by Armco, Inc., Bethlehem Steel and Inland Steel, respectively. Precipitation data for the 4 days previous to the day of sampling were obtained from nearby weather stations. However, the nearest evaporation observation sites were 20 or more miles from the storage piles.

It should be noted that the 24-hour periods preceding precipitation observation ended at 0800 hours at the Middletown station and at 0900 hours at the Gary station. Therefore, the precipitation "day" preceding sampling at these two locations extended to the morning of the day on which sampling occurred. Fortunately, with few exceptions, no precipitation occurred on the "day" of sampling. Because hourly precipitation data were available at Bethlehem, the day preceding sampling was taken to be the 24-hour period ending at 1400 hours on the sampling day.

A number of correlations of daytime surface moisture levels to precipitation and evaporation data were attempted for various site-specific data sets. The following conclusions were derived from this effort:

1. Correlations were improved, as expected, by treating coal and pellets separately and by separating data from active and dormant storage piles.

2. The strongest correlation was found to exist between weighted precipitation for the 4 days prior to sampling (as described below), and normalized storage pile surface moisture.

3. No correlation of storage pile surface moisture with evaporation as a separate variable was found.

4. The data from Inland Steel were not amenable to correlation, possibly because of inconsistency between Inland's standard sampling and analysis methods and those recommended by MRI and adopted by the other two plants.

TABLE 6-2. STORAGE PILE MOISTURE AND PRECIPITATION/EVAPORATION (ARMCO, INC., MIDDLETOWN, OHIO)

	Sampling		Precipitation (mm)[a]					Evaporation (mm)[b]					Moisture content of surface aggregate (%)	
	1978		Day previous				Weighted	Day previous				Weighted		
Aggregate	date	Time	1	2	3	4	value	1	2	3	4	value	Observed	Normalized
Active coal	7/24	0930	20.3	0	14.0	0	22.4	16.8	7.6	7.9	5.8	21.1	5.8	4.7
	8/1	1000	0	27.9	11.4	0	11.9	4.8	3.6	5.1	6.6	7.1	2.8	2.3
	8/7	0945	1.8	0.8	0	0	2.0	3.8	0.8	10.4	3.0	5.6	3.8	3.1
	8/18	0935	2.5	0.5	0	0	2.8	2.3	4.3	6.4	4.8	5.1	1.3	1.1
	8/21	1010	0	3.8	-	2.5	1.5	3.8	7.4	8.6	2.3	7.9	1.5	1.2
	8/28	1010	19.0	0.8	0	0	19.3	3.8	5.1	1.8	8.6	6.4	5.0	4.0
Dormant coal	7/24	1000	20.3	0	14.0	0	22.4	16.8	7.6	7.9	5.8	21.1	8.0	6.5
	8/1	1025	0	27.9	11.4	0	11.9	4.8	3.6	5.1	6.6	7.1	4.4	3.5
	8/7	1015	1.8	0.8	0	0	2.0	3.8	0.8	10.4	3.0	5.6	4.2	3.4
	8/21	1040	0	3.8	-	2.5	1.5	3.8	7.4	8.6	2.3	7.9	1.1	0.9
	8/28	1025	19.0	0.8	0	0	19.3	3.8	5.1	1.8	8.6	6.4	7.6	6.1
Active pellets	7/18	1420	0	0	0	0	0	7.4	8.4	7.9	7.9	11.9	2.8	2.8
	7/28	0830	0	0	0	20.6	1.0	5.8	7.4	4.8	7.6	9.7	1.3	0.4
	8/4	0830	0	3.9	0.5	0	4.6	3.0	3.6	3.6	4.8	5.1	2.5	0.8
	8/11	0930	0	13.5	0	0	5.1	3.8	5.1	4.8	4.1	6.6	2.4	0.8
	8/18	0910	2.5	0.5	0	0	2.8	2.3	4.3	6.4	4.8	5.1	4.4	1.5
	8/25	1200	0	0	0	0	0	8.6	2.5	3.8	6.9	10.4	0.66	0.6
	8/31	1200	41.9	1.3	5.1	19.0	43.9	4.8	2.5	5.6	3.8	6.9	5.3	4.7
Dormant pellets	7/18	1445	0	0	0	0	0	7.4	8.4	7.9	7.9	11.9	0.21	0.2
	7/28	0900	0	0	0	20.6	1.0	5.8	7.4	4.8	7.6	9.7	1.2	0.4
	8/4	0900	0	3.9	0.5	0	4.6	3.0	3.6	3.6	4.8	5.1	4.7	1.6
	8/11	1000	0	13.5	0	0	5.1	3.8	5.1	4.8	4.1	6.6	4.4	1.8

a/ From nonofficial Middletown rain gauge data.

b/ From Deer Creek Lake, Ohio, evaporation station.

TABLE 6-3. STORAGE PILE MOISTURE AND PRECIPITATION/EVAPORATION (BETHLEHEM STEEL, BETHLEHEM, PENNSYLVANIA)

Aggregate	Sampling 1978 date	Sampling Time	Precipitation (mm)[a/] Day Previous 1	2	3	4	Precipitation Weighted value	Evaporation (mm)[b/] Day Previous 1	2	3	4	Evaporation Weighted value	Moisture content of surface aggregate (%) Observed	Normalized
Dormant coal	9/14	1430	0	0	0	0.5	0	2.8	5.3	2.8	1.3	5.8	5.9	6.3
	9/25	1430	0	0	12.7	4.3	0.5	2.5	2.0	4.3	1.5	4.3	5.2	5.6
	9/29	1400	0	0	0	0	0	2.3	3.0	2.5	3.3	4.3	4.8	4.8
	11/10	1430	0	0	0	0	0	-	-	-	-	-	4.6	4.9
Dormant pellets	9/14	1400	0	0	0	0.5	0	2.8	5.3	2.8	1.3	5.8	2.6	2.6
	9/25	1500	0	0	1.3	4.3	0.5	2.5	1.3	4.3	1.5	4.3	2.2	2.2
	9/29	1430	0	0	0	0	0	2.3	3.0	2.5	3.3	4.3	1.8	1.8
	11/10	1400	0	0	0	0	0	-	-	-	-	-	1.3	1.3

a/ From Allentown - Bethlehem National Weather Service office.

b/ From Landisville 2NW, Pennsylvania, evaporation station.

TABLE 6-4. STORAGE PILE MOISTURE AND PRECIPITATION/EVAPORATION (INLAND STEEL, EAST CHICAGO, ILLINOIS)

Aggregate	Sampling 1978 date	Sampling Time	Precipitation (mm)[a/] Day Previous 1	2	3	4	Weighted value	Evaporation (mm)[b/] Day Previous 1	2	3	4	Weighted value	Moisture content of surface aggregate (%) Observed	Normalized
Iron pellets	7/26	1100	0	0	17.8	5.6	1.8	2.8	2.3	2.5	4.8	4.3	4.5	3.0
	8/4	1100	23.4	0	5.1	0	15.2	3.0	1.3	2.0	5.1	4.1	3.5	2.3
	8/9	1100	0	0	0	0	0	4.6	2.8	2.8	6.4	6.4	4.6	3.1
	8/17	1100	17.8	0	0	1.3	11.2	8.9	3.0	2.8	0.5	10.4	3.3	2.2
	8/23	1100	0	0	0	1.5	0	2.0	1.3	3.6	4.1	3.3	1.3	0.9
	8/30	1100	0	2.0	1.8	0	0.76	3.8	1.3	2.8	2.3	4.8	3.9	2.6
	9/6	1100	0	0	0	0	0	2.0	3.3	4.3	2.3	4.1	1.9	1.3
	9/13	1100	0.51	0	0	0	0.25	-	-	-	3.0	-	4.85	3.2
	9/20	1100	8.6	25.7	0	0	11.4	0.8	4.1	2.5	2.0	2.8	4.38	2.9
	9/27	1100	0	0	0	0	0	0.8	2.0	1.0	1.5	1.8	0.2	0.1
	10/5	1100	-	-	-	-	-	0.3	2.8	1.8	1.8	1.5	4.8	3.2
	10/11	1100	-	-	-	-	-	1.5	1.8	1.0	0.8	-	1.6	1.1
Coal	7/26	1100	0	0	17.8	5.6	1.8	2.8	2.3	2.5	4.8	4.3	6.0	4.8
	8/4	1100	23.4	0	5.1	0	15.2	3.0	1.3	2.0	5.1	4.1	3.8	3.0
	8/9	1100	0	0	0	0	0	4.6	2.8	2.8	6.4	6.4	5.7	4.6
	8/17	1100	17.8	0	0	1.3	11.2	8.9	3.0	2.8	0.5	10.4	8.9	7.1
	8/23	1100	0	0	0	1.5	0	2.0	1.3	3.6	4.1	3.3	0.82	0.7
	8/30	1100	0	2.0	1.8	0	0.76	3.8	1.3	2.8	2.3	4.8	1.32	1.1
	9/6	1100	0	0	0	0	0	2.0	3.3	4.3	2.3	4.1	1.33	1.1
	9/13	1100	0.51	0	0	0	0.25	-	-	-	3.0	0	9.22	7.4
	9/20	1100	8.6	25.7	0	0	11.4	0.8	4.1	2.5	2.0	2.8	3.47	2.8
	9/27	1100	0	0	0	0	0	0.8	2.0	1.0	1.5	1.8	1.19	1.0
	10/5	1100	-	-	-	-	-	0.3	2.8	1.8	1.8	1.5	5.37	4.3
	10/11	1100	-	-	-	-	-	1.5	1.8	1.0	0.8	-	4.56	3.6

a/ From Gary, Indiana, official rain guage.

b/ From Valparaiso, Indiana, water works.

The weighted precipitation (P) value takes into account that the more recent the precipitation, the stronger its effect on the observed storage pile moisture. It is calculated as follows:

$$P_w = \sum_{n=1}^{4 \text{ days}} P_n \exp[-(n-0.5)]$$

Thus, the residual effect of precipitation decreases exponentally and is neglected after 4 days.

As shown in Figures 6-3 and 6-4, a high degree of correlation between storage pile surface moisture and weighted precipitation was found for the Armco data. For both coal and pellets, the surface moisture levels of active piles were less sensitive to precipitation than the dormant piles. This is because the surfaces of the active piles are disturbed on a daily basis. Unfortunately, all of the Bethlehem samples were collected on days with $P_w = 0$, so that correlation of Bethlehem moisture values with weighted precipitation was meaningless.

The question might be raised as to why storage pile surface moisture correlated well with weighted precipitation but very poorly with evaporation as a separate variable. There are several possible explanations for this finding:

1. The evaporation in data were obtained from weather stations located several miles from the test piles.

2. Pan evaporation measured under full exposure conditions does not reflect microclimate effects around storage piles resulting from shading, wind channeling, etc.

3. Moisture transfer between the interior of a pile and the pile surface may contribute substantially to the surface moisture balance.

The regression equations given in Figures 6-3 and 6-4 may be used to determine monthly, seasonal or annual values of surface moisture for coal or pellet piles. This would be accomplished by substitution of weighted precipitation values calculated from daily precipitation data for the geographical area being considered. It would also be necessary to relate average normalized moisture for 1400 hours to the value for the time of day which represents the daily average.

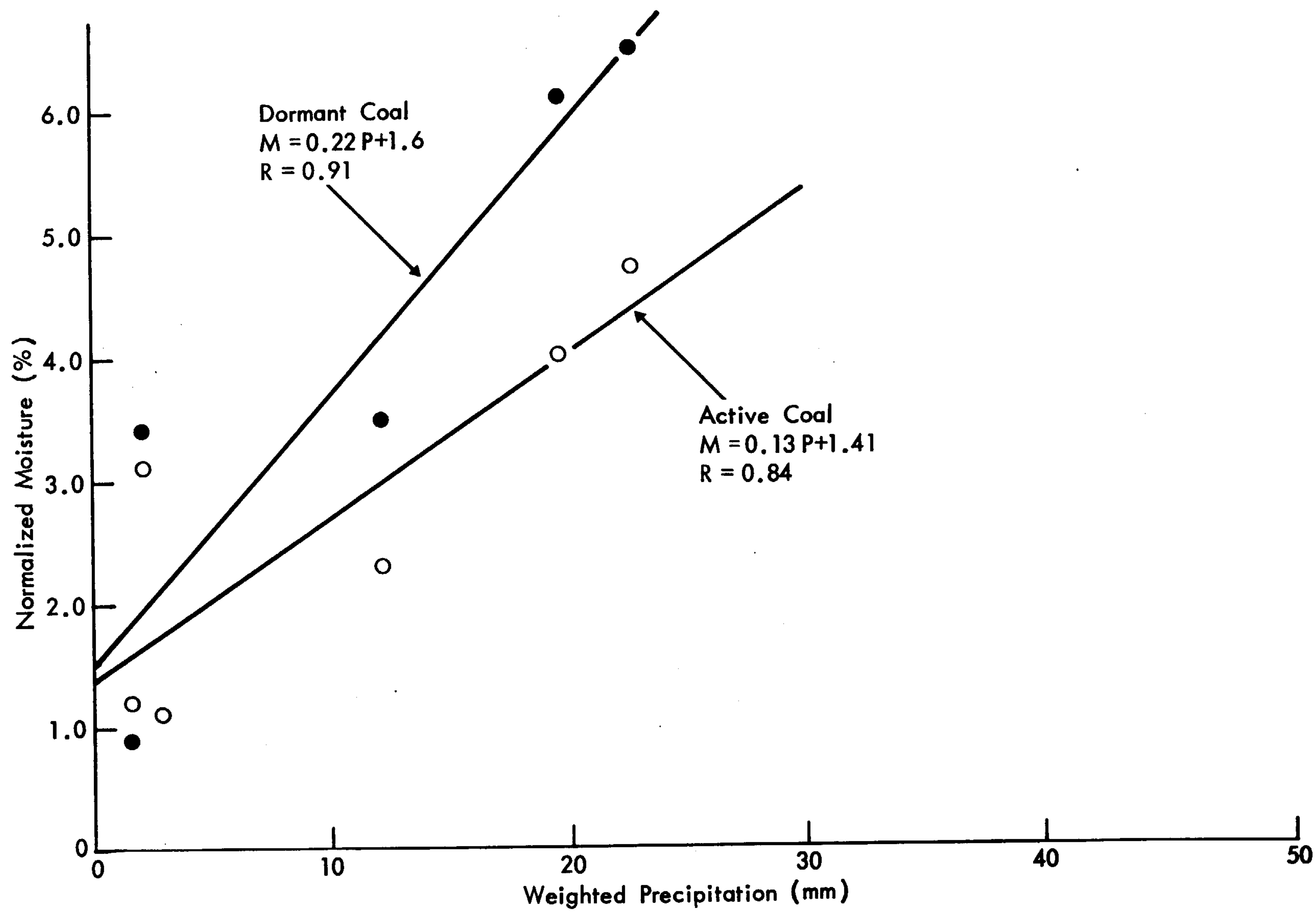


Figure 6-3. Correlation of normalized moisture with weighted precipitation--coal piles.

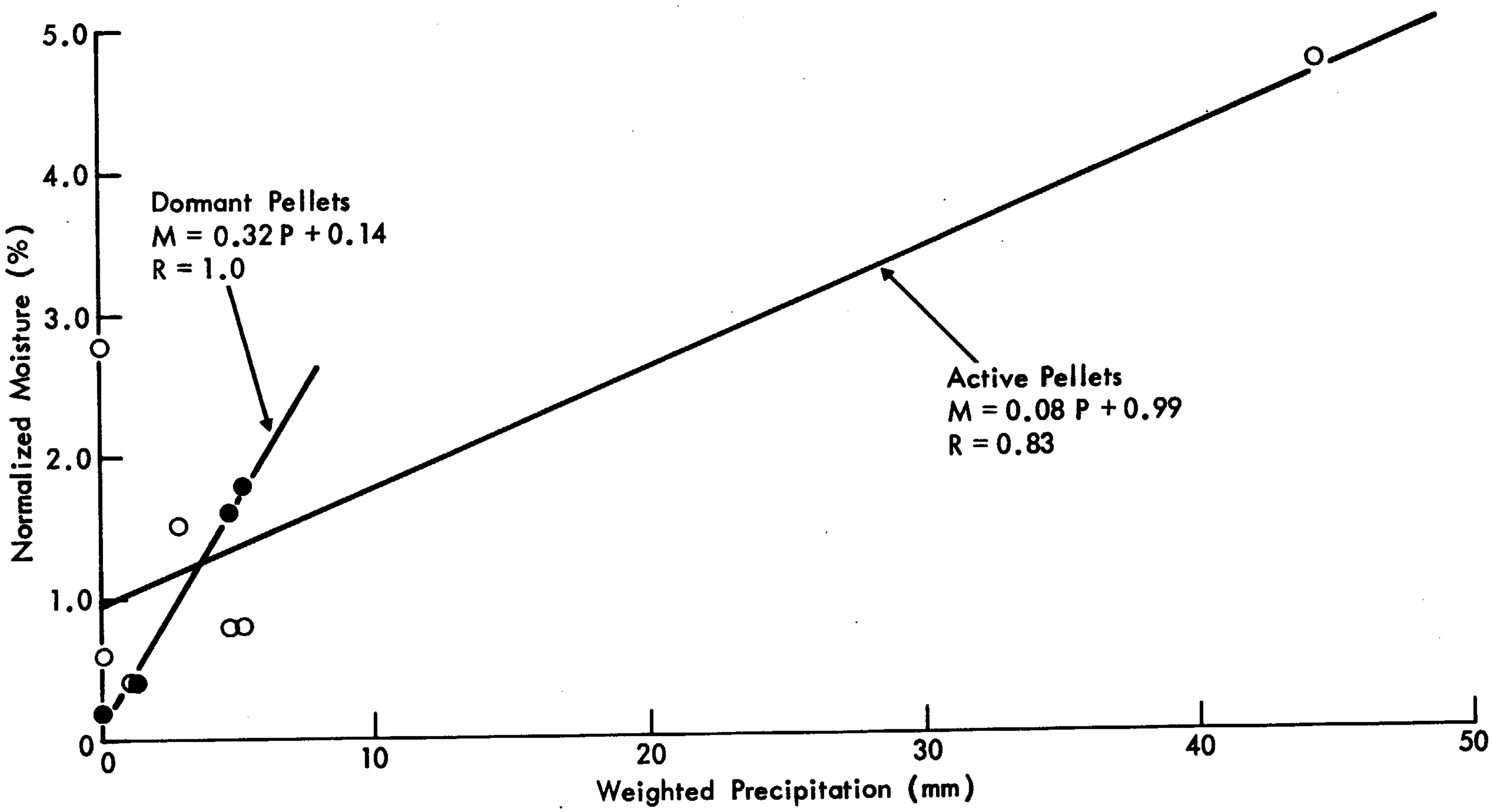


Figure 6-4. Correlation of normalized moisture with weighted precipitation--iron pellet piles.

SECTION 7.0

ADDITIONAL RESEARCH NEEDS

Listed below are suggestions for future work on open dust sources found within the iron and steel industry as well as other industries which involve extensive materials handling. These suggestions reflect our assessment of the highest priority research needs, based in part on the nature of frequent requests for information.

7.1 Emission Inventory Handbook

The MRI predictive emission factor equations are receiving widespread application in connection with requirements for State Implementation Plan revisions. Many requests for guidance on the selection of correction parameter values and on the determination of source extent values for specific industrial applications are being received. The preparation of a handbook for emission inventory of fugitive dust sources would provide a much needed resource for work in this area. The handbook would describe schemes for calculating correction parameters and source extent values for various source categories. In addition, typical correction parameter values would be provided for common types of emitting surfaces (road surface materials, stored aggregates, etc.).

7.2 Unpaved Road Dust Controls

As shown in Section 2, unpaved roads constitute the major source of fugitive dust within industries which handle large quantities of aggregate materials. Currently, the reliability of unpaved road emission estimates is limited primarily by lack of data on road dust control measures. The most common control practice is watering. Very little data exist on the effectiveness of watering as a function of road surface, traffic, and meteorological conditions. Clearly there is a need for accurate quantification of the time-dependent effectiveness of typical watering programs used in industry. The MRI Exposure Profiler is ideal for this application. Undoubtedly, this testing would shed substantial light on the effects of parameters (droplet size, coverage, intensity of application, etc.) which can be used to optimize watering. The information in Section 6 on storage pile moisture cycles would provide information pertinent to the proposed study. As part of this study, some testing of chemical dust suppressants might also be conducted.

7.3 Wind Erosion of Exposed Aggregate Materials

The information presented in Section 4.0 is useful in defining the complex principles underlying the phenomena of wind erosion of exposed aggregate materials. This work has involved *in situ* testing with a portable wind tunnel, which provides the distinct advantage of sampling under controlled conditions without prior disturbance of the natural surface condition. Although wind erosion of active (disturbed) materials is a major source of fugitive dust, presently available emissions data are far too limited to characterize this source. Additional fundamental investigation would provide valuable information as to physical parameters which enter into the wind erosion process, and direct means for minimizing emissions without the need for added controls.

SECTION 8.0

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2. Cowherd, C., Jr., K. Axetell, Jr., C. M. Guenther, and G. Jutze. Development of Emission Factors for Fugitive Dust Sources. Final Report, Midwest Research Institute for U.S. Environmental Protection Agency, Publication No. EPA-450/3-74-037, NTIS No. PB 238262/AS, June 1974.

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7. Gillette, Dale. Tests with a Portable Wind Tunnel for Determining Wind Erosion Threshold Velocities. Atmospheric Environment, 12:2309, 1978.

8. Cuscino, T., Jr. Taconite Mining Fugitive Emissions Study. Final Report, Midwest Research Institute for Minnesota Pollution Control Agency, June 7, 1979.

SECTION 9.0

GLOSSARY

Activity Factor - Measure of the intensity of aggregate material disturbance by mechanical forces in relation to reference activity level defined as unity.

Cloddiness - The mass percentage of an aggregate sample smaller than 0.84 mm in diameter as determined by dry sieving.

Cost-Effectiveness - The cost of control per pound of reduced fine particle emissions.

Dry Day - Day without measurable (0.01 in. or more) precipitation.

Dry Sieving - The sieving of oven-dried aggregate by passing it through a series of screens of descending opening size.

Duration of Storage - The average time that a unit of aggregate material remains in open storage, or the average pile turnover time.

Dust Suppressant - Water or chemical solution which, when applied to an aggregate material, binds suspendable particulate to larger particles.

Exposed Area, Effective - The total exposed area reduced by an amount which reflects the sheltering effect of buildings and other objects that retard the wind.

Exposed Area, Total - Outdoor ground area subject to the action of wind and protected by little or no vegetation.

Exposure - The point value of the flux (mass/area-time) of airborne particulate passing through the atmosphere, integrated over the time of measurement.

Exposure, Filter - Exposure determined from filter catch within an exposure sampler.

Exposure, Integrated - The result of mathematical integration of spatially distributed measurements of airborne particulate exposure downwind of a fugitive emissions source.

Exposure, Total - Exposure calculated from both filter catch and settling chamber catch within an exposure sampler.

Exposure Profiling - Direct measurement of the total passage of airborne particulate immediately downwind of the source by means of simultaneous multipoint isokinetic sampling over the effective cross-section of the fugitive emissions plume.

Exposure Sampler - Directional particulate sampler with settling chamber and backup filter, having variable flow control (5 to 20 cfm) to provide for isokinetic sampling at wind speeds of 4 to 15 mph.

Friction Velocity - A measure of wind shear stress on an exposed surface as determined from the slope of the logarithmic velocity profile near the surface.

Fugitive Emissions, Total - All particles from either open dust or process fugitive sources as measured immediately adjacent to the source.

Fugitive Emissions - Emissions not originating from a stack, duct, or flue.

Load-in - The addition of material to a storage pile.

Load-out - The removal of material from a storage pile.

Materials Handling - The receiving and transport of raw, intermediate and waste materials, including barge/railcar unloading, conveyor transport and associated conveyor transfer and screening stations.

Moisture Content - The mass portion of an aggregate sample consisting of unbound moisture as determined from weight loss in oven drying with correction for the estimated difference from total unbound moisture.

Particle Diameter, Aerodynamic - The diameter of a hypothetical sphere of unit density (1 g/cm^3) having the same terminal settling velocity as the particle in question, regardless of its geometric size, shape and true density.

Particle Diameter, Stokes - The diameter of a hypothetical sphere having the same density and terminal settling velocity as the particle in question, regardless of its geometric size and shape.

Particle Drift Distance - Horizontal distance from point of particle injection into the atmosphere to point of removal by contact with the ground surface.

Particulate, Fine - Airborne particulate smaller than 5 µm in Stokes diameter.

Particulate, Suspended - Airborne particulate smaller than 30 micrometers, in Stokes diameter, the approximate cut-off diameter for the capture of particulate matter by a standard high-volume sampler, based on a particle density of 2 to 2.5 g/cm^3.

Precipitation-Evaporation Index - A climatic factor equal to ten times the sum of 12 consecutive monthly ratios of precipitation in inches over evaporation in inches, which is used as a measure of the annual average moisture of exposed material on a flat surface of compacted aggregate.

Precision Factor - The precision factor (f) for an emission factor equation is defined such that the 95% confidence interval for a predicted emission factor value (P) extends from P/f to Pf; the precision factor is determined by exponentiating twice the standard deviation of the differences between the natural logarithms of the predicted and observed emission factors.

Road, Paved - A roadway constructed of rigid surface materials, such as asphalt, cement, concrete and brick.

Road, Unpaved - A roadway constructed of non-rigid surface materials such as dirt, gravel (crushed stone or slag), and oil and chip surfaces.

Road Surface Dust Loading - The mass of loose surface dust on a paved roadway, per length of roadway, as determined by dry vacuuming.

Road Surface Material - Loose material present on the surface of an unpaved road.

Roughness Height - A measure of the roughness of an exposed surface as determined from the y-intercept of the logarithmic velocity profile near the surface.

Source, Open Dust - Any source from which emissions are generated by the forces of wind and machinery acting on exposed aggregate materials.

Source, Process Fugitive Emissions - An unducted source of emissions involving a process step which alters the chemical or physical characteristics of a material, frequently occurring within a building.

Silt Content - The mass portion of an aggregate sample smaller than 75 micrometers in diameter as determined by dry sieving.

Spray System - A device for applying a liquid dust suppressant in the form of droplets to an aggregate material for the purposes of controlling the generation of dust.

Storage Pile Activities - Processes associated with aggregate storage piles, specifically, load-in, vehicular traffic around storage piles, wind erosion from storage piles, and load-out.

Surface Erodibility - Potential for wind erosion losses from an unsheltered area, based on the percentage of erodible particles (smaller than 0.85 mm in diameter) in the surface material.

Surface Stabilization - The formation of a resistive crust on an exposed aggregate surface through the action of a dust suppressant, which suppresses the release of otherwise suspendable particles.

Vehicle, Heavy Duty - A motor vehicle with a gross vehicle traveling weight exceeding 30 tons.

Vehicle, Light Duty - A motor vehicle with a gross vehicle traveling weight is less than or equal to 3 tons.

Vehicle, Medium Duty - A motor vehicle with a gross vehicle traveling weight is greater than 3 tons, but less than 30 tons.

Windbreak - A natural or man-made object which reduces the ambient wind speed in the immediate locality.

SECTION 10.0

ENGLISH TO METRIC UNIT CONVERSION TABLE

English unit	Multiplied by	Metric unit
lb/T	0.500	kg/t
lb/vehicle mile	0.282	kg/vehicle km
lb/acre yr	112	kg/km^2 yr
lb	0.454	kg
T	0.907	t
mph	0.447	m/s
mile	1.61	km
ft	0.305	m
acre	0.00405	km^2

APPENDIX A

EMISSION FACTOR CALCULATION PROCEDURES

This appendix summarizes the calculation procedures used to derive the emission factors presented in this report. Example calculations are presented for each source category.

1.0 Emission Rate

The passage of airborne particulate, i.e., the quantity of emissions per unit of source activity, is obtained by spatial integration (over the effective cross-section of the plume) of distributed measurements of exposure (mass/area). The exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement.

Mathematically stated, the total mass emission rate (R) is given by:

$$R = \frac{1}{t} \iint_A \frac{m(h,w)}{a}$$

where
- m = dust catch by exposure sampler after subtraction of background
- a = intake area of sampler
- t = sampling time
- h = vertical distance coordinate
- w = lateral distance coordinate
- A = effective cross-sectional area of plume

In the case of a line source or moving point source with an emission height near ground level, the mass emission rate per source length unit being sampled is given by:

$$R = \frac{W}{t} \int_0^H \frac{m(h)}{a} \, dh$$

where
- W = width of the sampling intake
- H = effective extent of the plume above ground

In order to obtain an accurate measurement of airborne particulate exposure, sampling must be conducted isokinetically; e.g., flow streamlines enter the sampler rectilinearly. This means that the sampling intake must be aimed directly into the wind and, to the extent possible, the sampling velocity must equal the local wind speed. The first condition is by far the more critical.

2.0 Isokinetic Corrections

If it is necessary to sample at a nonisokinetic flow rate (e.g., to obtain sufficient sample under light wind conditions), the following multiplicative factors should be used to correct measured exposures and concentrations to corresponding isokinetic values:

	Fine Particles ($d < 5\ \mu m$)	Coarse Particles ($d > 50\ \mu m$)
Exposure Multiplier	U/u	1
Concentration Multiplier	1	u/U

where:
u = sampling intake velocity at a given elevation
U = wind velocity at same elevation as u
d = aerodynamic (equivalent sphere) particle diameter

For a particle-size distribution containing a mixture of fine, intermediate, and coarse particles, the isokinetic correction factor is an average of the above factors weighted by the relative proportion of coarse and fine particles. For example, if the mass of fine particles in the distribution equals twice the mass of the coarse particles, the weighted isokinetic correction for exposure would be:

$$1/3\ [2(U/u) + 1]$$

3.0 Particle Size Distribution

As stated above, a cyclone preseparator (Sierra Instruments Model 230-CP) was used in conjunction with a high-volume cascade impactor (Sierra Instruments Model 235) to measure airborne particle size distribution. The purpose of the preseparator was to remove coarse particles which otherwise would tend to bounce through the impactor to the back-up filter, thereby causing fine particle measurement bias. Table A-1 gives the 50% cutoff diameters for the cyclone precollector and the impaction stages.

Based on laboratory calibration with monodisperse spheres of unit density, the cyclone was found to have a 50% cutoff diameter of 5.5 μm for a flowrate of 40 cfm. The manufacturer recommends that the value of 11 μm be used for the cutoff diameter at 20 cfm, reflecting an inverse proportion between the cutoff diameter and the flow rate. However, while some data have been compiled to support this dependence for small cyclones, which is presumed to be the result of turbulence effects, other data for lower inlet velocities seem to indicate that an inverse dependence of

TABLE A-1. 50% CUTOFF DIAMETERS FOR SIERRA CYCLONE PRESEPARATOR AND CASCADE IMPACTOR OPERATED AT 34 m^3/hr (20 cfm)

	Cutoff diameter (μm)					
Particle density	1 g/cm^3	2 g/cm^3	2.5 g/cm^3	3 g/cm^3	4 g/cm^3	5 g/cm^3
Cyclone	11	7.8	7.0	6.3	5.5	4.9
Stage 1	10.2	7.2	6.4	5.9	5.1	4.6
Stage 2	4.2	3.0	2.7	2.4	2.1	1.9
Stage 3	2.1	1.5	1.3	1.2	1.0	0.94
Stage 4	1.4	0.99	0.88	0.81	0.7	0.63
Stage 5	0.73	0.52	0.46	0.42	0.36	0.33

cutoff diameter on the square root of flow rate may apply, as dictated by traditional cyclone performance theory.A-1/ Nevertheless, the manufacturer's recommendation was followed in this study.

As indicated by the simultaneous measurement of airborne particle-size distribution, one impactor being used with a precollector and a second without a precollector, the cyclone precollector is very effective in reducing fine particle measurement bias. However, the following observations indicate that correction for residual coarse particle bounce is needed:

1. There is a monotonic decrease in collected particulate weight on each successive impaction stage followed by a several-fold increase in weight collected by the back-up filter.

2. Because the assumed value (0.2 μm)* for the effective cutoff diameter of the glass fiber back-up filter fits the progression of cutoff diameters for the impaction stages, the weight collected on the back-up filter should follow the particulate weight progression on the impactor stages.

The excess particulate on the back-up filter is postulated to consist of coarse particles that penetrated the cyclone (with small probability) and bounced through the impactor.

* Average of 0.3 μm, for which a high percentage of particulate is known to be removed by filtration, and 0.1 μm, which is frequently cited as the lower limit of particle removal for glass fiber filters.

To correct the measured particle size distribution for the effects of residual particle bounce, the following procedure was used:

1. The calibrated cutoff diameter for the cyclone preseparator was used to fix the upper end of the particle-size distribution.

2. At the lower end of the particle-size distribution, the particulate weight on the back-up filter was reduced to fit the particulate weight distribution of the impactor stages, thereby extending the monotonic decrease in particulate weight observed on the impactor stages.

The log-normal distribution determined in this manner is extrapolated to larger particle sizes as required for the calculations.

4.0 Adjustment of Emission Factors to Particle Size Cutoffs

In the body of this report, emission factors are presented for suspended particulates (particles smaller than 30 μm in Stokes diameter, based on a particle density of 2.5 g/cm^3) and for fine particulates (particles smaller than 5 μm in Stokes diameter, based on a particle density of 2.5 g/cm^3). These values are determined by multiplying the total emission factor by appropriate weight percentage values from the particle size distribution corrected to a particle density of 2.5 g/cm^3.

In order to find emission factors corresponding to other particle size cutoffs, the following steps must be taken:

1. For a given test, construct a straight-line particle size distribution on log-probability graph paper using the values for weight percents smaller than 30 and 5 μm.

2. Determine the value for weight percent smaller than the desired diameter (D_p).

3. Calculate the emission factor for particles smaller than D using the following expression:

$$EF_{<D_p} = EF_{<30\ \mu m} \times \left(\frac{\% < D_p}{\% < 30\ \mu m} \right)$$

5.0 Example Calculations

Tables A-2 through A-4, respectively, show example calculations for the three source categories tested by exposure profiling: vehicular traffic on unpaved roads; vehicular traffic on paved roads; and storage pile stacking.

TABLE A-2. EXAMPLE CALCULATION FOR RUN G-29--UNPAVED ROADS

	Result	
	Metric	Nonmetric
A. Plot filter exposure versus sampler height.	-	-
B. Graphically integrate to determine the area under the vertical exposure profile.	135 kg/km	480 lb/mile
C. Divide B by the number of vehicle passes (78) to arrive at the integrated filter exposure.	1.7 kg/vehicle km	6.1 lb/vehicle mile
D. Correct C to isokinetic conditions following the procedure given in Appendix A.	1.5 kg/vehicle km	5.4 lb/vehicle mile
E. Multiply D by the ratio of the percent < 30 μm (50%) over the percent captured on the filter (57%) to obtain the emission factor for particles smaller than 30 μm.	1.6 kg/vehicle km	5.6 lb/vehicle mile

TABLE A-3. EXAMPLE CALCULATION FOR RUN F-18--PAVED ROADS

	Result	
	Metric	Nonmetric
A. Plot filter exposure versus sampler height.	-	-
B. Graphically integrate to determine the area under the vertical exposure profile.	19 kg/km	67 lb/mile
C. Divide B by the number of vehicle passes (96) to arrive at the integrated filter exposure.	0.20 kg/vehicle km	0.70 lb/vehicle mile
D. Correct C to isokinetic conditions following the procedure given in Appendix A.	0.12 kg/vehicle km	0.44 lb/vehicle mile
E. Multiply D by the ratio of the percent < 30 µm (78%) over the percent captured on the filter (72%) to obtain the emission factor for particles smaller than 30 µm.	0.14 kg/vehicle km	0.48 lb/vehicle mile

TABLE A-4. EXAMPLE CALCULATION FOR RUN H-12--STORAGE PILE STACKING

	Result	
	Metric	Nonmetric
A. Plot filter exposure versus sampler height.	-	-
B. Graphically integrate to determine the area under the exposure surface.	91 kg	200 lb
C. Divide B by the number of stacker passes.	5.6 kg/stacker km	20 lb/stacker-mile
D. Multiply C by the stacker velocity (mph or m/sec) and the inverted stacking rate (hr/ton or hr/tonne) to arrive at the integrated filter exposure.	0.0010 kg/t	0.0020 lb/T
E. Correct D to isokinetic conditions following the procedure given in Appendix A.	0.0010 kg/t	0.0021 lb/T
F. Multiply E by the ratio of the percent < 21.4 μm (67%) over the percent captured on the filter (61%) to obtain the emission factor for particles smaller than 21.4 μm. (This correction simulates what the sampling equipment "sees" as particles < 30 μm when density is 4.9 g/cm^3.)	0.0011 kg/t	0.0023 lb/T

REFERENCE

A-1. Chan, T., and M. Lippman. Particle Collection Efficiencies of Air Sampling Cyclones: An Empirical Theory. Environmental Science and Technology, 11(4):377, 1977.

APPENDIX B

PROCEDURES FOR SURFACE AGGREGATE SAMPLING AND ANALYSIS

The predictive emission factor equations presented in this report require data on the properties of the dust-emitting aggregate materials being disturbed by the action of wind or machinery. This appendix presents recommended procedures for collection, preparation and laboratory moisture analysis of representative samples of loose aggregate materials from the surfaces of: (a) unpaved roads; (b) paved roads; (c) storage piles; and (d) exposed areas.

The starting point for development of the recommended procedures was a review of American Society of Testing and Materials (ASTM) Standards in search of standard methodologies applicable to the specific sampling and analysis problems.

When it was practicable, the recommended procedures were structured identically to ASTM standard procedures. When this was not possible, the attempt was made to develop the procedure in a manner consistent with the intent of the majority of pertinent ASTM Standards.

1.0 Number and Size of Incremental and Gross Samples

ASTM Standards generally suggest that (a) the number of gross samples to be taken is one per 900 tonnes (1,000 tons) of material; (b) the minimum size of a gross sample should range from 14 kg (30 lb) to 230 kg (500 lb) depending on the type and size distribution of the material; and (c) the number of incremental samples should range from 3 to 50. These general requirements apply to aggregate materials but not necessarily roadway surface materials.

The recommendations presented below are based on a desire to approach representative sampling yet remain within reasonable constraints of manpower and time. It is recommended that 23-kg (50-lb) gross samples be collected in a number of increments ranging from 10 for storage piles to 4 for unpaved roads. Paved road samples, while normally consisting of less than 23 kg (50 lb), will comprise a number of increments.

For a typical unpaved road, 9.1 m (30 ft) in width and having 5/8 cm (1/4 in.) of loose surface material (1.5 g/cm bulk density), there are approximately 140,000 kg (300,000 lb) or 140 tonnes (150 tons) of material in 1 mile. Consequently, one gross sample of at least 23 kg (50-lb) weight taken in at least four increments from a 16 km (10-mile) section of roadway (having similar surface material) would satisfy general ASTM criteria.

For a four-lane paved road of 15-m (50-ft) width, there is typically 230 kg (500 lb) of surface dust per road mile. To satisfy ASTM criteria, approximately 150 m (500 ft) of road length in increments stretching over 1,600 km (1,000 miles) would have to be sampled to achieve 23 kg (50 lb) of sample. Since this would involve an excessive commitment of time and manpower, a number of incremental samples of small size over a road segment not exceeding 40 km (25 miles) (having similar surface conditions) is recommended in order to reasonably approach representative sampling of paved roadway surfaces.

Because aggregate storage piles typically contain several thousand tons of material, it is recommended that one 23-kg (50-lb) gross sample consisting of 10 increments be collected from each pile. For very large piles exceeding 90,000 tonnes (100,000 tons), more than one gross sample should be taken.

Assuming that an exposed ground area is covered by a 5/8-cm (1/4-in.) thick layer of loose sand, soil, or crushed stone (1.5 g/cm^3 bulk density), 0.004 sq km (1 acre) would have 39,000 kg (85,000 lb) or 39 tonnes (43 tons) of surface material. Thus, one gross sample for every 0.1 sq km (25 acres) of exposed area would be consistent with ASTM Standards. Where there are large acreages of exposed area, it is recommended that one 23-kg (50-lb) gross sample be collected for every major exposed surface type (e.g., tailings, glacial drift, etc.).

2.0 Collection of Incremental and Gross Samples

This section will discuss the appropriate sample collection technique for each source type.

2.1 Unpaved Roads

The incremental samples from unpaved roads should be distributed over the road segment, as shown in Figure B-1. At least four incremental samples should be collected. If the surface condition of the road varies significantly, it must be broken into smaller sampling segments, each having a relatively uniform condition.

The loose surface material is removed from the hard road base with a whisk broom and a dustpan. Figure B-2 presents a data form to be used for the sampling of unpaved roads.

2.2 Paved Roads

Ideally, for a given road type (residential, commercial, industrial, etc.), one gross sample per every 40 km (25 miles) should be collected. This gross sample should consist of at least two separate increments per travel lane. Thus, the gross sample collected from a four-lane roadway would consist of eight sample increments.

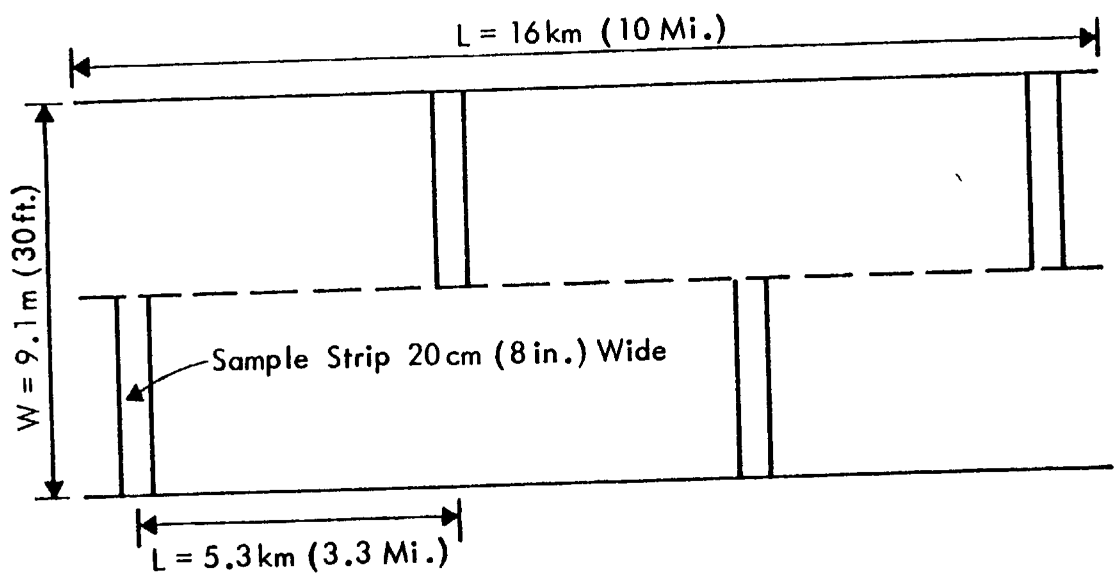

Figure B-1. Location of incremental sampling sites on an unpaved road.

MIDWEST RESEARCH INSTITUTE

MRI Project No.________ | Sampling Data Unpaved Roads | Date________ Recorded by________

Type of Material Sampled: ________

Site of Sampling: ________

SAMPLING METHOD

1. Sampling device: whisk broom and dust pan
2. Sampling depth: loose surface material
3. Sample container: metal or plastic bucket with sealed poly liner
4. Gross sample specifications:
   (a) 1 sample of 23 kg (50 lb.) minimum for every 16 km (10 mi.) sampled
   (b) composite of 4 increments: lateral strips of 20 cm (8 in.) width extending over traveled portion of roadway half

Indicate deviations from above method: ________

____

____

____

SAMPLING DATA

Sample No.	Time	Location	Surface Area	Depth	Quantity of Sample

DIAGRAM

4/78

Figure B-2. Sampling data form for unpaved roads.

Figure B-3 presents a diagram for the above sampling situation. Each incremental sample should consist of a lateral strip 0.3 to 3 m (1 to 10 ft) in width across a travel lane. The exact width is dependent on the amount of loose surface material on the paved roadway. For a visually dirty road, a width of 0.3 m (1 ft) is sufficient; but for a visually clean road, a width of 3 m (10 ft) is needed to obtain adequate sample.

The above sampling procedure may be considered as the preferred method of collecting surface dust from paved roadways. In many instances, however, the collection of eight sample increments may not be feasible due to manpower, equipment, and traffic/hazard limitations. Samples of questionable representativeness can be obtained from a single increment (curb to curb) on a given roadway. When it is necessary to resort to this sampling strategy, care must be taken to select sites that have dust loading and traffic characteristics typical of the entire roadway segment of interest. In this situation, sampling from a strip 3 m to 9 m (10 to 30 ft) in width is suggested. From this width, sufficient sample can be collected, and a step forward representativeness in sample acquisition will be accomplished.

Samples are removed from the road surface by vacuuming, preceded by broom sweeping if large aggregate is present. Figure B-4 presents a data form to be used for the sampling of paved roads.

As indicated previously, values for the dust loading on the traveled portion of the roadway are needed for inclusion in the emission factor equation. Information pertaining to dust loading on curb and parking areas is useful in estimating carry-on potential or to justify the need for roadway cleaning.

2.3 Storage Piles

In sampling the surface of a pile to determine representative properties for use in the wind erosion equation, a gross sample made up of top, middle, and bottom incremental samples should ideally be obtained since the wind disturbs the entire surface of the pile. However, it is impractical to climb to the top or even middle of most industrial storage piles because of the large size.

The most practical approach in sampling from large piles is to minimize the bias by sampling as near to the middle of the pile as practical and by selecting sampling locations in a random fashion. Incremental samples should be obtained along the entire perimeter of the pile. The spacing between the samples should be such that the entire pile perimeter is traversed with approximately equidistant incremental samples. If small piles are sampled, incremental samples should be collected from the top, middle, and bottom.

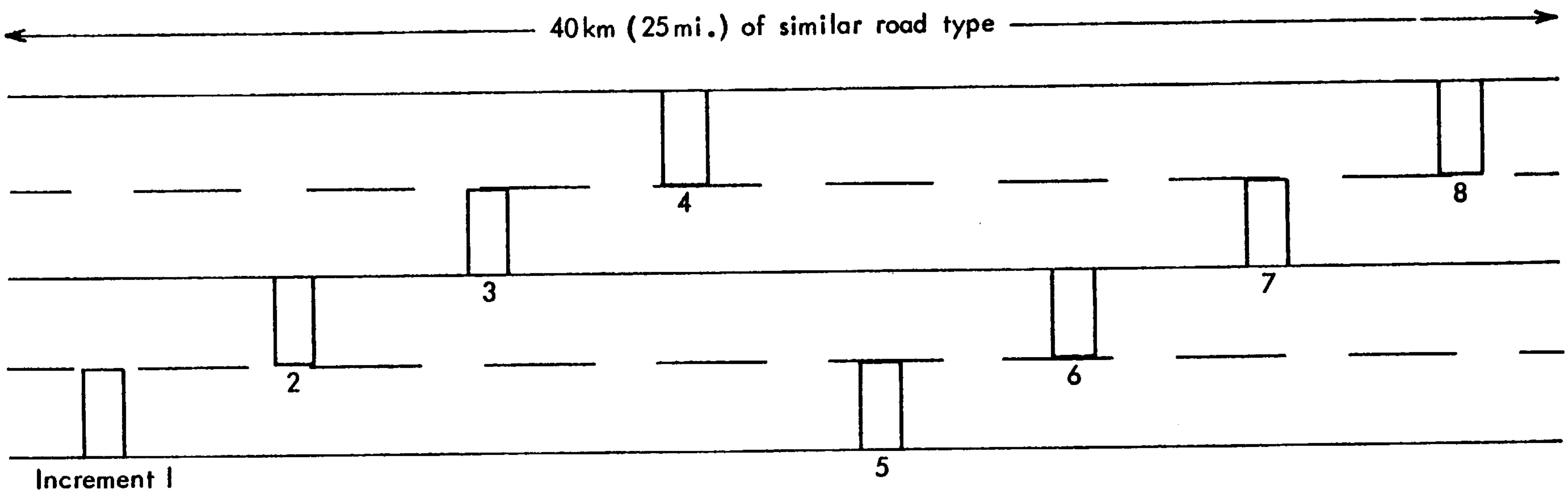

Figure B-3. Location of incremental sampling sites on a paved road.

MIDWEST RESEARCH INSTITUTE

MRI Project No. ________	Sampling Data Paved Roads	Date ________ Recorded by ________

Type of Material Sampled: ________________________

Site of Sampling: ________________________

Type of Pavement: ________________ Surface Condition ________________

SAMPLING METHOD

1. Sampling device: Portable vacuum cleaner (broom sweep first if loading is heavy)
2. Sampling depth: loose surface material
3. Sample container: metal or plastic bucket with sealed poly liner for coarse particles, vacuum cleaner bag for fine particles
4. Gross sample specifications:
   (a) 1 sample for significant road segment with given surface characteristics - not to exceed 40 km (25 mi.)
   (b) composite of 8 increments: lateral strips of 0.3 to 3 m (1 to 10 ft.) width, extending over traveled portion of roadway half

Indicate deviations from above method: ________________________

SAMPLING DATA

Sample No.	Vac Bag	Time	Surface Area	Quantity of Sample

Sample No.	Vac Bag	Time	Surface Area	Quantity of Sample

DIAGRAM: C = curb P = parking or travel lane T = travel lane

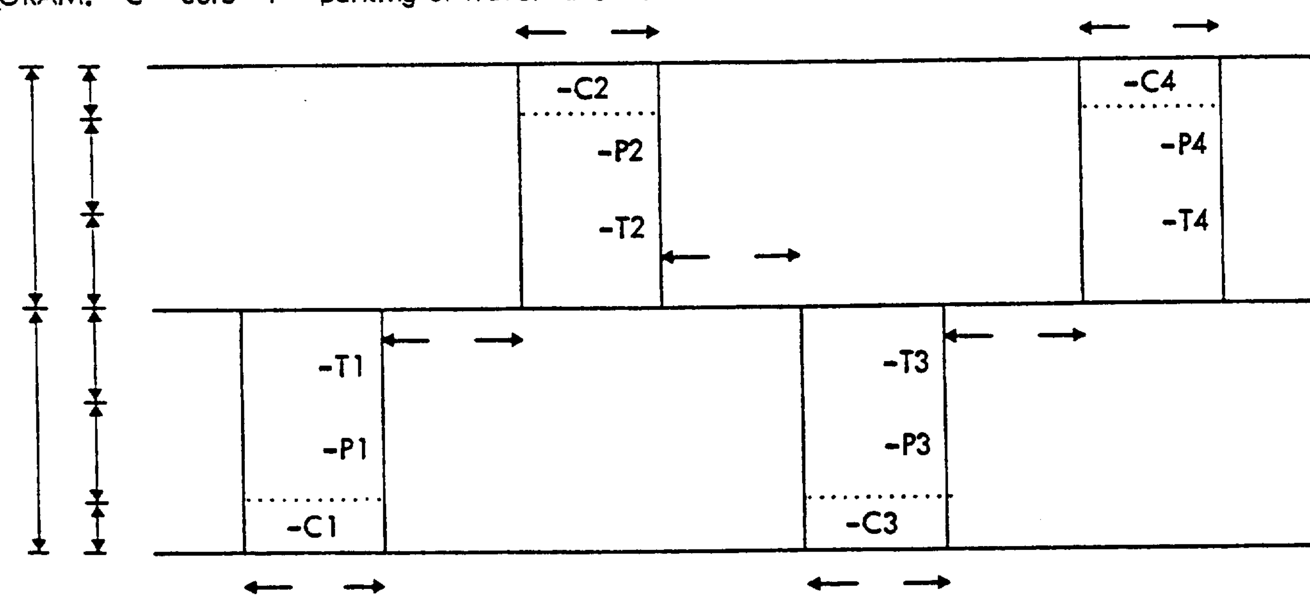

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Figure B-4. Sampling data form for paved roads.

An incremental sample (e.g., one shovelful) is collected by skimming the surface of the pile in a direction upward along the face. Every effort must be made by the person obtaining the sample not to purposely avoid sampling larger pieces of raw material. Figure B-5 presents a data form to be used for the sampling of storage piles.

In obtaining a gross sample for the purpose of characterizing a load-in or load-out process, incremental samples should be taken from the portion of the storage pile surface (a) which has been formed by the addition of aggregate material or (b) from which aggregate material is being reclaimed. Usually, it is not feasible to sample the aggregate material before or after it is in place in the pile.

2.4 Exposed Areas

The selection of incremental sampling locations for exposed areas should be done prior to obtaining samples. The exposed areas must be identified, preferably on a map; and the sites selected so that 10 incremental sampling sites cover the major acreage of similar surface type as equally spaced as possible.

MIDWEST RESEARCH INSTITUTE

MRI Project No. ____________

Sampling Data
Storage Piles

Date ____________
Recorded by ____________

Type of Material Sampled: ____________

Site of Sampling: ____________

SAMPLING METHOD

1. Sampling device: pointed shovel
2. Sampling depth: 10 - 15 cm (4 - 6 inches)
3. Sample container: metal or plastic bucket with sealed poly liner
4. Gross sample specifications:
   (a) 1 sample of 23 kg (50 lb.) minimum for every pile sampled
   (b) composite of 10 increments
5. Minimum portion of stored material (at one site) to be sampled: 25%

Indicate deviations from above method: ____________

SAMPLING DATA

Sample No.	Time	Location (Refer to map)	Surface Area	Depth	Quantity of Sample

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Figure B-5. Sampling data form for storage piles.

ASTM Standards describe the selection of the correct riffle size and the correct use of the riffle. Riffle slot widths should be at least three times the size of the material being divided. The following quote describes the use of the riffle:[B-1/]

> Divide the gross sample by using a riffle. Riffles properly used will reduce sample variability but cannot eliminate it. Riffles are shown in Figure B-6, (a) and (b). Pass the material through the riffle from a feed scoop, feed bucket, or riffle pan having a lip or opening the full length of the riffle. When using any of the above containers to feed the riffle, spread the material evenly in the container, raise the container, and hold it with its front edge resting on top of the feed chute, then slowly tilt it so that the material flows in a uniform stream through the hopper straight down over the center of the riffle into all the slots, thence into the riffle pans, one half of the sample being collected in a pan. Under no circumstances shovel the sample into the riffle, or dribble into the riffle from a small-mouthed container. Do not allow the material to build up in or above the riffle slots. If it does not flow freely through the slots, shake or vibrate the riffle to facilitate even flow.[B-1/]

The procedure for coning and quartering is best illustrated in Figure B-7. The following is a description of the procedure:

> (1) Mix the material and shovel it into a neat cone; (2) flatten the cone by pressing the top without further mixing; (3) divide the flat circular pile into equal quarters by cutting or scraping out two diameters at right angles; (4) discard two opposite quarters; (5) thoroughly mix the two remaining quarters, shovel them into a cone, and repeat the quartering and discarding procedures until the sample has been reduced to 0.9 to 1.8 kg (2 to 4 lb). Samples likely to be affected by moisture or drying must be handled rapidly, preferably in an area with a controlled atmosphere, and sealed in a container to prevent further changes during transportation and storage. Care must be taken that the material is not contaminated by anything on the floor or that a portion is not lost through cracks or holes. Preferably, the coning and quartering operation should be conducted on a floor covered with clean paper. Coning and quartering is a simple procedure which is applicable to all powdered materials and to sample sizes ranging from a few grams to several hundred pounds.[B-2/]

The size of the laboratory sample is important--too little sample will not be representative and too much sample will be unwield. Ideally, one would like to analyze the entire gross sample in batches, but this is not practical. While all ASTM Standards acknowledge this impracticality, they disagree on the exact size, as indicated by the range of recommended samples, extending from 0.05 to 27 kg (0.1 to 60 lb).

The main principle in sizing the laboratory sample is to have sufficient coarse and fine portions to be representative of the material and to allow sufficient mass on each sieve so that the weighing is accurate. A recommended rule of thumb is to have twice as much coarse sample as fine sample. A laboratory sample of 800 to 1,600 g is recommended since that is the largest quantity that can be handled by the scales normally available (1,600-g capacity).

4.0 Laboratory Analysis of Samples

Laboratory analysis of the samples to determine silt and moisture contents will be identical whether the samples originate from storage piles, roads, or exposed areas. Minor differences will occur for drying materials with chemically bound moisture.

4.1 Moisture Analysis

The basic recommended procedure for moisture analysis is determination of weight loss on oven drying. Table B-1 presents a step-by-step procedure for determining moisture content. Exceptions to this general procedure are made for any material composed of hydrated minerals or organic materials. Because of the danger of measuring chemically bound moisture for these materials if they are over-dried, the drying time should be lowered to only 1-1/2 hr. Coal and soil are examples of materials that should be analyzed by this latter procedure.

4.2 Silt Analysis

The basic recommended procedure for silt analysis is mechanical, dry sieving. A step-by-step procedure is given in Table B-2. The sieving time is variable; sieving should be continued until the net sample weight collected in the pan increases by less than 3.0% of the previous net sample weight collected in the pan. A minor variation of 3.0% is allowed since some grinding will occur, and consequently, the weight will continue to increase. When the change reduces to 3.0%, it is hoped that the natural silt has been passed through the No. 200 sieve screen and that any additional increase is due to grinding.

TABLE B-1. MOISTURE ANALYSIS PROCEDURES

1. Preheat the oven to approximately 110°C (230°F). Record oven temperature.

2. Tare the laboratory sample containers which will be placed in the oven. Tare the containers with the lids on if they have lids. Record the tare weight(s). Check zero before weighing.

3. Record the make, capacity, smallest division, and accuracy (if displayed) of the scale.

4. Weigh the laboratory sample in the container(s). Record the combined weight(s). Check zero before weighing.

5. Place sample in oven and dry overnight.[a/]

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

8. Calculate the sample weight as the oven-dried weight of the sample and container minus the weight of the container. Record the value.

a/ Dry materials composed of hydrated minerals or organic materials like coal and certain soils for only 1-1/2 hr.

TABLE B-2. SILT ANALYSIS PROCEDURES

1. Select the appropriate 8-in. diameter, 2-in. deep sieve sizes. Recommended U.S. Standard Series sizes are: 3/8 in., No. 4, No. 20, 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 particular sieve during sieving indicates that an intermediate sieve should be inserted.

2. Obtain a mechanical sieving device such as a vibratory shaker or a Roto-Tap.

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. Attain a scale (capacity of at least 1,600 g) and record make, capacity, smallest division, date of last calibration, and accuracy (if available).

5. Tare sieves and pan. 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 (probably immediately after moisture analysis) into the top 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 device and sieve for 20 min. Remove pan containing minus No. 200 and weigh. Replace pan beneath the sieves and sieve for another 10 min. Remove pan and weigh. When the difference between two successive pan sample weighings (where the tare of the pan has been subtracted) is less than 3.0%, the sieving is complete.

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

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

REFERENCES

B-1. D2013-72. Standard Method of Preparing Coal Samples for Analysis. Annual Book of ASTM Standards, 1977.

B-2. Silverman, Leslie, Charles E. Billings, and Melvin W. First. Particle Size Analysis in Industrial Hygiene. Academic Press, New York, New York, pp. 69-70, 1971.

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16. ABSTRACT The report gives results of field tests aimed at increasing the reliability of equations used to predict emission factors for open fugitive emission sources at iron and steel plants. The accuracy of previously developed equations is limited by the restricted number of actual test measurements used as their basis. Results of 18 emission tests of traffic-entrained dust from unpaved roads show that the previously developed equation for this source predicts measured emission factors within a mean prediction error of 16% of the mean measured value. An adjustment factor for the number of vehicle wheels should reduce the prediction error. Limited tests of chemical dust suppressants for unpaved roads indicate a high initial control efficiency which decays with passage of vehicles. Six tests of traffic on paved roads indicate that the previous equation consistently underpredicts emissions for paved roads in industrial plants. This is probably due to the effect of unpaved areas adjacent to the paved surfaces. Five tests of storage pile stacking show that the previous equation for continuous drop operations can be improved by adding a correction factor for drop distance. Twelve tests of wind erosion emissions, using a portable wind tunnel, yielded sufficient information on the dynamics of wind erosion from storage piles and bare ground areas.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Pollution	Dust	Pollution Control	13B	11G
Iron and Steel Industry		Stationary Sources	11F	
Leakage	Dust Control	Fugitive Emissions	14B	
Evaluation	Roads	Particulate		
Mathematical Models			12A	
Tests	Storage			15E
Wind Erosion			02C	

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