AP42 Section:	13.2.4
Reference:	7
Title:	*Taconite Mining Fugitive Emissions Study*, T. Cuscino, Jr., *et al.*, Minnesota Pollution Control Agency, Roseville, MN, June 1979.

- UNPAVED ROADS
AP-42
Section 11.2.1
Reference Number
8

MIDWES

~~#11 PRIMARY TEST REPORT AND REFERENCE FOR FUGITIVE DUST~~

~~RETURN TO AP-42 FILE #11.2~~

MRI REPORT

TACONITE MINING FUGITIVE EMISSIONS STUDY

FINAL REPORT

MRI Project No. 4523-L(1)
June 7, 1979

For

Minnesota Pollution Control Agency
Division of Air Quality
1935 West County Road B-2
Roseville, Minnesota 55113

Attn: Mr. Gary Eckhardt

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

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by

Thomas Cuscino, Jr.

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PREFACE

This program was conducted in Midwest Research Institute's Environmental and Materials Sciences Division. Dr. Chatten Cowherd, Head, Air Quality Assessment Section, served as program manager. Mr. Thomas A. Cuscino, Principal Investigator, is the main author of this report. Mr. Russel Bohn lead the crew that sampled emissions from unpaved roads at Erie Mining Company. He was assisted by Mr. Bob Stultz, Mr. Mark McLinden, Mr. Fritz Hoffmeister, and Dr. Ralph Keller. Ms. Christine Maxwell was responsible for the analysis of data gathered from the unpaved road emission testing. A separate study involving silt and moisture sample collection, preparation, and analysis was performed over a 2-month period by Mr. John Pegors and Mr. Lyle Hobbs of the Minnesota Pollution Control Agency.

Approved for:

MIDWEST RESEARCH INSTITUTE

L. J. Shannon, Executive Director
Environmental and Materials
Sciences Division

June 7, 1979

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SUMMARY

This study was designed to improve the predictive emission factor equations developed by Midwest Research Institute (MRI) for open dust sources. Improvements were to occur as a result of additional source testing. Improvements were to provide a higher degree of accuracy for emission inventories of taconite mining operations.

The taconite mining sources selected for testing were those that contributed the largest amount of actual particulate emissions to the atmosphere. An initial emission inventory estimate indicated that heavy truck traffic on unpaved roads was the largest source, contributing 66% of the total suspended emissions (particles less than 30 μm) attributed to open dust sources at a taconite mine.

To perform the initial inventory estimate properly, size distributions and moisture contents for the aggregates and soils comprising the open dust sources were needed. A sampling program extending over a period of 2 months was performed to quantify these parameters at a taconite mine. Detailed procedures for collection, preparation, and analysis of the aggregate material samples were developed using ASTM standards as guidelines.

Eleven tests were conducted to quantify emissions from haul trucks traveling on unpaved roads. The exposure profiling technique developed by MRI was utilized for these tests. Tests were performed on dry untreated surfaces, chemically stabilized surfaces, and wet surfaces following a rain.

The predictive emission factor equation previously developed by MRI was improved by the addition of these new test data to the already existing data base. The modified equation has a precision of 1.48 which means that the actual emission factor value will be within a factor of 1.48 times the predicted value 95% of the time. This is a significant improvement over the previous equation which had a precision of 1.69.

Finally, the control efficiency of a lignin sulfonate chemical treatment was shown to decay with time from 91 to 83% with only a portion of 1 day's road usage. Also, a rain of 1.13 in. over 2 days produced control efficiencies ranging from 54 to 89% on different roads the day after the rain.

SECTION 1.0

INTRODUCTION

Thirteen townships and one section of a 14th township within the Mesabi Iron Range in northern Minnesota are presently classified as nonattainment for the total suspended particulate (TSP) secondary National Ambient Air Quality Standard (NAAQS).[1/] One of the major contributions to the TSP problem, along the Mesabi Iron Range, is suspected to be fugitive emissions from open dust sources associated with taconite mining.

Taconite ore (lean iron ore) mining in the United States is a large industry for which the major production (70%) occurs in Minnesota. One of the major taconite deposits in Minnesota occurs along the Mesabi Range. The six taconite mining and processing facilities which existed along the Mesabi Range in 1973, with a capacity to produce 40.9 million long tons (LT) of beneficiated iron ore pellets, have expanded to eight facilities in 1978 with a capacity to produce 62.7 million LT.[2/]

Taconite ore mining necessitates handling large amounts of material. For example, in 1976 the seven operating taconite mines on the Mesabi Range handled 130 x 10^6 LT of crude ore, 56.4 x 10^6 LT of waste rock, 43 x 10^6 LT of surface material, and 40.5 x 10^6 LT of pellets. Each handling operation involving these large quantities of material is a source of fugitive emissions.

Major material handling mining and storage processes at taconite mines which produce fugitive emissions are: (a) haul and service truck traffic on unpaved roads; (b) wind erosion from storage piles, dumps, and tailings basins; (c) dumping material from rail, truck, or conveyor onto piles; and (d) blasting.

1.1 PROJECT OBJECTIVES

The primary objective of this study was to improve the predictive emission factor equations previously developed by MRI for open dust sources.[3-5/] The tasks designed to accomplish this objective were:

<u>Task I - Develop a Fugitive Emissions Inventory for Open Dust Sources at Erie Mining Company (EMC)</u> - A preliminary emissions inventory was developed for a representative taconite mine (EMC) in order to determine the most important sources. The most important sources, i.e., those with the largest emissions, were candidates for testing.

Task II - Develop Improved Emission Factor Equations for Major Sources - Emission factors for the most important sources were measured by field testing at EMC in order to increase the existing data base. Revised predictive emission factor equations were calculated, based on the expanded data base.

1.2 UNITS

One word of caution concerning units is in order. In the iron ore industry, weights of material are given predominantly in long tons (LT), where 1 LT = 2,240 lb. MRI uses predictive equations which require vehicle weights and material capacities in short tons (ST), where 1 ST = 2,000 lb. The reader is cautioned to observe which unit of tonnage is being used.

SECTION 2.0

PRELIMINARY EMISSION INVENTORY FOR OPEN DUST SOURCES

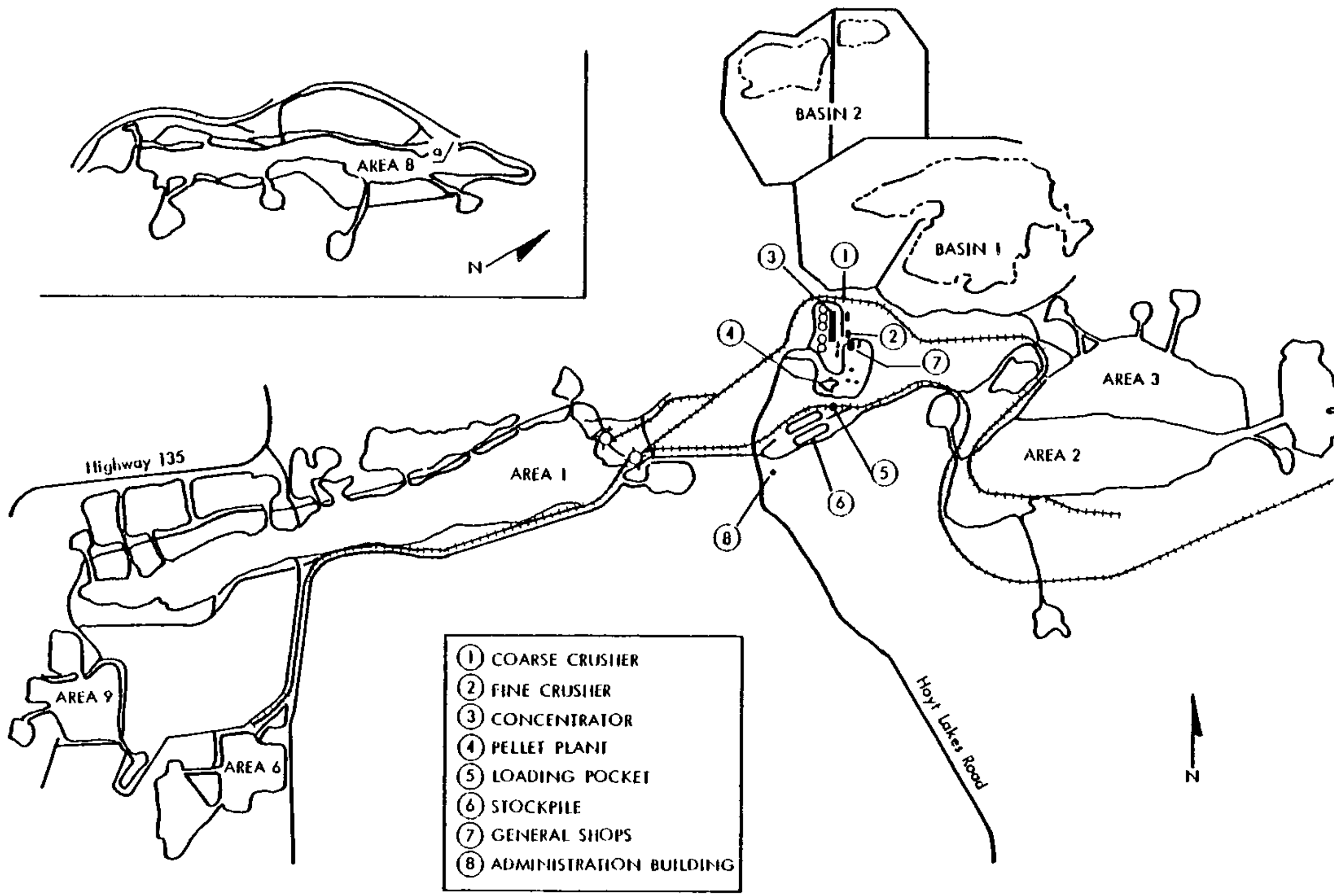
A preliminary emission inventory was conducted at EMC (see Figure 1) to determine the most significant open dust sources, where significance was measured by the amount of emissions released annually. The following section presents the emission factor correction parameters, the source extents, and the control efficiencies utilized to calculate annual emission rates.

The year 1976 was utilized as the base year, since it is the most recent year during which Erie was operated near capacity. The amount of material handled in 1976 is shown in Figure 2. The fact that 1976 was dry in relation to other years is unimportant to this study, since all the open dust source emissions would have risen proportionately due to the dry climatic conditions with no change in relative source significance.

In this study, the comparison of one source to another is important, rather than the absolute value of the emissions from any source since the only use for the inventory is to select the source to be tested, i.e., the source with the most emissions. These tests will be used to validate the appropriate MRI predictive emission factor equation. On the other hand, in a companion study entitled "Iron Range Air Quality Analysis," the absolute value of emissions is important. MRI's emission factor equations have the inherent capability to allow for variation in climatic parameters. The report entitled "Iron Range Air Quality Analysis" should be consulted to see how climatic variation was handled.

2.1 DETERMINATIONS OF EMISSION FACTOR CORRECTION PARAMETERS

The correction parameters in the MRI emission factor equations are utilized to allow for the variation in emission factors that result from variations in surface material characteristics, equipment characteristics, and climatic conditions. Table 1 shows the correction parameters in the context of their respective predictive emission factor equations. The following sections describe the values assigned to correction parameters and the methodology utilized to derive these values.



a/ Map shows location of processing plants in relation to various mining areas. Area 8, shown in the insert, is located approximately 20 miles to the northeast of the plant site.

Figure 1. Layout of Erie Mining Company.

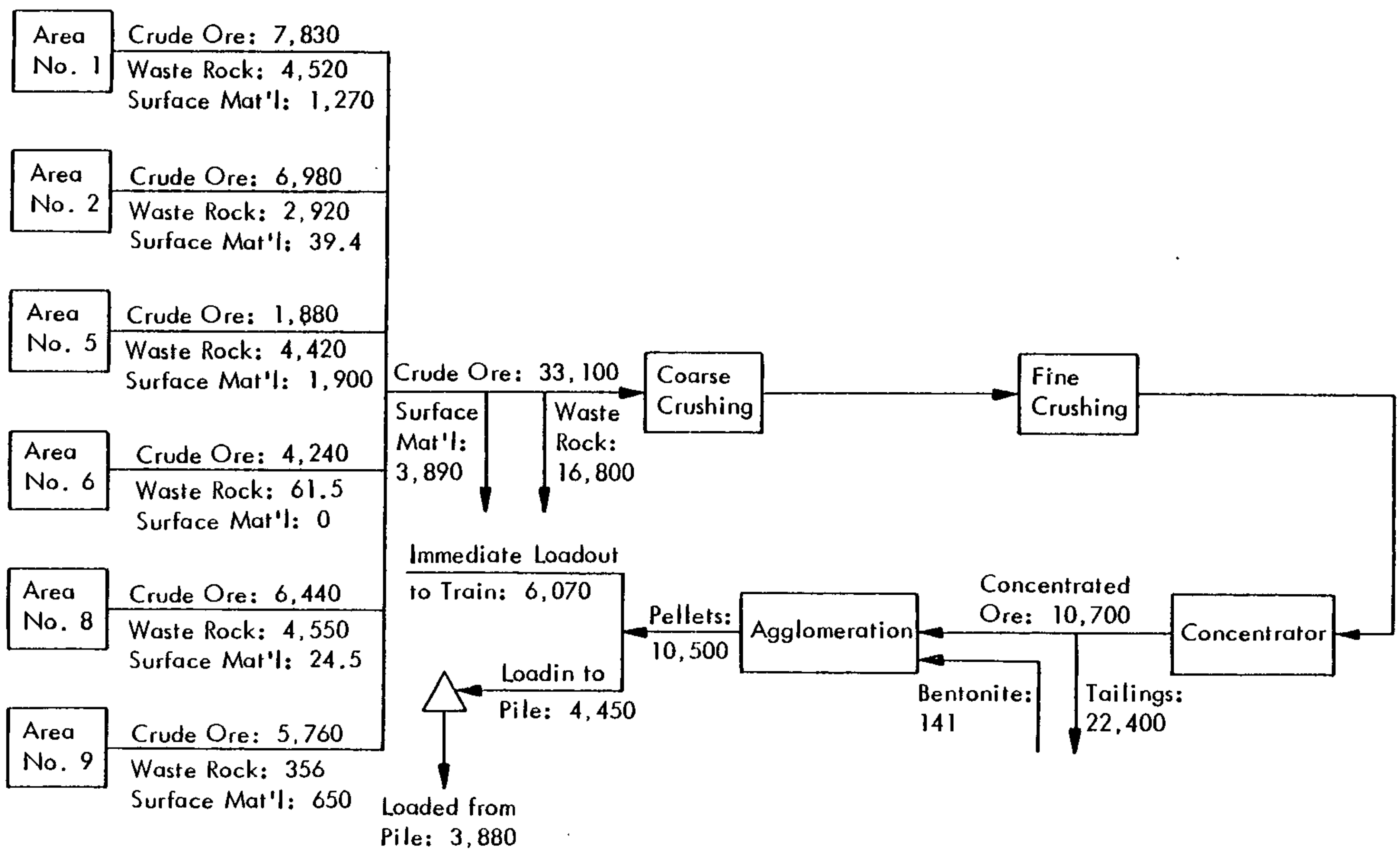


Figure 2. 1976 Material flow diagram in 1,000 LT (Erie Mining Company).

TABLE 1. MRI EXPERIMENTALLY DETERMINED EMISSION FACTORS FOR OPEN DUST SOURCES

Source Category	Measure of Extent	Emission Factor[a/] (lb/unit of source extent)	Reliability[b/]	Correction Parameters
1. Unpaved roads	Vehicle-miles traveled	$5.9 \left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.8}$	A-B	s = Silt content of road surface material, aggregate, or eroding surface (%)
2. Paved roads	Vehicle-miles traveled	$0.45 \left(\frac{4}{N}\right)\left(\frac{s}{10}\right)\left(\frac{L}{5,000}\right)\left(\frac{W}{3}\right)^{0.8}$	B-C	S = Average vehicle speed (mph) W Average vehicle weight (short tons)
3. Continuous load-in to storage piles (e.g., stacker, transfer station)	Tons of material put through storage	$0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)}{\left(\frac{M}{2}\right)^2}$	B	L = Surface dust loading on traveled portion of road (lb/mile) U = Mean wind speed (mph)
4. Active storage pile maintenance and traffic	Tons of material put through storage	$0.10\ K \left(\frac{s}{1.5}\right)\left(\frac{d}{235}\right)$	C	M = Unbound moisture content of aggregate (%) Y = Dumping device capacity (cu yd)
5. Active storage pile wind erosion	Tons of material put through storage	$0.05 \left(\frac{s}{1.5}\right)\left(\frac{d}{235}\right)\left(\frac{f}{15}\right)\left(\frac{D}{90}\right)$	C	K = Activity factor (= 1 for operation with truck traffic intensity of 50 trips/day)
6. Inactive storage pile wind erosion	Acres of storage per year	$1,200 \left(\frac{s}{1.5}\right)\left(\frac{d}{235}\right)\left(\frac{f}{15}\right)$	C	d = Number of dry days per year
7. Batch load-out from storage piles (e.g., front-end loader to truck)	Tons of material put through storage	$0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)}{\left(\frac{M}{2}\right)^2\left(\frac{Y}{6}\right)}$	B	f = Percentage of time wind speed exceeds 12 mph D = Duration of material in storage (days)
8. Wind erosion of exposed areas	Acre-years of exposed land	$3,400 \frac{\left(\frac{e}{50}\right)\left(\frac{s}{15}\right)\left(\frac{f}{25}\right)}{\left(\frac{P\text{-}E}{50}\right)^2}$	C	e = Surface erodibility (short tons/acre/year) P-E = Thornthwaite's precipitation-evaporation index N = Number of traveled lanes

a/ Emission factors for dust particles smaller than 30 μm in diameter based on particle density of 2.5 g/cm^3.

b/ A = Excellent; numerous field measurements.
B = Above average; limited number of field measurements.
C = Average; limited data and/or published emission factors where the accuracy is not stated.
D = Below average; engineering estimates made by knowledgeable personnel.
E = Poor; estimated values; assumptions not given.

2.1.1 Determination of Surface Material Characteristics

The surface materials of concern at EMC are: (a) soil, (b) rock, (c) crude taconite ore, (d) tailings, (e) pellets, and (f) road surface materials. A surface material in this context is defined as any material exposed to the wind. Table 2 shows the physical characteristics that influence dust emissions. Moisture is not included in Table 2, but rather in a following section on climatic conditions.

TABLE 2. SURFACE MATERIAL PHYSICAL CHARACTERISTICS THAT INFLUENCE DUST EMISSIONS

Surface material	Important characteristics
Soil	Silt
Rock	Silt
Crude taconite ore	Silt
Tailings	Silt Erodibility
Pellets	Silt
Road surface materials	Silt

Silt content (percent of material smaller than 75 μm in diameter) of several surface materials and cloddiness of tailings (percent smaller than 840 μm in diameter) were measured by collection and analysis of samples at EMC over the span of several weeks. The erodibility of a material has been related to cloddiness.[6] Table 3 shows the results of these tests. Sampling of the tailings basin beaches was terminated early in the sampling program after the entire beach was chemically treated with Coherex. The sample collection, preparation, and analysis procedures for unpaved roads, exposed areas (e.g., tailing basin beaches), and storage piles are given in Appendix A.

Silt content was not measured for soil and rock dumps, so values had to be estimated. Since the dumps are exposed to rain and much of the dump surface is not covered by new material in any single year, it was assumed that much of the fine material is washed into the pile. Consequently, the fine surface material exposed to wind erosion was estimated to be relatively low. The surface silt content of dumps at EMC was estimated to be 0.5 and 0.25% for soil

TABLE 3. SILT AND ERODIBILITY MEASUREMENTS AT EMC

Sampling location[a]	Variable analyzed	1978 Date 4/25	5/2	5/11	5/17	5/24	5/30	6/6	6/7	6/8	6/15	6/22	6/28	Avg.	SD[c]
Service road	Silt (%)	7.1	4.8	-	3.6	2.4	-	3.2	-	-	3.5	4.6	4.8	4.3	1.4
	Time	0930	0900	-	0815	0830	-	0850	-	-	0830	1145	1400	-	-
Haul road[b]	Silt (%)	9.2	9.7	-	6.3	4.1	-	4.3/3.7/6.2	-	3.8/6.2/5.6	-	-	-	5.9	2.1
	Time	1130	0800	-	0900	0915	-	0935/1440/1620	-	1230/1500/1700	-	-	-	-	-
Tailings basin beach	Silt (%)	10.9	10.9	-	-	-	-	-	-	-	-	-	-	10.9	0
	Cloddiness (%)	32.6	26.7	-	-	-	-	-	-	-	-	-	-	29.7	4.2
	Time	1345	1100	-	-	-	-	-	-	-	-	-	-	-	-
Pellet pile[d]	Silt (%)	-	2.9	2.9	4.3	2.2	3.5	3.7	3.2	-	5.4	2.7	-	3.4	0.96
	Time	-	1045	0845	1030	1300	1300	1030	1190	-	0945	1230	-	-	-

a/ All surfaces were uncontrolled, i.e., not covered with water, oil, or other chemicals.

b/ Samples were from three different haul roads.

c/ SD = standard deviation.

d/ The pile surface sampled had probably been undisturbed since early November 1977.

and rock, respectively. These values are low, as they should be, when compared with the measured values in Table 3, for example.

Silt content for crude taconite ore was also not measured. The fresh-blasted banks of crude taconite ore were composed of such large chunks of material that sampling was deemed unnecessary. The silt content is obviously low; and, in addition, the large chunks provide a wind shield so that the fine material that does exist in the bank is not exposed to threshold wind speeds. Consequently, the silt content was assumed to be negligible in value.

2.1.2 Determination of Equipment Characteristics

The important equipment characteristics are vehicle weight, vehicle speed, and power shovel bucket size. These values were obtained from plant personnel. The predominant haul truck at EMC in 1976 was an 85-LT capacity truck, weighing 58 ST unloaded and 154 ST loaded. These trucks had an average speed of 15 mph unloaded and 9 mph loaded. The weight and speed of passenger vehicles and some service trucks were quantified as 3 ST and 30 mph, while other service trucks were quantified at 5 and 25 ST and 20 mph. The power shovel bucket size for the sources considered in this study was 14 yd^3.

2.1.3 Determination of Climatic Conditions

Table 4 shows the climatic conditions which had to be quantified in order to estimate emissions from each surface material. Most of the climatic data were available from climatic records maintained at EMC, who have their own weather station adjacent to the administration building. Weather data from EMC for 1976 showed that 255 days had no measurable precipitation (< 0.01 in.). Only 197 days had either measurable precipitation or snow cover. The mean annual wind speed was 8.4 mph and the wind speed exceeded 12 mph 28.3% of the time. From data previously compiled by MRI, the P-E Index for the state climatic region containing EMC is 112.[3/]

The only climate-related variable which was not available in existing records was material surface moisture. Consequently, sampling/analysis was performed on a weekly basis at EMC to determine the variation in moisture of four different materials over a span of 2 months. These samples are the same ones that were tested for silt as reported in Table 3. Table 5 summarizes the results of the moisture sampling program. Also included in Table 5 are rainfall and evaporation data to facilitate comparison of moisture from day to day.

2.1.4 Summary of Correction Parameter Values Used

Table 6 shows on a source-by-source basis the parameters necessary to make the predictive equations shown in the table applicable to EMC. Substitution of these values into the equations in Table 1 will yield the emission factors for each source.

TABLE 4. CLIMATIC CONDITIONS THAT INFLUENCE DUST EMISSIONS

Source	Surface materials affected	Important climatic conditions
Unpaved roads	Road surface materials	Dry days per year Snowcover
Continuous load-in	Pellets	Mean annual wind speed Material surface moisture[a/]
Storage pile wind erosion	Pellets Rocks Surface	Dry days per year Percent of the time the wind exceeds 12 mph Snowcover
Wind erosion of exposed areas	Tailings basin beach and slopes	Percent of the time the wind exceeds 12 mph Thornthwaite's P-E Index[3/] Snowcover
Batch load-out	Pellets	Mean annual wind speed Material surface moisture[a/] Snowcover

a/ Material surface moisture is related to climatic conditions such as amount of rain, days since last rain, solar radiation, relative humidity, mean wind speed, and temperature, and is consequently listed under climatic conditions.

TABLE 5. MOISTURE MEASUREMENTS AT EMC

Sampling location	Variable analyzed	1978 Date 5/2	5/11	5/17	5/24	5/30	6/6	6/7	6/8	6/15	6/22	6/28	Avg.	SD
Service road	Moisture (%)	0.56	-	0.5	0.4	-	0.9	-	-	0.4	0.3	0.3	0.48	0.21
	Time	0900	-	0815	0830	-	0845	-	-	0830	1145	1400	-	-
Haul road	Moisture (%)	1.3	-	1.5	0.8	-	-	-	-	-	-	-	1.2	0.32
	Time	0800	-	0900	0915	-	-	-	-	-	-	-	-	-
Tailings basin beach	Moisture (%)	0.35	-	-	-	-	-	-	-	-	-	-	0.35	0
	Time	1100	-	-	-	-	-	-	-	-	-	-	-	-
Pellet pile	Moisture (%)	0.18	0.72	0.05	-	4.5	-	1.9	2.3/1.8/1.6	0.06	-	-	1.5	1.4
	Time	1045	0845	1035	-	1300	-	1300	0915/1200/1430	0945	-	-	-	-
-	Rainfall on measurement date (in.)	0	0.01	0	0	0.14	0.85	0.28	0.01	Trace	0	0	-	-
-	Rainfall in preceding 3 days (in.)	0	1.17	0	0	1.63	0.06	0.91	1.03	0.06	0	0.15	-	-
-	Evaporation (in.)	-	-	0.21	0.21	0.02	0.27	0.13	0.18	0.01	0.28	0.23	-	-
-	Time of rain	-	-	-	-	0700-1900	1700-2400	0000-1000	-	-	-			

TABLE 6. SUMMARY OF CORRECTION PARAMETERS USED

Source	Correction parameters
Vehicular traffic on unpaved roads	s = 5.9% (loaded and unloaded haul trucks on haul roads)
	= 4.3% (light-duty and medium-duty vehicles on service roads)
	S = 9 mph (loaded haul trucks)
	= 15 mph (unloaded haul trucks)
	= 20 mph (medium-duty vehicles)
	= 30 mph (light-duty vehicles)
	W = 58 ST (unloaded haul trucks)
	= 154 ST (loaded haul trucks)
	= 5 and 25 ST (medium-duty vehicles)
	= 3 ST (light-duty vehicles)
Wind erosion	s = 0.5% (soil)
	= 0.25% (rock)
	= 3.4% (pellets)
	= 10.9% (tailings basin beaches)
	= 10.9% (tailings basin slopes)
	d = 255 dry days (soil rock and pellets)
	f = 28.3% (soil, rock, pellets, and tailings basins and beaches)
	P-E = 112 (tailings basins and beaches)
	e = 75 ST/acre/year (tailings basins and beaches)
	D = 197 days (pellets)
Pellet handling	s = 5.0% (loading pocket to railcar and stacker to pile)
	S = 3.4% (pile to railcar)
	U = 8.4 mph (loading pocket to railcar, stacker to pile, and pile to railcar)
	M = 1.5% (loading pocket to railcar and stacker to pile)
	M = 0.25% (pile to railcar)
	Y = 14 yd^3 (pile to railcar)

These emission factors will be called uncontrolled even though some of the climatic parameters which provide control are in the predictive equations. It should also be emphasized that these emission factors represent the mass of particles smaller than 30 μm in diameter which is equivalent to the mass that a Hi-Volume sampler would measure.

2.2 DETERMINATION OF EMISSION FACTOR VALUES

The correction parameters quantified in Section 2.1 were substituted in the equations in Table 1 to yield the emission factors applicable to EMC in 1976. The resulting values are shown in Table 7.

The only emission factor in Table 8 that was not obtained from predictive equations was blasting. Table 8 shows the results of all the known testing currently available for blasting. The wide range of values measured (two orders of magnitude) shows the need for further testing to develop a predictive equation to quantify the emissions. The emission factor for blasting was obtained by deleting the highest and the lowest values in Table 8, deleting 0.013 lb/ST which was reported as atypically high, and averaging the remaining two values.

2.3 DETERMINATION OF SOURCE EXTENT

All the source extent data for 1976 were provided by mine personnel. Either past production records or mine personnel estimates were obtained and utilized wherever possible. The sources of interest and the source extent data necessary are shown in Table 9.

In order to calculate the vehicle-miles traveled on unpaved roads, three sources of information were used: (a) the 1976 actual one-way haul distance by mine area and by material; (b) the amount of material moved from each area; and (c) the average haul truck capacity. Table 10 shows the 1976 actual one-way haul distances and the actual amounts of material handled.

In order to calculate the number of trips, the actual long tons of material handled were divided by the average amount handled per trip. The truck fleet in 1976 was composed of 24, 85-LT capacity trucks, seven, 45-LT capacity trucks, three, 100-LT capacity trucks, and one, 170-LT capacity truck. Since the 85-LT capacity trucks were predominant, the average amount handled per trip was assumed to be 85 LT.

Finally, the vehicle-miles traveled one way in 1976 were calculated by multiplying the one-way haul distance by the number of trips. The vehicle-miles listed in Table 10 were traveled one way by loaded trucks and the opposite way by unloaded trucks.

TABLE 7. EMISSION FACTOR VALUES UTILIZED

Source	Emission factor value	Control inherent in value
Vehicular traffic on unpaved roads		
• Loaded haul trucks	20.3 lb/VMT	Uncontrolled
• Unloaded haul trucks	15.6 lb/VMT	Uncontrolled
• Medium-duty vehicles	2.1-7.7 lb/VMT	Uncontrolled
• Light-duty vehicles	2.1 lb/VMT	Uncontrolled
Wind erosion		
• Soil stockpile	870 lb/acre/year	Corrected for precipitation
• Rock stockpile	435 lb/acre/year	Corrected for precipitation
• Pellet stockpile	0.51 lb/ST	Corrected for precipitation
• Tailings basin beach	836 lb/acre/year	Corrected for precipitation
• Tailings basin slope	836 lb/acre/year	Corrected for precipitation
Pellet handling		
• Loading pocket to railcar	0.0054 lb/ST	Corrected for precipitation
• Stacker to pile	0.0054 lb/ST	Corrected for precipitation
• Pile to railcar	0.056 lb/ST	Uncontrolled
Blasting	0.006 lb/ST	Uncontrolled
Vehicular traffic on paved roads		
• Medium-duty vehicles	0.27 lb/VMT	Uncontrolled
• Light-duty vehicles	0.18 lb/VMT	Uncontrolled

TABLE 8. BLASTING EMISSION FACTORS

Emission factor (lb/ST)	No. of tests	Material	Reference
0.16[a]	1	Granite	7
0.00015[a]	1	Limestone	8
0.0083[b]	[c]	Bituminous coal	9
0.013[d]	1	Overburden	10
0.0042[e]	2	Lignite coal	10

a/ Particles less than 40 μm in diameter.

b/ Particles less than 7 μm in diameter.

c/ Unknown.

d/ Reference 9 indicates that this value is atypically high. This value represents particulate that has a regional impact, i.e., beyond 5 km from the source.

e/ This value was given as 11.7 lb/blast and was converted to pounds per short ton given 30,000 ft^2 blasted at a depth of 4 ft with a banked coal density of 1 ST/yd^3. This value represents particulate that has a regional impact, i.e., beyond 5 km from the source.

TABLE 9. SOURCE EXTENT DATA NEEDED

Source	Annual source extent
Vehicular traffic on unpaved roads	Vehicle-miles traveled by each vehicle weight class and by each vehicle speed class
Wind erosion from soil dumps	Acres exposed
Wind erosion from rock dumps	Acres exposed
Wind erosion from tailings basin	Acres exposed
Handling of pellets	Short tons
Wind erosion from pellet stockpile	Short tons
Blasting	Short tons shot

TABLE 10. VEHICLE-MILES TRAVELED BY HEAVY-DUTY TRAFFIC ON UNPAVED ROADS

Mine area	Material	1976 Actual one-way haul distance (ft)	Actual long tons handled by haul truck in 1976	No. of trips in 1976[a]	Vehicle-miles traveled one way
1	Surface	8,100	1,270,000	14,900	22,900
1	Rock	5,538	4,520,000	53,200	55,800
1	Ore	2,520	107,000	1,260	601
2	Surface	4,450	39,400	464	391
2	Rock	6,400	2,920,000	34,300	41,600
2	Ore	4,293	5,820,000	68,500	55,700
5	Surface	2,657	1,900,000	22,400	11,300
5	Rock	2,831	4,420,000	52,000	27,900
5	Ore	2,214	1,880,000	22,200	9,300
6	Rock	2,200	61,500	723	302
6	Ore	4,408	4,240,000	49,900	41,600
8	Surface	3,200	24,500	288	174
8	Rock	3,523	4,550,000	53,500	35,700
8	Ore	3,594	6,440,000	75,700	51,600
9	Surface	4,900	651,000	7,650	7,100
9	Rock	3,000	356,000	4,190	2,380
9	Ore	5,089	5,760,000	67,700	65,300

a/ Actual long tons handled divided by 85 LT/load.

The vehicle-miles traveled by light-duty and medium-duty vehicles on unpaved roads were determined by mine personnel from (a) the EMC 1976 mine equipment budget distribution and (b) an estimate of the miles traveled on unpaved roads per vehicle. Table 11 shows the equipment assumed to be traveling mainly in the mines, the estimated miles of travel per vehicle occurring in 1976, and the total vehicle-miles traveled.

In order to determine the vehicle-miles traveled in each mine area, the total vehicle-miles traveled were apportioned by the percent of the total material moved from each area. It was assumed that the amount of light-duty and medium-duty traffic in each area was directly proportional to the amount of activity (i.e., material moved in each area).

The total amount of material handled at EMC by truck or rail was obtained from past plant records. Table 12 shows the amount of material handled in each area. As indicated in Table 12, 62% of the material handled was crude ore and the most active area, in terms of total material handled, was Area 1. The amount of tailings as presented earlier in the report was calculated by subtracting the long tons of concentrate from the long tons of crude ore milled. Both of these values were available from past production records.

The extent of the exposed dumps and tailings basins in 1976 were measured from maps of each mine area by EMC land reclamation personnel. A certain percentage of the dumps and the tailings basin beaches and slopes is controlled either by chemical treatment or by vegetation. For example, in 1976, 450 acres of tailings pond beaches were treated with a 10% solution of Coherex in water and an application rate of 0.25 gal. of solution per square yard. This control treatment started May 21, 1976, and was completed July 14, 1976. Treated areas where the crust deteriorated after the initial application were treated on an as-needed basis. Table 13 summarizes the data presented by EMC personnel.

The amount of pellets produced and the average amount stockpiled were obtained with the help of plant personnel. Production records indicated that 10,500,000 LT of pellets were produced in 1976, with 6,070,000 LT loaded immediately into trains from an overhead bin, and 4,450,000 LT placed into the pile for a storage duration which averaged 6 months in 1976.

The average amount of pellets stockpiled was a calculated value based on the assumption that EMC stops shipping pellets in early January and does not resume until early April. It was assumed that the stockpile grew from zero on January 1, to 4,450,000 LT by the end of April, and then was depleted to zero by the end of December. Consequently, the average amount in the stockpile over the year was 2,225,000 LT.

Table 14 shows the extent of blasting at EMC in 1976. EMC personnel provided data describing the total long tons shot in 1976 by mine area. It was assumed that all the crude ore in each area was shot and that the difference between the total shot and the crude shot yielded the waste rock that was shot.

TABLE 11. VEHICLE-MILES TRAVELED BY LIGHT-DUTY AND MEDIUM-DUTY VEHICLES ON UNPAVED ROADS

Vehicle type	Weight class	No. of vehicles	1976 Estimated miles (miles/vehicle/yr)	1976 Vehicle-miles traveled
Flatbed service trucks	L	47	9,000	423,000
1/2-Ton pickups	L	66	25,000	1,650,000
3/4-Ton pickups	L	2	7,000	14,000
Sedan and station wagons	L	4	7,000	28,000
Carryalls	L	10	5,000	50,000
Buses	M	8	10,000	80,000
Sprinkler trucks	M	2	8,000	16,000
Fuel trucks	M	6	8,000	48,000
1-Ton pickups	M	6	7,000	42,000
Weld trucks	M	1	7,000	7,000
Electric line trucks	M	2	8,000	16,000
Lube vans	M	4	8,000	32,000
Total				2,406,000

TABLE 12. MATERIAL HANDLING BY TRUCK OR RAIL AT EMC IN 1976

Area	Amount handled (1,000 LT)				
	Material				
	Surface	Waste rock	Crude ore	Total	% of Total
1	1,270	4,520	7,830	13,600	25
2	39.4	2,920	6,980	9,940	18
5	1,900	4,420	1,880	8,200	15
6	0	61.5	4,240	4,300	8
8	24.5	4,550	6,440	11,000	21
9	650	356	5,760	6,760	13
Total	3,890	16,800	33,100	53,800	100
% of Total	7	31	62	100	

TABLE 13. EXPOSED AREAS AT EMC IN 1976

Source	Acres uncontrolled	Acres controlled	
		Vegetation	Chemicals
Stockpiles			
Rock	762	368[b]	
Soil	228	375[c]	
Tailings basin[a]			
Slope	50	25	
Beach	563	450	450[d,e]

a/ There were 769 acres that were water covered.
b/ Anthropogenic vegetation started June 3, 1976, and was completed July 22, 1976.
c/ Natural vegetation.
d/ EMC personnel estimate 900 acres were treated but 50% were retreatments.
e/ Initial treatment started May 21, 1976, and was completed July 14, 1976. Dilution rate was 1:9; application intensity was 0.26 gal. of solution per square yard (130 gal. of concentrate/acre).

TABLE 14. AMOUNT OF MATERIAL BLASTED AT EMC IN 1976

Area	Material	Source extent (LT/yr)
1	Waste rock	4,430,000
	Ore	7,830,000
2	Waste rock	1,400,000
	Ore	6,980,000
5	Waste rock	5,200,000
	Ore	1,880,000
6	Waste rock	474,000
	Ore	4,240,000
8	Waste rock	4,200,000
	Ore	6,440,000
9	Waste rock	112,000
	Ore	5,760,000

2.4 DETERMINATION OF CONTROL EFFICIENCY

The controls used at EMC to reduce emissions from vehicles traveling on unpaved roads are varied. Watering, oiling, Trex (a lignosulfonate), and Coherex are used. In addition to these anthropogenic controls, the natural effects of precipitation also reduce emissions.

Days with precipitation in excess of 0.01 in. or snowcover in excess of 1 in. occurred during 46% of 1976. A 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 snowcover. In any case, further experimentation is needed to verify and/or refine this factor.

The efficiency of Coherex has not yet been definitively quantified but tests have shown a decay after only 1 day of heavy truck usage from 100 to 85% efficiency.[11/] Watering once per day has been measured at 0 to 70% efficiency.[12/] Trex, being soluble in water, tends to become ineffective after heavy rains. Since the mileage of roads treated by the different chemicals and the application rate and frequency were not recorded by EMC personnel, the overall annual efficiency could only be estimated. A value of 50% was selected.

Control of wind erosion from stockpiles, dumps, and tailings basins was attributable to the natural events of precipitation and snowcover. Equation 6, as presented in Table 1, already has a correction for precipitation (rain and snow) incorporated in the 1,280 constant. Twenty-three percent of the days with no precipitation still had more than 1 in. of snow on the ground. Thus, a control efficiency of 23% was applied to the already partially controlled emission factor.

In addition to natural control on the tailings basin beaches, the nature of the tailings disposal process yields some control. A certain portion of the beach is always active, that is, spigoting is occurring. This is assumed to occur over no more than 10% of the beach at any one time and, consequently, a 10% control was applied in addition to the 23% control obtained from snowcover to yield a net control of 31%.

At EMC, the loading pocket has rubber aprons which act as a nearly total enclosure around the operation of loading pellets into railcars from an overhead bin. This enclosure is vented to rotoclones which are estimated conservatively at 96% efficiency.[12/]

Emissions from load-in and load-out operations at the pellet stockpile are assumed to be controlled by natural mechanisms. Precipitation and snow-cover were assumed to provide a 46% reduction in potential emissions.

2.5 CALCULATION OF EMISSION RATES

The data presented in Sections 2.1 through 2.4 were utilized to calculate the controlled emission rates for all the important sources at EMC. Table 15 summarizes the emission factors, source extents, control efficiencies, and controlled emission rates for the various fugitive emission sources at EMC. Also shown in Table 15 is the rank of each source in order of significance on a source-by-source basis and on a generic source category basis.

SECTION 3.0

EMISSION FACTOR MEASUREMENT

After selecting the largest contributing source(s) of fugitive particulate emissions in the taconite industry, replicate field tests were conducted on these major sources. This testing was conducted to increase the existing data base and thereby improve the predictive emission factor equations already available. The predictive equations existing before this present study are shown in Table 1.

3.1 SELECTION OF SOURCE(S) FOR TESTING

The selection of the source(s) to be tested was based on Table 15. The assumption made was that the largest source(s) at EMC would also be the largest source(s) at the other seven taconite mines. Consequently, the source(s) tested are the most important source(s) in the industry.

From Table 15, it is clear that unpaved roads and specifically haul trucks are the major source of emissions in the taconite industry. Since nearly all of the previous testing by MRI was concerned with emissions from light-duty vehicles, the testing of heavy-duty vehicles was a logical choice in order to improve the reliability of the predictive equations.

The second category of sources in order of importance would be wind erosion. While the annual contribution of wind erosion to the particulate burden of the atmosphere at EMC is much less than that of vehicular traffic on unpaved roads and blasting, wind erosion can easily be a dominant cause of high daily concentrations. For this reason, wind erosion was deemed worthy of study. This is reinforced by the low reliability of the predictive equation for wind erosion as shown in Table 1.

The logical third choice for a source to be tested based on Table 15 would have been blasting. This is reinforced by the fact that no adequate predictive equations exist for blasting emissions. But due to the vastness of the plume, even near to the source where turbulent diffusion has not had time to expand the plume, and the destructive nature of the source, sampling that would produce meaningful and accurate emission factors was deemed unattainable using presently accepted sampling techniques.

TABLE 15. 1976 EMISSION INVENTORY FOR EMC

Source	Uncontrolled emission factor[a]	Annual source extent	Control efficiency (%)		Annual controlled emission rate (ST)	Individual source rank	Category-wide source rank
Vehicular traffic on unpaved roads							1
• Loaded haul trucks	20.3 lb/VMT	430,000 VMT	73	Watering, chemicals, precipitation, and snowcover	1,180	1	
• Unloaded haul trucks	15.6 lb/VMT	430,000 VMT	73		906	2	
• Medium-duty vehicles	7.7 lb/VMT	81,200 VMT	73		84		
	2.1 lb/VMT	241,000 VMT	73		68	7	
• Light-duty vehicles	2.1 lb/VMT	2,165,000 VMT	73		614	4	
Vehicular traffic on paved roads							4
• Medium-duty traffic	0.27 lb/VMT	68,000 VMT	46	Precipitation and snowcover	5	14	
• Light-duty traffic	0.18 lb/VMT	2,160,000 VMT	46		105	9	
Wind erosion							2
• Soil stockpile	870[b] lb/acre/year	228[c] acres	23	Snowcover	76	10	
• Rock stockpile	435[b] lb/acre/year	762[c] acres	23		128	8	
• Pellet stockpile	0.51[b] lb/ST	4,165,000 ST	23		820	3	
• Tailings basin beach	830[b] lb/acre/year	563[c] acres	31	Snowcover and spigoting	162	6	
• Tailings basin slope	816[b] lb/acre/year	50[c] acres	23	Snowcover	16	12	
Pellet handling							5
• Loading pocket to railcar	0.0054 lb/ST	6,800,000 ST	80	Rotoclone	3.7	15	
• Stacker to pile	0.0054 lb/ST	4,980,000 ST	0		13	13	
• Pile to railcar	0.056 lb/ST	4,350,000 ST	46	Precipitation and snowcover	66	11	
Blasting	0.006 lb/ST	55,900,000 ST	0		168	5	3

a/ Only particles less than 30 μm in diameter.

b/ Already corrected to allow for emissions reduction during wet days.

c/ Represents only unvegetated acres. Emissions from the vegetated acres shown in Table 13 were deemed negligible.

In this study, only emissions from haul trucks traveling on unpaved roads were tested. The effectiveness of a chemical dust suppressant was also tested although many more tests in this area are still needed to adequately quantify these control measures.

In the future, the second category of importance, wind erosion, should be investigated. This can be accomplished with a portable wind tunnel equipped with particulate sampling equipment. Such a device has already been used by MRI in another research effort. Variables affecting the emission factor such as material silt content, material surface moisture, mean wind speed, surface roughness, and material erodibility should be quantified concurrently with the emission factor.

3.2 TESTING METHODOLOGY

The following sections will discuss the implementation of the vertical profiling technique developed by MRI[3/] for measuring emissions from unpaved roads.

3.2.1 Testing Methodology for Unpaved Roads

The exposure profiling method was developed by MRI[3/] to measure particulate emissions from specific open sources, utilizing the isokinetic profiling concept which is the basis for conventional source testing. For measurement of nonbuoyant fugitive emissions, sampling heads are distributed over a vertical network positioned just downwind (usually about 5 m) from the source. Sampling intakes are pointed into the wind and sampling velocity is adjusted to match the local mean wind speed, as monitored by distributed anemometers. A vertical line grid of samplers is sufficient for measurement of emissions from line or moving point sources while a two-dimensional array of samplers is required for quantification of area source emissions. Figure 3 shows the profiler used for one-dimensional plumes such as those from vehicles traveling on unpaved roads when viewed perpendicular to the road.

3.2.1.1 Grid Size and Sampling Duration--

Sampling heads are distributed over a sufficiently large portion of the plume so that vertical and lateral plume boundaries may be located by spatial extrapolation of exposure measurements. The size limit of area sources for which exposure profiling is practical is determined by the feasibility of erecting sampling towers of sufficient height and number to characterize the plume. This problem is minimized by sampling when the wind direction is parellel to the direction of the minimum dimension of the area source.

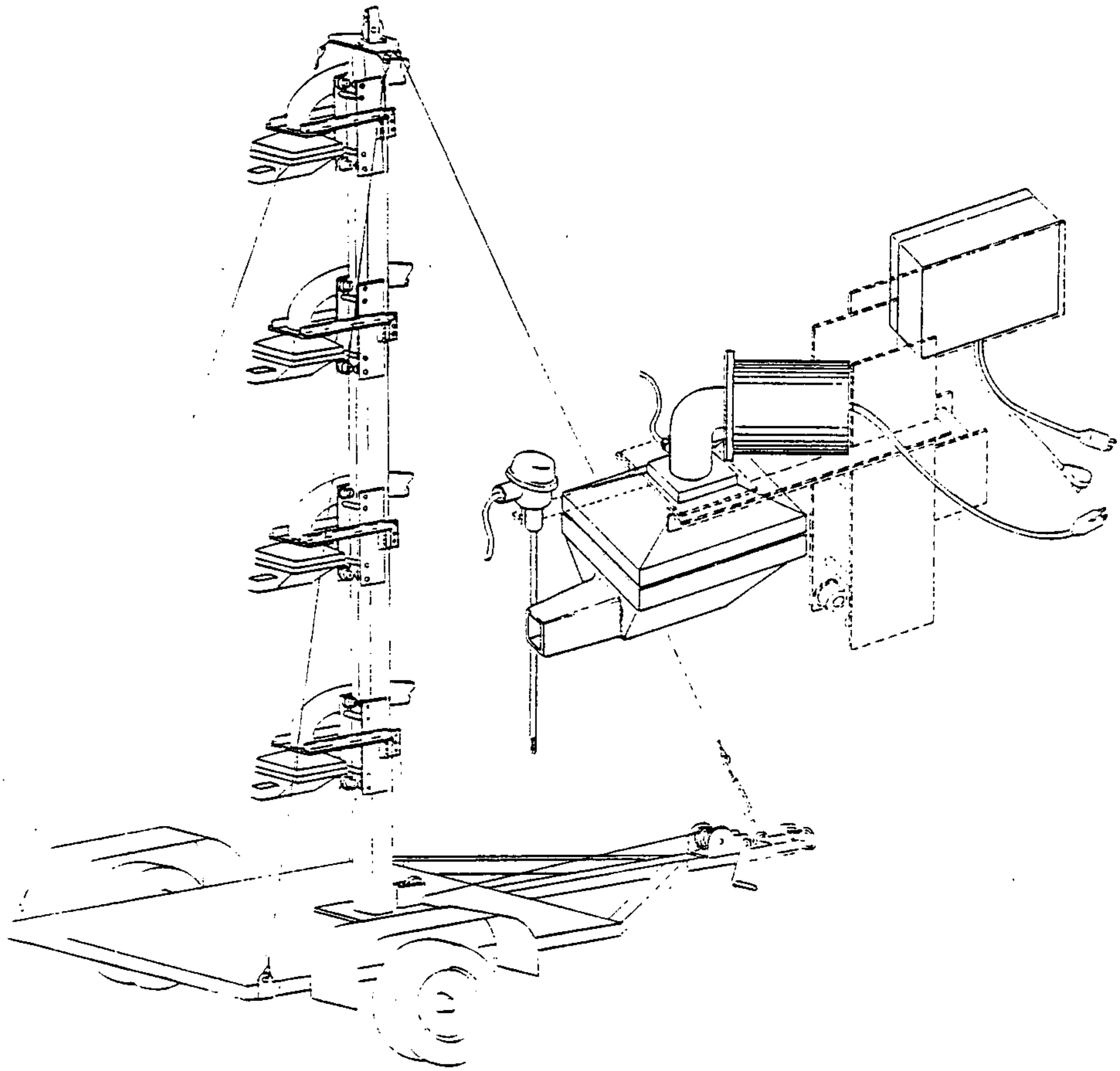


Figure 3. MRI exposure profiler - line source mode

The size of the sampling grid needed for exposure profiling of a particular source may be estimated by observation of the visible size of the plume or by calculation of plume dispersion. Grid size adjustments may be required based on the results of preliminary testing.

Particulate sampling heads should by symmetrically distributed over the concentrated portion of the plume containing about 90% of the total mass flux (exposure). For example, if the exposure from a point source is normally distributed, as shown in Figure 4, the exposure values measured by the samplers at the edge of the grid should be about 25% of the center-line exposure.

Sampling time should be long enough to provide sufficient particulate mass and to average over several units of cyclic fluctuation in the emission rate (for example, vehicle passes on an unpaved road). The first condition is easily met because of the proximity of the sampling grid to the source.

Assuming that sample collection media do not overload, the upper limit on sampling time is dictated by the need to sample under conditions of relatively constant wind direction and speed. In the absence of passage of weather fronts through the area, acceptable wind conditions might be anticipated to persist for a period of 1 to 6 hr.

3.2.1.2 Calculation Procedure--

The passage of airborne particulate, i.e., the quantity of emissions per unit of source activity, can be 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:

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

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, and

A = effective cross-sectional area of plume.

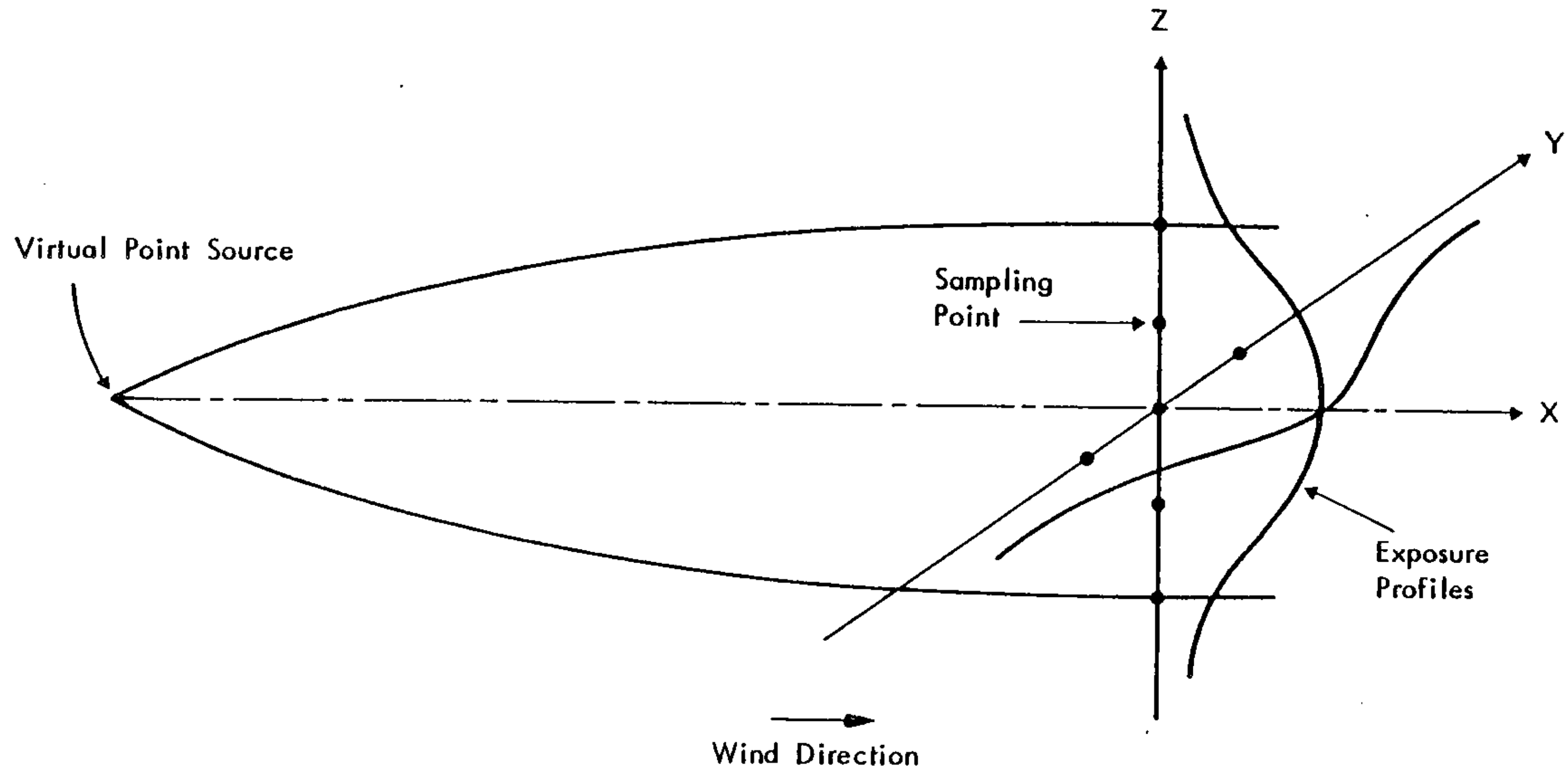


Figure 4. Example exposure profiling arrangement.

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

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

where W = width of the sampling intake, and

H = effective extent of the plume above ground.

In order to obtain an accurate measurement of airborne particulate exposure, sampling must be conducted isokinetically, i.e., 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.

If it is necessary to sample at a nonisokinetic flow rate (for example, to obtain sufficient sampler under light wind conditions), multiplicative factors may be used to correct measured exposures to corresponding isokinetic values.[3,4] These corrections require information on the particle size distribution of the emissions.

High-volume cascade impactors with glass fiber impaction substrates, which are commonly used to measure particle size distribution of atmospheric particulate, may be adapted for sizing of fugitive particulate. A cyclone preseparator (or other device) is needed to remove coarse particles which otherwise would be subject to particle bounce within the impactor causing fine particle bias.[4] Once again, the sampling intake should be pointed into the wind and the sampling velocity matched to the mean local wind speed.

If it is necessary to sample at a nonisokinetic flow rate (for example, 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:[4]

	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, and

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:

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

As stated above, a cyclone preseparator was used in conjunction with a high-volume cascade impactor 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 backup filter, thereby causing fine particle measurement bias.

Although the cyclone precollector was designed by the manufacturer to have a 50% cutoff diameter of 7.6 μm (particle density of 2.5 g/cm^3 and flow rate of 40 acfm), laboratory calibration of the cyclone, reported in May 1976, indicated the effective cutoff diameter to be 3.5 μm for a particle density of 2.5 g/cm^3 and a flow rate of 40 acfm. Because this value overlapped the cutoff diameter of the first impaction stage (6.4 μm), and was nearly equal to that of the second stage, it was decided to eliminate the first two stages of the impactor and operate with only the last three stages and a backup filter. The cascade impactor was operated at 20 acfm which produced a 50% cutoff diameter for the cyclone precollector of 7 m for a particle density of 2.5 g/cm^3.

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 fact that there is generally a monotonic decrease in collected particulate weight on each successive impaction state, followed by a several-fold increase in weight collected by the backup filter, indicates that additional correction for coarse particle bounce is needed.

The excess particulate on the backup filter is postulated to consist of coarse particles that penetrated the cyclone (with small probability) and bounced through the impactor. 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 backup filter was reduced by setting it equal to the average percentage collected on the last two stages of the impactor.

In summary, by increasing the existing data base through replicate exposure profiling of open dust sources under varying conditions of source activity and properties of the emitting surface, emission factor formulas can be improved. These formulas account for the fraction of silt (fines) in the emitting surface, the surface moisture content, and the rate of mechanical energy expended in the process which generates the emissions. The predictive emission factor equations are determined as a function of the particle size of concern in the atmosphere.

3.3 TEST RESULTS AND EXAMPLE CALCULATIONS

This subsection provides a detailed presentation of the test results and corresponding calculation procedures for the tests performed to quantify emissions from haul trucks traveling on unpaved roads.

3.3.1 Traffic on Unpaved Roads

An understanding of sampling equipment locations during testing is important to the interpretation of the results. Figures 5 and 6 display a top and side view, respectively, of the general equipment layout during the unpaved road tests. In addition to the profiler which was generally located 5 m from the edge of the road, four hi-vols were located 5 m upwind, and 5, 20, and 50 m downwind. The Sierra cascade impactor was located 5 m downwind. Wind speed and direction devices were located 5 m upwind and 50 m downwind.

Table 16 gives information on the time of each unpaved road test and the prevailing meteorological conditions at the site. Also given for each test is the number of vehicle passes by vehicle type. Table 17 gives the climate conditions which may have had an effect on the emission generated during the tests.

Table 18 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. Also given for each high-volume sampling head is the exposure measurement consisting of particulate collected by the filter following the settling chamber.

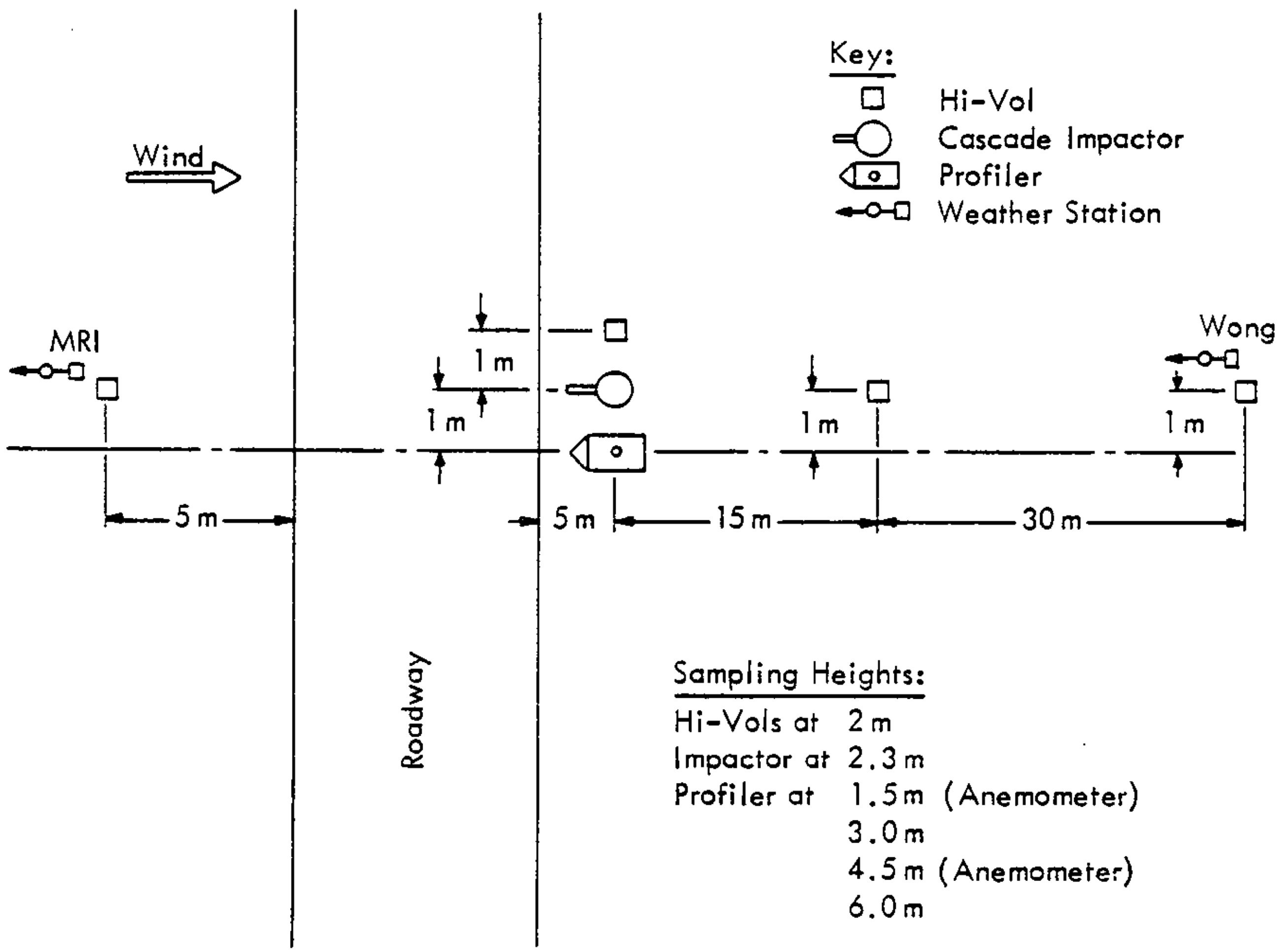


Figure 5. Positioning of air sampling equipment--top view.

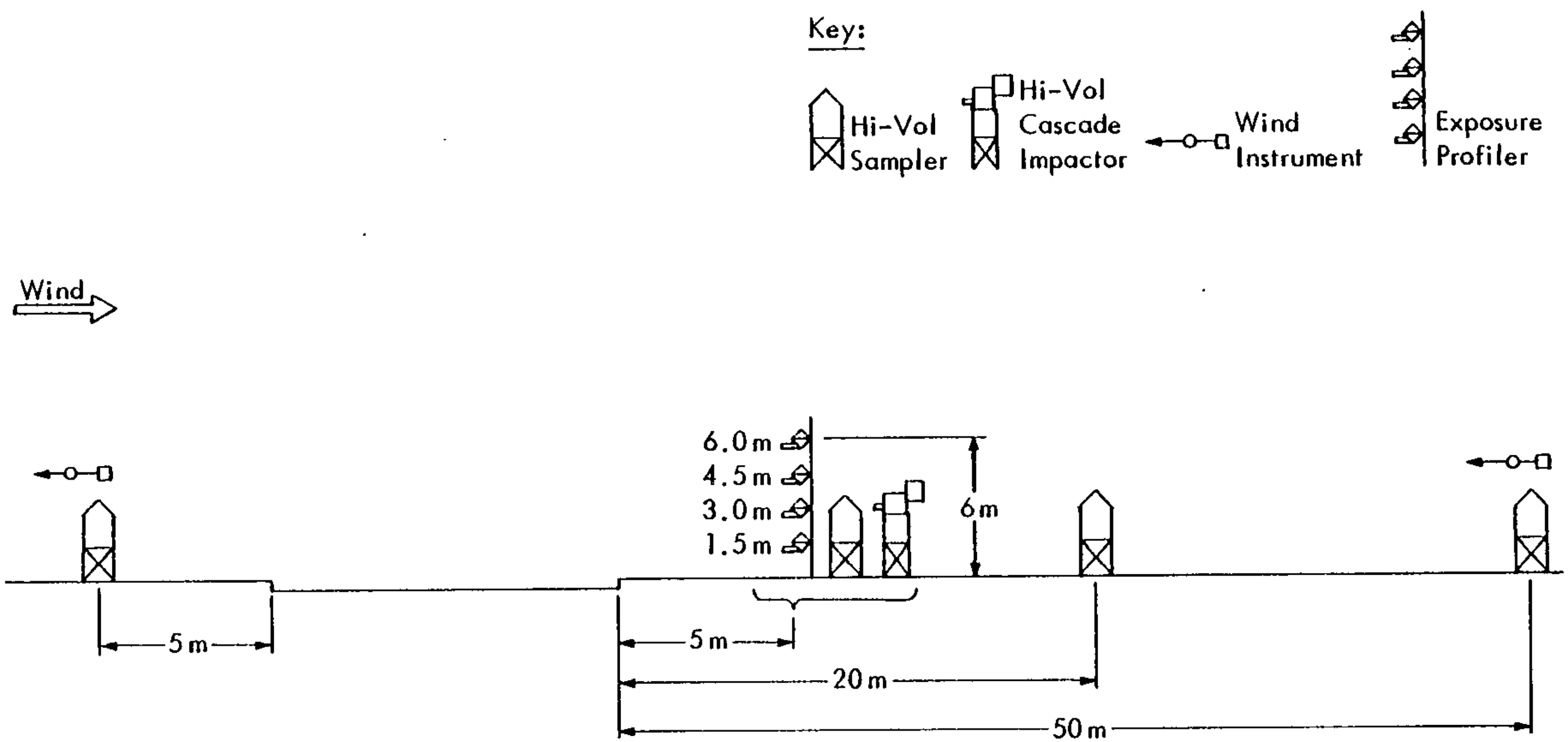


Figure 6. Positioning of air sampling equipment--side view.

TABLE 16. EMISSIONS TEST PARAMETERS--UNPAVED ROADS

Surface material	Test	Date	Start Time	Exposure sampling duration (min)	Source orientation	Ambient temperature (°F)	Wind direction	Wind speed (mph) At 1.5 m	Wind speed (mph) At 4.5 m	Cloud cover (%)	No. of vehicle passes
Sand-gravel	1-1	6/5/78	14:45	55	N-S	78[a]	WSW	-	-	0	15 unloaded haul trucks
	1-2	6/6/78	10:15	35	N-S	70	SSW	11	14	0	15 unloaded haul trucks
	1-3	6/6/78	11:20	44	N-S	78	SSW	14	20	0	15 unloaded haul trucks
	1-4	6/6/78	14:42	47	N-S	78[b]	SSW	12	17	20	15 loaded haul trucks
	1-5	6/6/78	16:29	44	N-S	78	SSW	9	13	80-100	15 loaded haul trucks
	1-6	6/8/78	9:49	68	N-S	62	WSW	3	4	0 (80% haze)	30 loaded haul trucks
Untreated crushed rock	1-7	6/8/78	15:09	52	NNE-SSW	73	WSW	14	16	80	15 mixed[c]
	1-8	6/8/78	16:23	29	NNE-SSW	72	WSW	13	14	90	11 mixed[d]
Crushed rock treated with Trex[a]	1-9	6/9/78	10:30	66	NNE-SSW	52	SSE	1	1.5	0	21 mixed
	1-10	6/9/78	12:37	58	NNE-SSW	63	SSE	1.5	2	50	21 mixed
	1-11	6/9/78	14:00	43	NNE-SSW	66	SSE	2	3	90	19 mixed

a/ Trex is a lignosulfonate chemical dust suppressant.
b/ Assumed value.
c/ Thirteen haul trucks; two pickups.
d/ Nine haul trucks; one pickup; one dozer.

TABLE 17. CLIMATIC CONDITIONS AFFECTING TESTS

Date	Temperature (°F)			Relative humidity (%)		Precipitation		
	Min.	Max.	Avg.	Noon	Midnight	Amount (in.)	Start time	Stop time
6/1/78	40	54	47	85	90	0.53	0001	0245
6/2/78	38	62	50	50	90	0.02	0002	0300
6/3/78	35	68	52	35	90	0	--	--
6/4/78	49	68	58	50	65	0.06	0300	0345
6/5/78[a]	39	76	58	40	95	0	--	--
6/6/78[a]	46	81	54	35	85	0.85	1725	2400
6/7/78	40	59	40	85	90	0.28	0001	1040
6/8/78[a]	33	69	51	40	75	0.01	0615	--
6/9/78[a]	30	60	45	35	85	0	--	--

a/ Test days.

TABLE 18. PLUME SAMPLING DATA--UNPAVED ROADS

Test No.	Sampling height (m)	Sampling rate (cfm)	Total exposure (mg/cm^2)	Filter exposure (mg/cm^2)
I-1	1.5	20.0	1.44	0.76
	3.0	23.5	0.71	0.51
	4.5	25.5	0.61	0.45
	6.0	27.0	0.48	0.32
I-2	1.5	21.0	2.33	0.65
	3.0	25.5	1.29	0.55
	4.5	28.0	1.29	0.54
	6.0	29.0	1.13	0.46
I-3	1.5	33.0	2.83	1.61
	3.0	36.0	2.77	1.18
	4.5	39.5	1.64	0.91
	6.0	39.5	0.88	0.54
I-4	1.5	33.0	4.41	2.81
	3.0	36.0	3.59	2.35
	4.5	39.5	2.30	1.60
	6.0	39.5	1.40	0.76
I-5	1.5	33.0	5.26	3.74
	3.0	36.0	3.83	2.72
	4.5	39.5	3.68	2.55
	6.0	39.5	2.18	1.64
I-6	1.5	14.8	0.60	0.19
	3.0	20.0	0.32	0.18
	4.5	21.0	0.76	0.26
	6.0	22.5	0.44	0.22
I-7	1.5	34.0	5.35	3.56
	3.0	36.5	3.65	2.45
	4.5	39.5	2.32	1.76
	6.0	39.0	1.65	0.98

(continued)

TABLE 18. (Concluded)

Test No.	Sampling height (m)	Sampling rate (cfm)	Total exposure (mg/cm^2)	Filter exposure (mg/cm^2)
I-8	1.5	34.0	2.30	1.70
	3.0	36.5	1.74	1.19
	4.5	39.5	0.85	0.68
	6.0	39.0	0.46	0.31
I-9	1.5	12.5	0.30	0.10
	3.0	15.5	0.35	0.16
	4.5	16.5	0.30	0.14
	6.0	17.0	0.27	0.09
I-10	1.5	12.0	0.77	0.26
	3.0	15.5	0.56	0.21
	4.5	16.5	0.35	0.18
	6.0	17.0	0.41	0.19
I-11	1.5	12.0	0.72	0.19
	3.0	15.5	0.62	0.13
	4.5	16.5	0.42	0.16
	6.0	17.0	0.36	0.17

Table 19 gives for each test the integrated exposure value and 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 in close proximity, near the center of the plume. Concentrations measured by the profiler head at 1.5 m are, in general, higher than values measured by the other two units because the profiler sampled at 1.5 m above ground rather than 2 m.

Table 20 summarizes the particle sizing data for the 11 unpaved road tests. Particle size is expressed as Stokes (equivalent-sphere) diameter based on actual density of silt-size particles. In addition to data from the cascade impactor measurements, Table 20 also gives for each run the average percent of the exposure measurement consisting of filter catch weighted by the exposure value measured by each sampling head.

Table 21 presents the emission factors corrected to represent particles smaller than 30 μm in diameter. Also indicated in Table 21 are material properties which constitute correction factors to the emission factors.

Table 22 presents an example emission factor calculation. The calculation is based on data for Test I-1.

TABLE 19. SUSPENDED PARTICULATE CONCENTRATION AND EXPOSURE MEASUREMENTS--UNPAVED ROADS

Surface material	Test No.	Particulate concentration ($\mu g/m^3$) at 2 m above ground				Isokinetic ratio for profiler (u/U)	Integrated[b/] filter exposure (lb/vehicle mile)
		Background	Downwind, including background				
			Profiler[a/]	Standard Hi-Vol	Cascade impactor		
Sand-gravel	I-1	13	1,510	1,430	376	1.32	9.2
Sand-gravel	I-2	169	2,540	671	4,020	0.77	10.2
Sand-gravel	I-3	169	1,810	1,930	1,800	0.89	19.0
Sand-gravel	I-4	169	2,870	2,250	2,990	1.05	33.4
Sand-gravel	I-5	169	4,240	4,800	4,160	1.33	49.5
Sand-gravel	I-6	90	1,140	389	576	2.04	2.3
Untreated crushed rock	I-7	90	2,810	2,540	3,780	1.01	38.8
Untreated crushed rock	I-8	90	2,370	1,591	3,320	1.10	23.7
Crushed rock treated with trex	I-9	58	616	383	588	4.35	2.0
Crushed rock treated with trex	I-10	58	2,600	689	881	3.23	2.7
Crushed rock treated with trex	I-11	58	1,370	939	566	2.32	2.4

a/ Isokinetic at 1.5 m.

b/ Nonisokinetic.

TABLE 20. PARTICLE SIZING DATA SUMMARY--UNPAVED ROADS (Density = 3 g/cm^3)

Surface material	Test no.	Cascade impactor: Mass median diameter (μm)	Cascade impactor: Percent < 30 μm	Cascade impactor: Percent < 5 μm	Cascade impactor: Percent > 50 μm	Cascade impactor: Ratio a/	Profiler: Weighted average % capture on the filter
Sand-gravel	I-1	>100 b/	26 b/	12.5 b/	69 b/	0.48 b/	62
Sand-gravel	I-2	>100	26	12.5	69	0.48	37
Sand-gravel	I-3	53	39	12	51	0.31	52
Sand-gravel	I-4	68	35	11	56	0.31	64
Sand-gravel	I-5	70	38	16.5	55	0.43	71
Sand-gravel	I-6	34	48	17.5	42	0.36	40
Untreated crushed rock	I-7	>100	20	8	75	0.4	67
Untreated crushed rock	I-8	75	36	15	56	0.42	72
Crushed rock treated with Trex	I-9	28	52	14	35	0.27	40
Crushed rock treated with Trex	I-10	58	41	19	52	0.46	40
Crushed rock treated with Trex	I-11	9.4	84.5	29	7	0.34	31

a/ Percent < 5 μm ÷ percent < 30 μm.

b/ Assumed the same as I-2.

TABLE 21. EMISSION FACTOR SUMMARY--UNPAVED ROADS

Surface material	Test no.	Measured emission factor[a] (lb/vehicle mile)	Vehicle passes	Surface material: Density[b] (g/cm^3)	Surface material: Silt (s) (%)	Vehicle speed (S) (mph)	Average gross vehicle weight (W) (ST)
Sand-gravel	I-1	3.7	15	3.0	4.7[c]	15	67
Sand-gravel	I-2	7.5	15	3.0	4.7[c]	15	67
Sand-gravel	I-3	14.5	15	3.0	4.7[c]	15	67
Sand-gravel	I-4	18.1	15	3.0	4.7[c]	15	157
Sand-gravel	I-5	25.0	15	3.0	4.7[c]	15	157
Sand-gravel	I-6	2.3	30	3.0	2.4[d]	20	157
Untreated crushed rock	I-7	11.6	15	3.0	6.1[e]	13.5	118
Untreated crushed rock	I-8	11.6	11	3.0	6.1[e]	13.5	117
Crushed rock treated with Trex	I-9	2.0	21	3.0	1.3	13	110
Crushed rock treated with Trex	I-10	2.3	21	3.0	1.5	13	112
Crushed rock treated with Trex	I-11	3.5	19	3.0	1.8	14	127

a/ Represents particles smaller than 30 μm in diameter.

b/ Assumed value.

c/ Average of samples taken during I-2, I-3 and I-4.

d/ 1.0% was measured before the test and 3.8% after. The 1.0% was not representative as the wet road made it difficult to collect a proper sample.

e/ Average of samples taken during I-7 and I-8.

TABLE 22. EXAMPLE CALCULATION FOR TEST I-1--UNPAVED ROADS

	Result
A. Plot filter exposure versus sampler height	-
B. Graphically integrate to determine the area under the vertical exposure profile	138 lb/mile
C. Divide B by the number of vehicle passes (15) to arrive at the integrated filter exposure	9.2 lb/vehicle-mile
D. Multiply C by the ratio of the percent $<30\ \mu m$ (26) over the weighted average percent captured on the filter (62) to obtain the emission factor for particles smaller than $30\ \mu m$	3.9 lb/vehicle-mile
E. Correct D to isokinetic conditions following the procedure given in Section 3.2.1	3.7 lb/vehicle-mile

SECTION 4.0

PREDICTIVE EMISSION FACTOR EQUATION

This section presents the analysis of the test data presented in Section 3.3.1. The objective of the analysis was to determine if the test data added to the existing data base indicated that a modification of the unpaved road predictive emission factor equation was needed.

4.1 UNPAVED ROADS

Table 23 summarizes all the unpaved road emission tests performed by MRI. The measured emission factors along with the important independent variables affecting emissions are shown. In addition, the predicted emission factors calculated using the revised emission factor equation resulting from the addition of the EMC tests to the existing data base are also shown. Finally, a comparison of predicted versus actual emissions is shown in Table 23 and in Figure 7.

Tests in Table 23 that are preceded by R represent experiments performed in Kansas on rural roads; tests preceded by A, E, F, and G represent experiments performed on unpaved roads in iron and steel plants; and tests preceded by I represent experiments performed on unpaved haul roads at EMC.

It should be noted that several of the tests listed in Table 23 were not used in revising the unpaved road emission factor equation. This is because the equation is applicable only for (a) uncontrolled roads during dry conditions and (b) roads which have reached an equilibrium condition with the traffic traveling upon it, i.e., where the amount of fine particulate produced on the road by grinding the aggregate equals the amounts lost from the road into the air.

The following 10 tests were not utilized in the analysis of the data base for the aforementioned reasons. Tests F-24, F-25, I-9, I-10, and I-11 were performed on controlled roads. Tests I-6, I-7, and I-8 were performed the day after heavy rains. Tests I-1 and I-2 were performed on a new road which had not had a chance to equilibrate with the traffic upon it.

TABLE 23. PREDICTED VERSUS ACTUAL EMISSIONS FOR UNCONTROLLED, UNPAVED ROADS DURING DRY CONDITIONS

Run	Road surface Type	Road surface Silt (%)	Average vehicle Speed (mph)	Average vehicle Weight (ST)	Average No. of vehicle wheels	Emission factor[a] Predicted[b] (lb/VMT)	Emission factor[a] Actual (lb/VMT)	Predicted / Actual
R-1	Crushed limestone	12	30	3	4.0	5.9	6.0	0.98
R-2		12	30	3	4.0	6.4	6.8	0.94
R-3		13	40	3	4.0	8.5	7.9	1.08
R-8	Dirt	20	30	3	4.5	10.4	8.1	1.29
R-10		5	40	3	4.0	3.3	3.9	0.85
R-13		68	30	3	4.0	33.0	32.0	1.03
A-14	Crushed slag	4.8	30	70	4.0	21.4	21.5	1.00
A-15		4.8	30	70	4.0	21.4	23.0	0.93
E-1	Dirt	8.7	14	34	9.4	16.7	13.6	1.23
E-2		8.7	16	34	8.3	18.0	12.2	1.47
E-3		8.7	16	23	6.4	12.0	14.5	0.83
F-21	Dirt/ crushed slag	9.0	15	3	4.0	2.2	3.0	0.73
F-22		9.0	15	3	4.0	2.2	1.7	1.29
F-23		9.0	15	4	4.1	2.7	2.3	1.19
F-24	Dirt/slag (Coherex®)[c]	0.03	15	3	4.0	d/	0.073	-
F-25		0.02	15	3	4.0	d/	0.36	-
G-27	Crushed slag	5.3	22	17	11.0	10.7	12.0	0.89
G-28		5.3	23	12	9.5	8.1	7.2	1.13
G-29		5.3	24	9	7.8	6.3	5.6	1.12
G-30		4.3	25	14	8.5	7.5	8.7	0.87
G-31		4.3	29	3	6.2	6.1	6.1	0.99
G-32		4.3	22	30	13.0	14.0	16.0	0.88
I-1[e]	Crushed rock and glacial till	4.7	15	67	6.0	d/	3.7	-
I-2[e]		4.7	15	67	6.0	d/	7.5	-
I-3[e]		4.7	15	67	6.0	12.4	14.5	0.86
I-4[e]		4.7	15	157	6.0	22.6	18.1	1.25
I-5[e]		4.7	15	157	6.0	22.6	25.0	0.90
I-6[e,f]		2.4	20	157	6.0	d/	2.3	-
I-7[g]	Crushed rock (taconite/ waste)	6.1	13.5	118	6.0	d/	11.6	-
I-8[g]		6.1	13.5	127	6.0	d/	11.6	-
I-9	Crushed rock (TREX)[c]	1.3	13	110	6.0	d/	2.0	-
I-10		1.5	13	112	6.0	d/	2.3	-
I-11		1.8	24	127	6.0	d/	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.

d/ Equation not applicable for reasons shown in footnotes c, e, and f.

e/ Test Series I-1 through I-6 performed on previously inactive road.

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

g/ Assumed value.

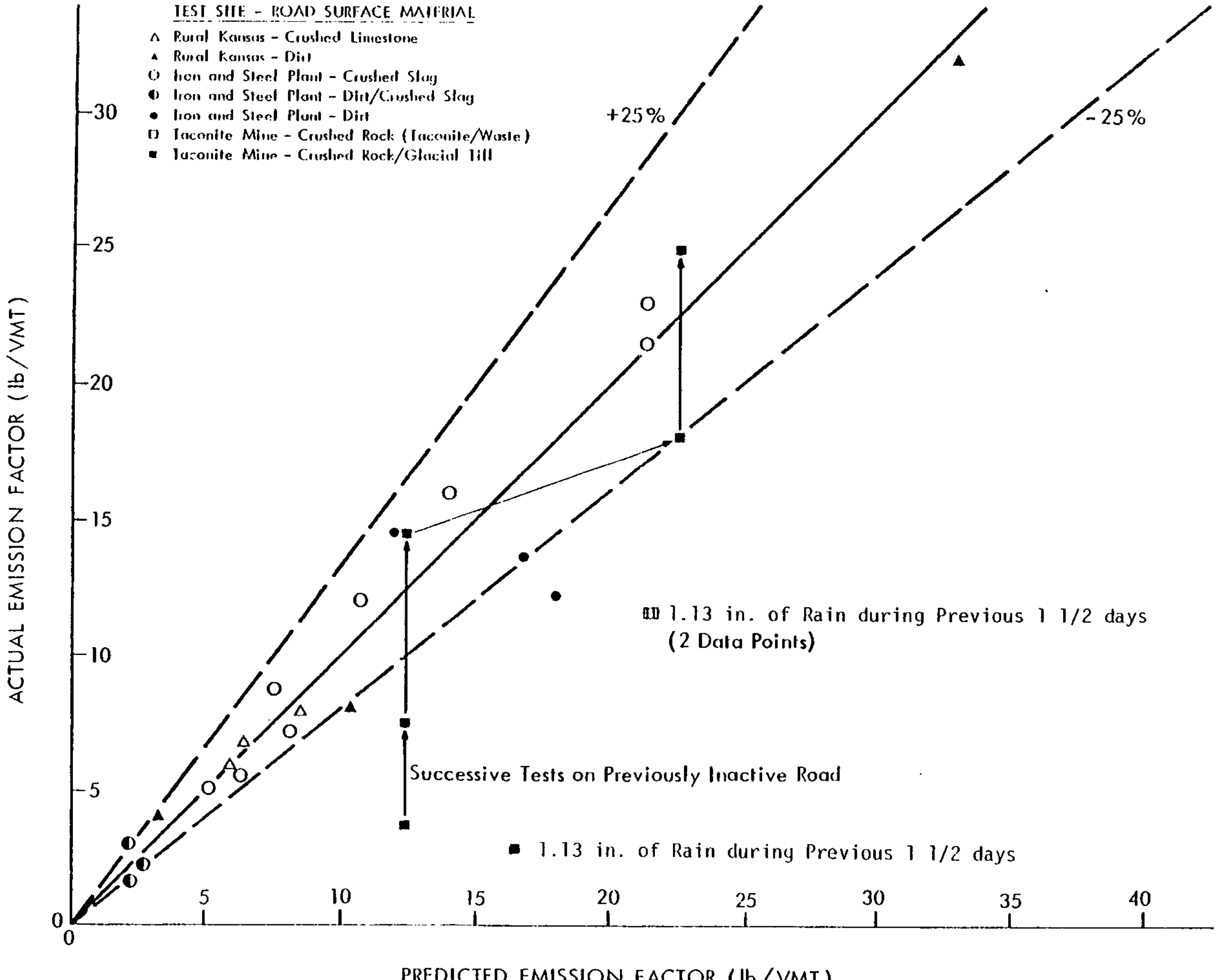


Figure 7. Comparison of predicted and actual emissions--untreated roads

A multiple regression analysis was performed on the remaining 23 tests. An equation of the following form was proposed:

$$EF = \alpha \, s^{\beta_1} S^{\beta_2} W^{\beta_3} w^{\beta_4}$$

where α, β_1, β_2, β_3, and β_4 = constants to be determined, and

w = average number of wheels per vehicle.

The other terms in the proposed form of the revised predictive equation are defined in Table 1. The proposed form of the equation was then linearized by taking the logarithm of both sides and performing a least squares multiple linear regression on the data. The results of the analysis are shown as follows:

Parameter	Mean	95% confidence interval
α	0.00424	
β_1	0.9007	0.749-1.052
β_2	1.0688	0.818-1.319
β_3	0.7088	0.630-0.788
β_4	0.4117	0.182-0.641

The precision of the equation using the above parameters is 1.43; that is, 95% of the actual measured emission factors will be within a factor of 1.43 of the predicted emission factors.

In order to preserve some continuity with previous MRI equations and in order to simplify the equation somewhat, MRI proposes the use of the following parameters:

$$\alpha = 0.00380$$

$$\beta_1 = 1.0$$

$$\beta_2 = 1.0$$

$$\beta_3 = 0.7$$

$$\beta_4 = 0.5$$

Using the above parameters, the precision is 1.48 and is not significantly lowered. Consequently, the revised predictive equation can be written as follows:

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

Thus, the only changes suggested in the old predictive equation listed in Table 1 is to lower the power of the weight correction term from 0.8 to 0.7 and to add a correction factor for the number of wheels on the vehicle. The values predicted in Table 23 were calculated using the above revised predictive equation.

SECTION 5.0

CONCLUSIONS

This final section presents the conclusions gleaned from (a) the analysis of silt and moisture contents measured at EMC for several materials, (b) the emission inventory of EMC, (c) the testing performed at EMC on controlled haul roads, and (d) the analysis of the extended data base created by the additional testing of unpaved roads at EMC.

The following is a list of conclusions based on the results of this study:

1. The silt content of mine haul and service roads (approximately 5%) is generally lower than that of public unpaved roads in rural areas. Possible explanations for this could be the difference in hardness of the road surface materials or more frequent road maintenance in the mines.

2. The silt content (minus 200 mesh) of the tailings basin beach (11%) is lower than one might expect considering that about 50% of the material spigoted is silt. [14/] This is due to the fact that a greater proportion of minus 200 mesh is carried with the spigoted water into the main water body than is the plus 200 mesh. Conversely, the coarser material is left on the beach.

3. The moisture content of a material may be strongly related to the amount of rain falling in the previous 3 days minus the evaporation occurring over the same period. Figure 8 shows the above variables plotted against one another for samples taken from the pellet stockpile. There are not enough data points in Figure 8 to quantify an exact relationship. Only the general conclusion can be made that surface moisture increases as net precipitation summed over the previous 3 days increases.

4. The major source of fugitive emissions at EMC is vehicular traffic on unpaved roads. Vehicular traffic on unpaved roads produces 66% of the total of 4,410 ST of fugitive emissions smaller than 30 μm in diameter; wind erosion produces 26%; blasting produces 4%; pellet handling and vehicular traffic on paved roads each produce approximately 2%. The blasting emissions estimate is the most uncertain of the five categories while the vehicular emissions estimate from unpaved roads is highly reliable.

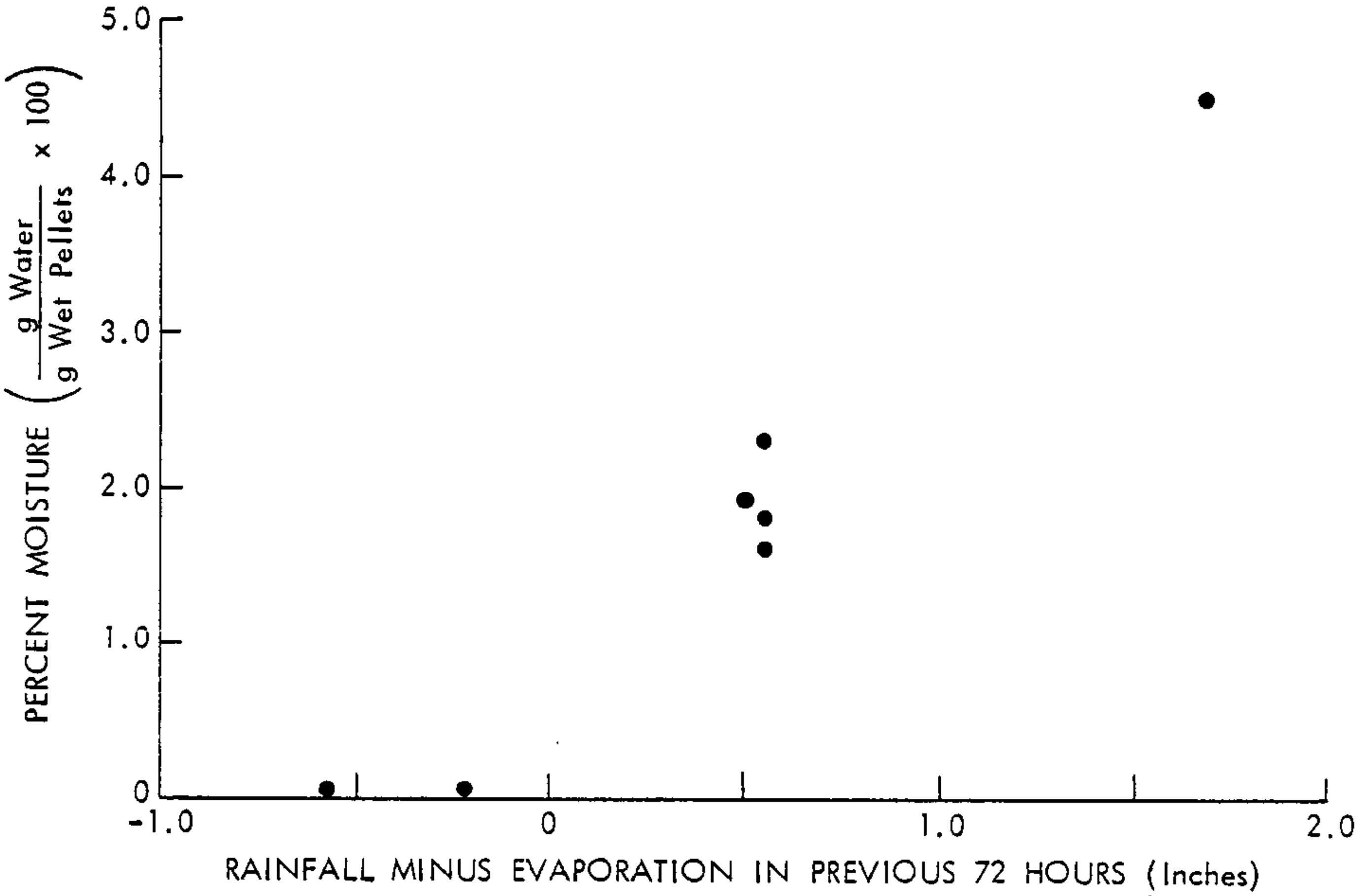


Figure 8. Surface moisture versus rainfall and evaporation for Erie Mining Company pellets.

5. Table 21 shows the actual emissions measured from a crushed rock road treated with Trex, a lignosulfonate, approximately 1/2 to 1 day before the tests. The application density is estimated to be 0.08 gal. of solution per square yard with the solution concentration estimated at 20 to 25% Trex in water. Tests I-7 and I-8 were performed on the same road as Tests I-9, I-10, and I-11, but with the road surface untreated in Tests I-7 and I-8. The average measured emission factor for Tests I-7 and I-8 is 11.6 lb/vehicle-mile. But since Tests I-7 and I-8 were measured on the day after 1.13 in. of rain, the measured values are not representative of dry road conditions. Predicted values for Tests I-7 and I-8 yield an average of 21.5 lb/vehicle-mile, which is the emissions expected from the road were it dry. The control efficiencies yielded by Trex when compared to emissions from the road in a dry condition were 91, 89, and 83% for Tests I-9, I-10, and I-11, respectively. This reduction in emission control confirms the concept that a chemical palliative measure will lose its effectiveness with time. There is not enough data here to calculate the rate of change of control efficiency. The decay of control efficiency with road usage is shown for Trex and Coherex in Figure 9.

6. The effects of rainfall are shown by comparing a measured average of Tests I-4 and I-5 with the measured results of Test I-6. The average emission factor for Tests I-4 and I-5 was 21.5 lb/vehicle-mile. This was reduced by 1.13 in. of rain over the previous 2 days to a value of 2.3 lb/vehicle-mile yielding a control efficiency of 89%. Tests I-7 and I-8 were also conducted on the day following 1.13 in. of rain and yielded an average emission factor of 11.6 lb/vehicle-mile. The predicted emission factor value for the same road and traffic type had the road been dry would have been 21.5 lb/vehicle-mile. This yields a 54% control efficiency.

7. Tests I-1, I-2, and I-3 as shown in Figure 8 indicate that a newly resurfaced haul road requires approximately 30 haul truck passes (67 tons) at a speed of 15 mph before equilibrium conditions are established with respect to the mass of fines comprising the road surface.

8. The predictive equation presented in Table 1 has been modified due to the additional tests performed at EMC. The modified equation has a precision factor of 1.48 which means that the actual value will be within a factor of 1.48 times the predicted value 95% of the time. This is a significant improvement over the old predictive equation shown in Table 1 which had a precision of only 1.69.

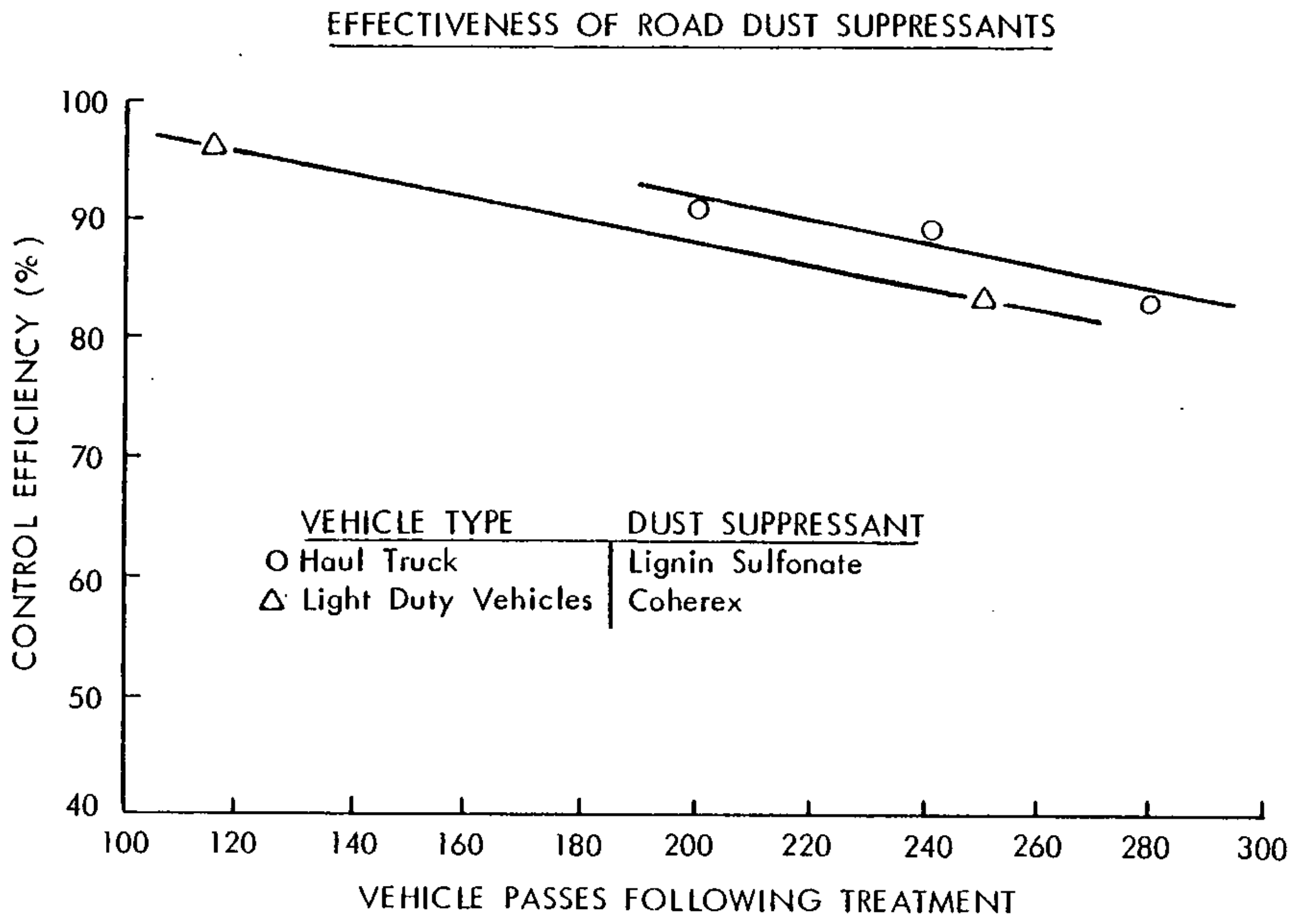


Figure 9. Effectiveness of road dust suppressants.

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GLOSSARY

aggregate - a granular material of mineral composition such as sand, gravel, shell, slag, or crushed stone, used with a cementing medium to form mortars or concrete, or alone as in base courses, railroad ballasts, etc.

aggregate, coarse - (1) aggregate predominantly retained on the No. 4 (4.75-mm) sieve; or (2) that portion of an aggregate retained on the No. 4 (4.75-mm) sieve.

NOTE: The definitions are alternatives to be applied under differing circumstances. Definition (1) is applied to an entire aggregate either in a natural condition or after processing. Definition (2) is applied to a portion of an aggregate.

Aggregate, fine - (1) aggregate passing the 3/8 in. (9.5-mm) sieve and almost entirely passing the No. 4 (4.75-mm) sieve and predominantly retained on the No. 200 (75-μm) sieve, or (2) that portion of an aggregate passing the No. 4 (4.75-mm) sieve and retained on the No. 200 (75-μm) sieve.

air drying - the process of equilibrating the sample to the moisture of the laboratory atmosphere.

bulk material - any material composed of crushed or natural pieces with a wide variety of sizes, for example, coal, soil, aggregate, iron ore, etc.

feed scoop - a scoop or pan having straight sides and equal to the effective length of the riffle. The scoop is used to feed the stand type riffle.

lot - a quantity of material (often 1,000 short tons) to be represented by a gross sample.

moisture, chemically bound - moisture recoverable from the decomposition of organic molecules or by separation from hydrated minerals.

moisture in coal, free - what portion of total moisture in coal (determined in accordance with ASTM Method D 3302) that is in excess of inherent moisture in coal (determined in accordance with ASTM Method D 1412 - Test for the Equilibrium Moisture of Coal at 96 to 97% Relative Humidity and 30°C). It is not to be equated with the weight loss upon air drying. Free moisture is sometimes referred to as surface moisture in connection with coal.

moisture in coal, inherent - that moisture existing as a quality of the coal seam as it exists in its natural state of deposition and includes only that water considered to be part of the deposit and not that moisture which exists as a surface addition. To establish a finite measurement of this quality, it is essential to conform to conditions for its determination as established in ASTM Method D 1412. Inherent moisture is not to be equated with the moisture remaining after air-drying.

moisture in coal, total - that moisture determined as the loss in weight in an air atmosphere under rigidly controlled conditions of temperature, time and air flow as established in ASTM Method D 3302.

riffle - a hand-feed sample divider device that divides the sample into two parts of approximately the same weight.

sample division - the process whereby a sample is reduced in weight without change in particle size distribution.

sample, gross - a sample representing one lot and composed of a number of increments on which neither reduction nor division has been performed.

sample, incremental - a small portion of the lot collected by one operation of a sampling device and normally combined with other increments from the lot to make a gross sample.

sample reduction - the process whereby a sample is reduced in particle size by crushing or grinding without change in weight.

screen - in laboratory work, an apparatus in which the apertures are circular, for separating sizes of material.

sieve - in laboratory work, an apparatus in which the apertures are square, for separating sizes of material.

silt content - the mass portion of a bulk material sample smaller than 75 μm in diameter (passing a No. 200 sieve) as determined by dry sieving.

size, maximum (of aggregate) - in specifications for, or description of aggregate, the smallest sieve opening through which the entire amount of aggregate is required to pass.

size, nominal maximum (of aggregate) - in specifications for, or description of aggregate, the smallest sieve opening through which the entire amount of the aggregate is permitted to pass. Specifications on aggregate usually stipulate a sieve opening through which all of the aggregate may, but need not, pass so that a stated maximum proportion may be retained on that sieve. A sieve opening so designated is the nominal maximum size of the aggregate.

size, top - the opening of the smallest screen in the series upon which is retained less than 5 percent of the sample (see Method ASTM D 431).

APPENDIX A

PROCEDURES FOR BULK MATERIAL SAMPLE COLLECTION, PREPARATION, AND SILT AND MOISTURE ANALYSIS

1.0 INTRODUCTION

As can be seen from Table 1 (in the main body of the report), the degree of accuracy to which the emission factor is quantified depends on the degree of accuracy within which the specific independent parameters are quantified. Variables such as vehicle speed, vehicle weight, bucket size, and duration of material in storage can be estimated rather accurately. The climatic parameters can usually be obtained from a nearby weather station. But two specific parameters, namely material silt and surface moisture contents, must normally be measured at the sites of interest.

The purpose of this appendix is to present recommended collection, preparation, and silt and surface moisture analysis procedures for representative samples of bulk materials from the surface of (a) storage piles, (b) unpaved roads, and (c) exposed areas. This objective has been accomplished by a two-fold approach:

1. Review the 1977 American Society of Testing and Materials (ASTM) Standards in search of standard methodologies applicable to the specific problem.

2. Recommend procedures identical to ASTM standard procedures, if possible, or at least consistent with the intent of the majority of pertinent ASTM Standards.

Many of the items used in this appendix constitute a special jargon used in the ASTM Standards. A glossary which contains definitions of these special terms is provided at the back of this appendix.

2.0 RECOMMENDED SAMPLE COLLECTION PROCEDURES

This section focuses on the representative collection of samples. The principle that a sample of representative size distribution yields a representative moisture sample in addition to a representative size sample underscores the importance of avoiding size segregation.

2.1 NUMBER AND SIZE OF INCREMENTAL AND GROSS SAMPLES

This subsection applies to the collection of samples from storage piles, unpaved roads, and exposed areas. ASTM Standards suggest minimum sizes of a gross sample ranging from 30 to 500 lb depending on the type and size distribution of the material. The number of incremental samples ranges from 3 to 50.

The recommendations made herein are based on a desire to approach representative sampling, yet remain within the constraints of manpower and time. It is recommended that 50-lb gross samples be collected in 10 increments of approximately 5 lb each.

If it is necessary to mail a sample to a distant laboratory for analysis, the 50-lb gross sample should still be collected in 10 increments. It can then be divided by coning and quartering or riffling into a subsample (e.g., approximately 5 lb) which can be mailed.

ASTM Standards generally suggest that the number of gross samples to be taken is one per 1,000 tons of material. At a typical taconite ore mine, this would mean hundreds of samples from piles. As a compromise, a recommendation is made to take at least one gross sample per significant pile. For example, this should produce on the order of 10 storage pile samples at a large taconite mining and processing operation.

For an unpaved road 60 ft wide with an average of 1/4 in. of material (1.5 g/cm^3 bulk density), there are approximately 619,000 lb or 310 short tons (ST) of material in 1 mile. Consequently, one gross sample of at least 50 lb weight for every 3 miles of road (composed of similar surface material) would satisfy general ASTM criteria.

In collecting a gross sample from an exposed area, only the surface which is exposed to the wind is actually of interest. Assuming a 1/4-in. thick loose layer of sand, soil, or crushed stone (1.5 g/cm^3 in bulk density), 1 acre would have 85,000 lb or 43 tons of surface material. Thus, one gross sample for every 25 acres of exposed area would be consistent with ASTM Standards. For the average taconite mine, one might have to sample approximately 1,000 exposed acres (i.e., 40 gross samples). Unfortunately, this is too many samples for most research efforts. Thus, it is recommended that one 50-lb gross sample be collected for every major exposed surface type (e.g., tailings, glacial drift, etc.).

2.2 METHODOLOGY FOR COLLECTION OF INCREMENTAL AND GROSS SAMPLES

2.2.1 Storage Piles

Several operations listed in Table 1 (in the main body of the report) represent sources of emissions caused by bulk material handling or wind erosion. Each source actually represents a natural or mechanical disturbance of a given portion of the bulk material. It is the size distribution of the portion of the material disturbed that is desired.

During wind erosion, the entire surface of the pile is disturbed by the natural action of the wind. Consequently, a representative sample for silt or moisture must include incremetal samples from the entire surface of the pile.

During continuous and batch load-in activity, the entire amount of material dropped is disturbed, and thus, the sample must be representative of the material dropped.

For storage pile maintenance, like wind erosion, it is the surface of the pile that is disturbed. Since storage pile maintenance may occur at the bottom of the pile (e.g., pile cleanup operations) or from the bottom to the top of the pile (e.g., movement of dead storage to live storage by clamshell or dozer), the sample must represent the material disturbed.

During batch load-out, the entire amount of material in a pile will eventually be disturbed. The concept of time is important since the size distribution of a pile is biased. It is well-known that the mere formation of a pile causes size segregation. The larger particles have more momentum and thus bounce farther down the banks of the pile. Thus, the bottom of the pile has the large chunks and the size distribution becomes finer as one moves to the top of the pile. For batch load-out, the emission factor is related to the material silt content of the specific batch and therefore is related to what portion of the pile is being loaded out--the bottom, middle, or top.

Samples Needed to Characterize Storage Pile Wind Erosion--

In sampling the surface of a pile to determine a representative silt value for use in the wind erosion equation, a gross sample made up of top, middle, and bottom incremental samples should ideally be acquired, since the wind is disturbing the entire surface of the pile. Unfortunately, it is impractical to climb to the top or even middle of most industrial piles, which are inherently large.

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. Minimization of bias can be accomplished by selecting sampling locations in a truly random fashion. The person obtaining the sample should walk around the perimeter of the pile and arbitrarily select a point on the pile as near to the middle of the pile as the person can reach or climb. An incremental sample (i.e., one shovelful) can then be acquired by skimming the surface of the pile to a depth of 2 to 4 in. in a direction upward along the face.

In the preceding procedure for sampling storage piles, bias is minimized by reaching as close to the middle of the pile as possible in order to acquire a sample representing an average between the top and bottom. Every effort must be made by the person obtaining the sample not to purposely avoid sampling larger pieces of raw material.

If small piles are sampled, incremental samples should be collected from the top, middle, and bottom of the pile.

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.

Samples Needed to Characterize Continuous and Batch Load-In--

The ideal method of collection for continuous load-in operations as proposed in several ASTM Standards is to sample from a stopped conveyor belt. Since this is impractical for most industrial operations, another approach must be recommended.

It is most difficult to gather a representative sample from a batch load-in process such as the dumping of a railcar, truck, or loader--the falling stream is too wide and short-lived to sample.

In addition, collection of a representative sampling of the material in the device before dumping is difficult since the material is size-segregated in the railcar, truck, or loader. It is usually impractical to stop the load-in process while a person attempts to extract a representative sample from one of the dumping devices.

Since all material in a pile is loaded in, a sample representative of all the material in the pile (surface and interior) is desired. This is slightly different in concept than the silt sample for the wind erosion equation which was to represent the surface only. But it can reasonably be assumed that a sample representing the entire surface will also represent the interior which was once itself the surface of the pile. The only factor to cast doubt on this assumption is rain, which washes the fines from the surface to the interior. If a pile is active, load-in will be performed on a regular basis and the surface will be constantly renewed. In this case, one can still attempt to acquire a representative sample of the entire pile from the surface.

In conclusion, the same sample obtained for determining the silt value in the wind erosion equation can be used to represent the silt value in the batch and continuous load-in equations as applied to an active pile. The methodology for gathering incremental samples is given in the previous subsection.

Samples Needed to Characterize Storage Pile Maintenance--

Representative sampling of this source for silt content depends much on the type of maintenance and equipment used. Storage pile maintenance consists of either pile tidiness or placement of dead storage in a live storage position. Pile tidiness usually involves a dozer which moves material at the bottom of the pile. On the other hand, creation of more live storage may involve dozers, loaders, or even clamshells and may occur at the bottom, middle, or top of the pile. In a specific plant, the maintenance procedures have to be understood before a representative silt sample can be collected. As an industry-wide average, one might expect operations to occur at the bottom, middle, and top of a storage pile; consequently, sample collection methodology discussed in the wind erosion subsection applies.

Samples Needed to Characterize Batch Load-Out--

If long-term emissions from batch load-out of a pile are of interest, then a sample representative of the entire pile is appropriate and can be obtained using the procedures described in previous subsections. This approach is recommended for an emission inventory. On the other hand, if short-term emissions are of concern (e.g., emission tests for determination of an emission factor), then the sample should be representative of only the material loaded out and not the entire pile.

Pile size segregation is the key issue necessitating the two aforementioned approaches. In emission factor testing, batch load-out occurs from the bottom of the pile and the material at the bottom of the pile is larger than the remainder of the pile. Consequently, a gross sample representing the entire pile is not adequate.

The most practical approach for obtaining a representative silt value during emission factor testing is to gather incremental samples from the area of the pile close to where the loader is operating. The increments should be spaced over the duration of the test.

2.2.2 Unpaved Roads

The incremental samples from unpaved roads can be acquired as shown in Figure A-1. The general objective is to select L, the road length per gross sample, once the road width and material depth are known. At least four incremental samples, collected as shown in Figure A-1, should be gathered.

For a typical taconite mine, given a road width of 60 ft, an average material depth of 1/4 in., and a bulk density of 1.5 g/cm^3, each incremental sample (8-in. strip across half the road) will contain 40 lb of material. The calculated spacing would be 1 mile between each incremental sample. Consequently, four incremental samples will yield a gross sample of 160 lb, which is much better than the recommended 50 lb per gross sample.

The method of collecting an incremental sample is to sweep an 8-in. wide strip halfway across the road. At least four strips should be collected with each strip gathered on an alternate half of the road. The material should be collected by sweeping with a wisk broom into a dustpan. All four incremental samples comprise one gross sample to be analyzed for silt content.

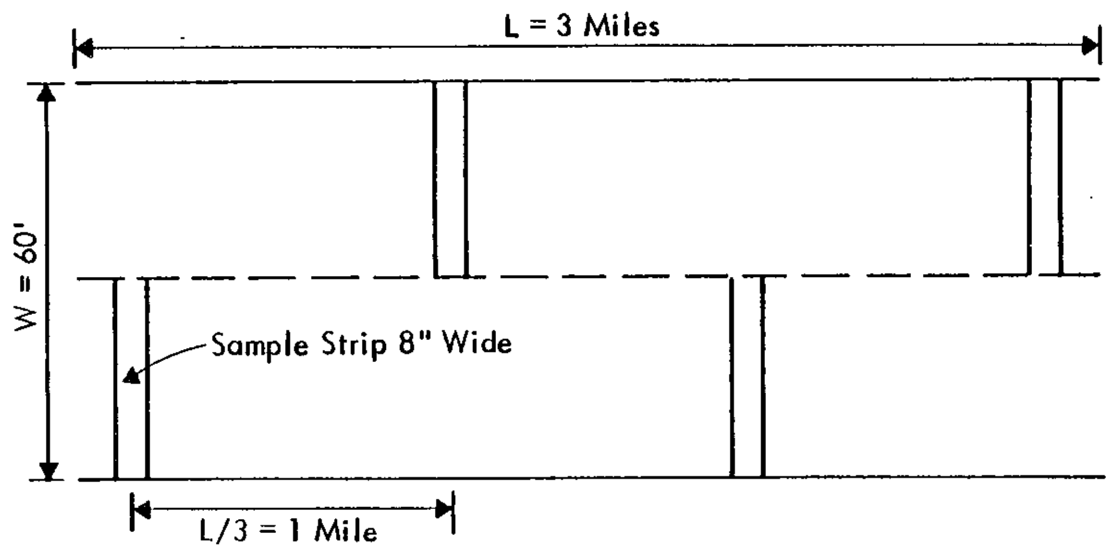

Figure A-1. Location of incremental sampling sites on unpaved roads in a taconite mine.

2.2.3 Exposed Areas

The selection of incremental sampling locations for exposed areas should be done prior to obtaining samples. The exposed acres 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.

At each incremental sampling site, a 1-ft square section should be selected in a random manner, within the area previously designated. If the surface is smooth, as a tailings basin might be, the 1-ft square can be swept down to hardpan with a dustpan and a wisk broom. If 5 lb of material are not collected, expand or contract the size of the square until at least 5 lb are gathered. If the surface is rough (e.g., a plowed field), the specific incremental sample site must still be found in a random manner. A thin layer of the surface must be removed with a straight-edged shovel from the entire 1-ft square. Again, the size of this square can be increased or decreased until 5 lb are gathered.

3.0 RECOMMENDED SAMPLE PREPARATION PROCEDURES

Once the 50-lb gross sample is brought to the laboratory (5-lb subsample if it is mailed), the sample must be prepared for silt and moisture analysis. There are three questions to be answered: (a) what is the recommended procedure for dividing a sample, (b) to what size does one subdivide the sample, and (c) does the sample need to be crushed for the moisture analysis.

A 50-lb gross sample can be divided by using: (a) mechanical devices, (b) alternate shovel method, (c) riffle, or (d) coning and quartering method. Mechanical division devices will not be discussed since they are not found in many laboratories. The alternate shovel method is actually only necessary for samples on the order of hundreds of pounds. Consequently, only the use of the riffle and the coning and quartering method will be discussed here.

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.[A1/] The following quote describes the use of the riffle:

> Divide the crushed gross sample by using a riffle. Riffles properly used will reduce sample variability but cannot eliminate it. Riffles are shown in Figure A-2 (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

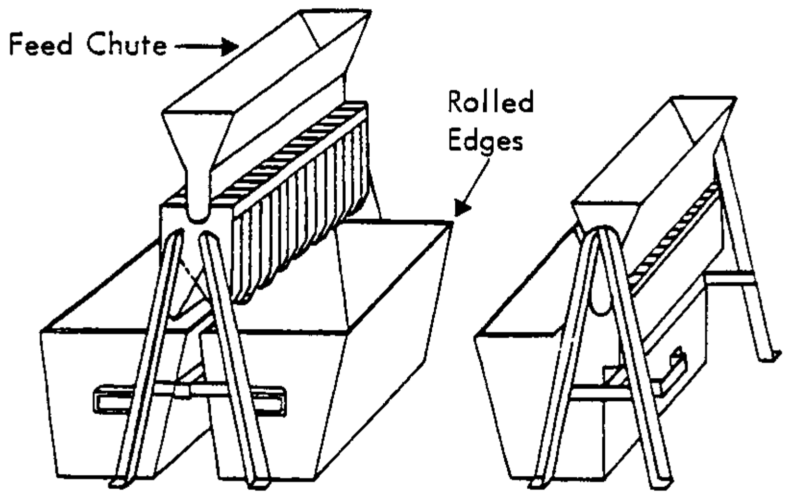

Figure A-2. Sample dividers (riffles).[A1] container, raise the container, and hold it with its front edge resting on top of the feed chute, then slowly tilt it so that the material flows in a uniform stream through the hopper straight down over the center of the riffle into all the slots, thence into 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.[A1/]

The procedure for coning and quartering is best illustrated in Figure A-3. 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 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.[A2/]

The size of the laboratory sample is important--too little sample will not be representative and too much sample will be unwieldy. Ideally, one would like to analyze the entire gross sample in batches, but practically, a laboratory size sample must be prepared. While all ASTM Standards acknowledge this, they disagree on the exact size as indicated by the range of recommended samples which extends from 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 pile 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 it is the largest that can be handled by the scales normally available (1,600-g capacity).

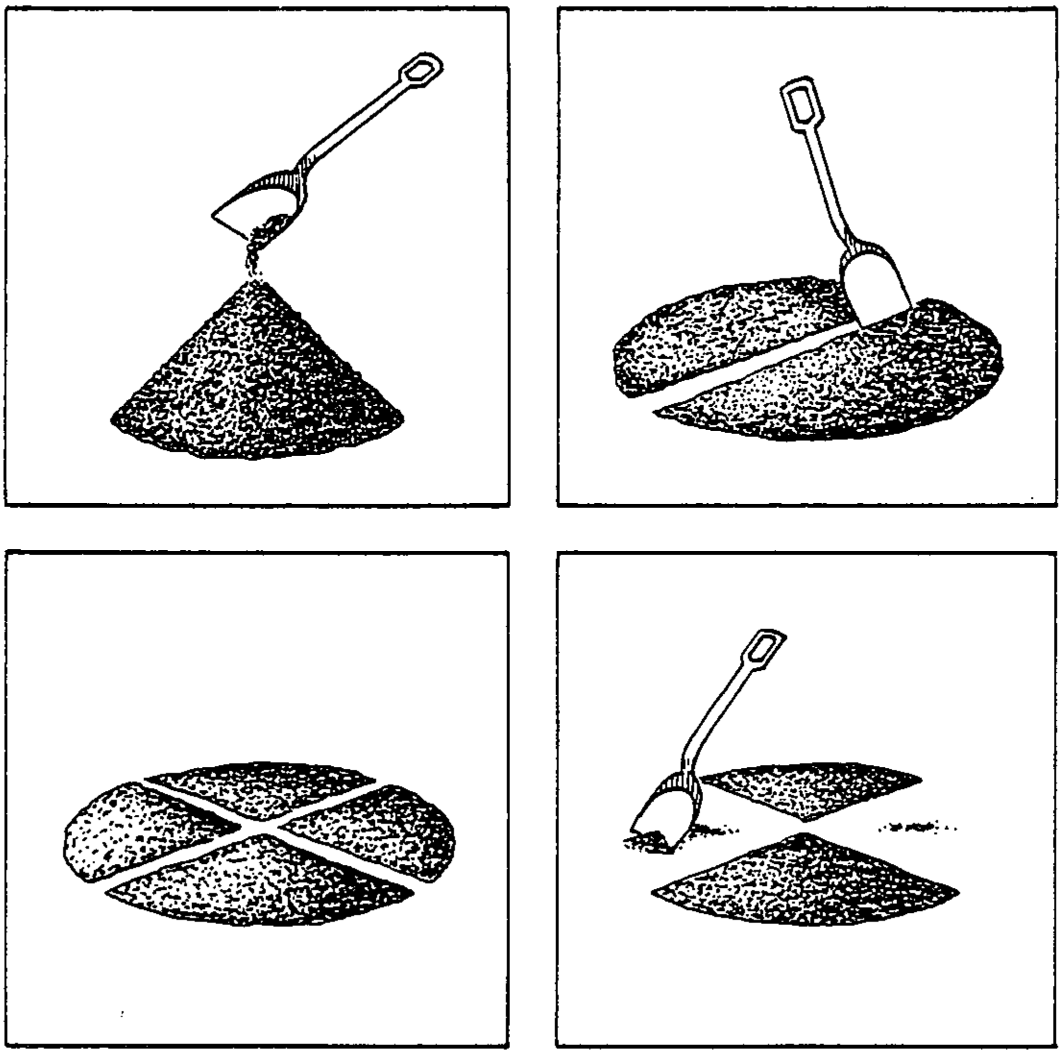

Figure A-3. Coning and quartering.[A2]

The question of crushing the sample to perform the moisture analysis hinges on the size and type of the material and what type of moisture is desired. It has already been stated that crushing reduces potential sample division bias. With most laboratory equipment, only relatively friable materials like coal and coke can be crushed. The ASTM Standards reflect this practical consideration since only friable samples containing large pieces are recommended for crushing. The issue is easily resolved since the moisture and silt sample are recommended to be one and the same for purposes of shortening time in the laboratory. The sample cannot be crushed as this would destroy the sample silt integrity.

4.0 RECOMMENDED SAMPLE ANALYSIS PROCEDURES

Analysis of the laboratory samples for silt and surface moisture will be identical whether the samples originate from storage piles, unpaved 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 oven drying. Table A-1 presents a step-by-step procedure for determining surface moisture.

Exceptions to the general procedure of Table A-1 include any material composed of hydrated minerals or organic materials. Because of the danger of measuring chemically bound moisture from 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 A-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 further increase is due to grinding.

TABLE A-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.

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

TABLE A-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. 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 Ro-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 (as 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.

5.0 CONCLUSIONS

Sample collection, preparation, and analysis procedures have been recommended for storage piles, unpaved roads, and exposed areas. Since no ASTM Standards directly applicable to these specific configurations of bulk material were found, recommended techniques were based on (a) principles found in related ASTM Standards and (b) a concern for practicality in relation to manpower and time expenditures.

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A2. 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.