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MRI REPORT

IRON AND STEEL PLANT OPEN SOURCE FUGITIVE EMISSION CONTROL EVALUATION

DRAFT FINAL REPORT

EPA Contract No. 68-02-3177, Assignment No. 1
MRI Project No. 4862-L(1)

Date Prepared: June 5, 1980

Prepared for

Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

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PREFACE

This report was prepared for the Environmental Protection Agency's Industrial Environmental Research Laboratory under EPA Contract No. 68-02-3177, Work Assignment No. 1. Mr. Robert V. Hendriks, Metallurigical Processes Branch, was the requestor of this work. The report was prepared in Midwest Research Institute's Air Quality Assessment Section (Dr. Chatten Cowherd, Head). Dr. Cowherd was the principal author.

Approved for:

MIDWEST RESEARCH INSTITUTE

Chatten Cowherd

for M. P. Schrag, Director
Environmental Systems Department

June 5, 1980

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1.0 INTRODUCTION

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

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

Recent studies of fugitive emissions from integrated iron and steel plants[1,2] have provided strong evidence that open dust sources (specifically, vehicular traffic on unpaved and paved roads and storage pile activities) rank with steel-making furnaces and sinter machines as sources which emit the largest quantitites of fine and suspended particulate matter, taking into account typically applied control measures. Moreover, preliminary analysis of promising control options for both process sources of fugitive emissions and open dust sources indicate that control of open dust sources has a highly favorable cost-effectiveness ratio for particulate. Although limited in scope, these studies show that open dust sources should occupy a prime position in control strategy development for fugitive particulate emissions within integrated iron and steel plants.

Recent guidance for State Implementation Plan revision has generally included provisions for control of open dust sources. However, lack of information on emissions and control capabilities for these sources has prevented control officials from taking full advantage of control strategies that include provision for control of the open dust sources. Furthermore, although trade-offs between open sources and process sources might result in significantly improved air quality at a lower cost, this improvement can only occur if open dust sources can be quantified and controlled successfully.

This report presents an evaluation of existing data on the quantities of pollutants from open dust sources in steel plants and on the capability of control procedures for eliminating or reducing these emissions. Based on this evaluation, a testing program designed to provide needed data on emissions and controls is outlined.

2.0 OPEN DUST SOURCES AND POTENTIAL EMISSIONS

The open dust sources which are found within integrated iron and steel plants may be placed into the following generic categories, based on similarity of physical mechanisms for dust generation:

- Vehicular traffic on unpaved surfaces

  Unpaved roads
  Storage pile maintenance
  Unpaved parking lots

- Vehicular traffic on paved surfaces

- Batch drop operations

  Loaders
  Railcars
  Trucks
  Gantry/clamshell buckets

- Continuous drop operations

  Stackers
  Conveyor transfer stations
  Bucket wheels

- Wind erosion

  Storage piles
  Exposed areas

The ranking of the emissions potential of open dust sources within the integrated iron and steel industry is an important tool in deciding where control studies should be focused. This requires the development of a nationwide emissions inventory for the industry.

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

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

where: R = mass emission rate
M = source extent
e = uncontrolled emission factor, i.e., rate of uncontrolled emissions per unit of source extent
c = fractional efficiency of control

Because of the wide range of particle size associated with emissions from open dust sources, it is important that the applicable particle size range be specified for the calculated emission rate. The particle size range is that for which the uncontrolled emission factor and the fractional efficiency of control apply.

As noted above, a nationwide inventory of emissions from open dust sources within the integrated iron and steel industry was developed as part of an earlier study.[2] For that inventory, source extent values were based in part on: (a) 1976 industry consumption of coal and pelletized iron ore, and (b) 1977 surveys of four plants. Representative source parameter values were taken to be the averages of the values obtained from the plant surveys. Representative control practices for the industry were based on the plant surveys, and control efficiency values for these measures were estimted. The emission factors used for the inventory were those judged to be the most reliable at the time of the inventory.

The reliability of the emissions inventory was limited by its dependence on data from the plant surveys and on assumed values where data were lacking. The four surveyed plants may not have constituted an adequate data base to represent the industry. Emission factor data were sparse for some generic source categories, and control efficiency data were almost totally lacking.

The remainder of this section reports on the efforts to develop a more reliable emissions inventory to be used as the basis for determining the open dust sources and most promising control measures for which further testing is needed.

2.1 EMISSIONS DATA FROM PREVIOUS STUDIES

The most extensive emission factor data base available to date for open dust sources is that developed by Midwest Research Institute (MRI).[2] As shown in Table 1, the MRI emission factors take the form of predictive equations which contain correction parameters to account for source variability. The correction parameters may be grouped into the following categories:

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

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

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

The emission factors developed by MRI have been made specific to particles smaller than 30 μm in Stokes diameter, so that emissions may be related to ambient concentrations of total suspended particulate. The upper size limit of 30 μm for suspended particulate is the approximate effective cutoff diameter for capture of fugitive dust by a standard high volume particulate sampler (based on a typical particle density of 2 to 2.5 g/cm).[3] It should be noted, however, that analysis of parameters affecting the atmospheric

TABLE 1. FUGITIVE DUST EMISSION FACTORS EXPERIMENTALLY DETERMINED BY MRI

Source category	Measure of extent	Emission factor[a/] (lb/unit of source extent)	Correction Parameters
1. Unpaved roads	Vehicle-Miles Traveled	$5.9 \left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{d}{365}\right)$	s = Material Silt Content (%)
2. Paved Roads	Vehicle-Miles Traveled	$0.09\ I \left(\frac{4}{N}\right)\left(\frac{s}{10}\right)\left(\frac{L}{1,000}\right)\left(\frac{W}{3}\right)^{0.7}$	S = Average Vehicle Speed (mph) W = Vehicle Weight (tons)
3. Batch Load-In (e.g., front-end loader, railcar dump)	Tons of material Loaded In	$0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{h}{10}\right)}{\left(\frac{M}{2}\right)^{2}\left(\frac{Y}{6}\right)}$	L = Surface Dust Loading on Traveled Portion of Road (lb/mile)
4. Continuous Load-In (e.g., stacker, transfer station)	Tons of Material Loaded In	$0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{h}{10}\right)}{\left(\frac{M}{2}\right)^{2}}$	U = Mean Wind Speed (mph) M - Material Surface Moisture Content (%)
5. Active Storage Pile Maintenance and Traffic	Tons of Material Put Through Storage	$0.10\ K \frac{s}{1.5}\left(\frac{d}{235}\right)$	Y = Dumping Device Capacity (yd^3) K = Activity Correction[b/]
6. Active Storage Pile Wind Erosion	Tons of Material Put Through Storage	$0.05 \left(\frac{s}{1.5}\right)\left(\frac{d}{235}\right)\left(\frac{f}{15}\right)\left(\frac{D}{90}\right)$	d = Number of Dry Days Per Year
7. Batch Load-Out	Tons of Material Loaded Out	$0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{h}{10}\right)}{\left(\frac{M}{2}\right)^{2}\left(\frac{Y}{6}\right)}$	f = Percentage of Time Wind Speed Exceeds 12 mph at 1 ft above the ground D = Duration of Material Storage (days)
8. Wind Erosion of Exposed Areas	Acre-Years of Exposed Land	$3,400 \frac{\left(\frac{e}{50}\right)\left(\frac{s}{15}\right)\left(\frac{f}{25}\right)}{\left(\frac{P-E}{50}\right)^{2}}$	e = Surface Erodibility (tons/acre/year)
			P-E = Thornthwaite's Precipitation-Evaporation Index
			N = Number of Traveled Lanes
			I = Industrial Road Augmentation Factor[c/]
			w = Average Number of Wheels on Vehicle Mix
			h = Drop Height (ft)

a/ Represents particulate smaller than 30 μm in diameter based on particle density of 2.5 g/cm^3.

b/ Equals 1.0 for front-end loader maintaining pile tidiness and 50 round trips per truck per day in the storage area.

c/ * Equals 7.0 for trucks coming from unpaved to paved roads and releasing dust from underbody of vehicle;
* Equals 3.5 when 20% of the vehicles are forced to travel temporarily with one set of wheels on an unpaved road berm while passing on narrow roads;
* Equals 1.0 for traffic entirely on paved surfaces.

transport of fugitive dust indicates that only the portion smaller than about 5 μm in diameter will be transported over distances greater than 5 to 10 km from the source.[4]

Other than MRI's previous work, a few emission factor data for open dust sources exist. Estimated emission factors have been developed for the handling and transfer of storage materials. An uncontrolled emission factor of 0.033 lb/ton coke for coke being dumped into a blast furnace was calculated from a measured blast furnace cyclone catch.[5] This factor might be applicable to a coke conveyor transfer station. AISI[6] estimated an emission factor of 0.13 lb/ton of coke for a conveyor transfer station. Also AISI[6] discovered an emission factor range from the literature of 0.04 to 0.96 lb/ton coal for general coal handling. Speight[7] estimated a value of 1.0 lb/ton for general coal handling.

In connnection with MRI's emission factor development program,[2] limited testing of the effects of a chemical dust suppressant was also conducted. Coherex® (a petroleum-based emulsion) was used to treat a dirt/slag surfaced service road traveled by light- and medium-duty vehicles at an integrated iron and steel plant. Coherex® was applied at 10% strength in water.

Figure 1 shows a plot of measured dust control efficiency as a function of the number of vehicle passes following application of the road dust suppressant. Control efficiency was calculated by comparing controlled emissions with uncontrolled emissions measured prior to road surface treatment. As indicated, the effectiveness of the road dust suppressant was initially high but began to decay with road usage. It should also be noted that the apparent performance of Coherex® was negatively affected by tracking of material from the untreated road surface connected to the 100-m treated segment.

Figure 1 also shows the results obtained from the similar testing of another chemical dust suppressant at a taconite mine.[8] TREX (ammonium) lignin sulfonate--a water soluble by-product of papermaking) was applied to the waste rock aggregate comprising the surface of a haul road. A 20 to 25% solution of TREX in water was sprayed on the road at a rate of 0.08 gal./sq yard of road surface.

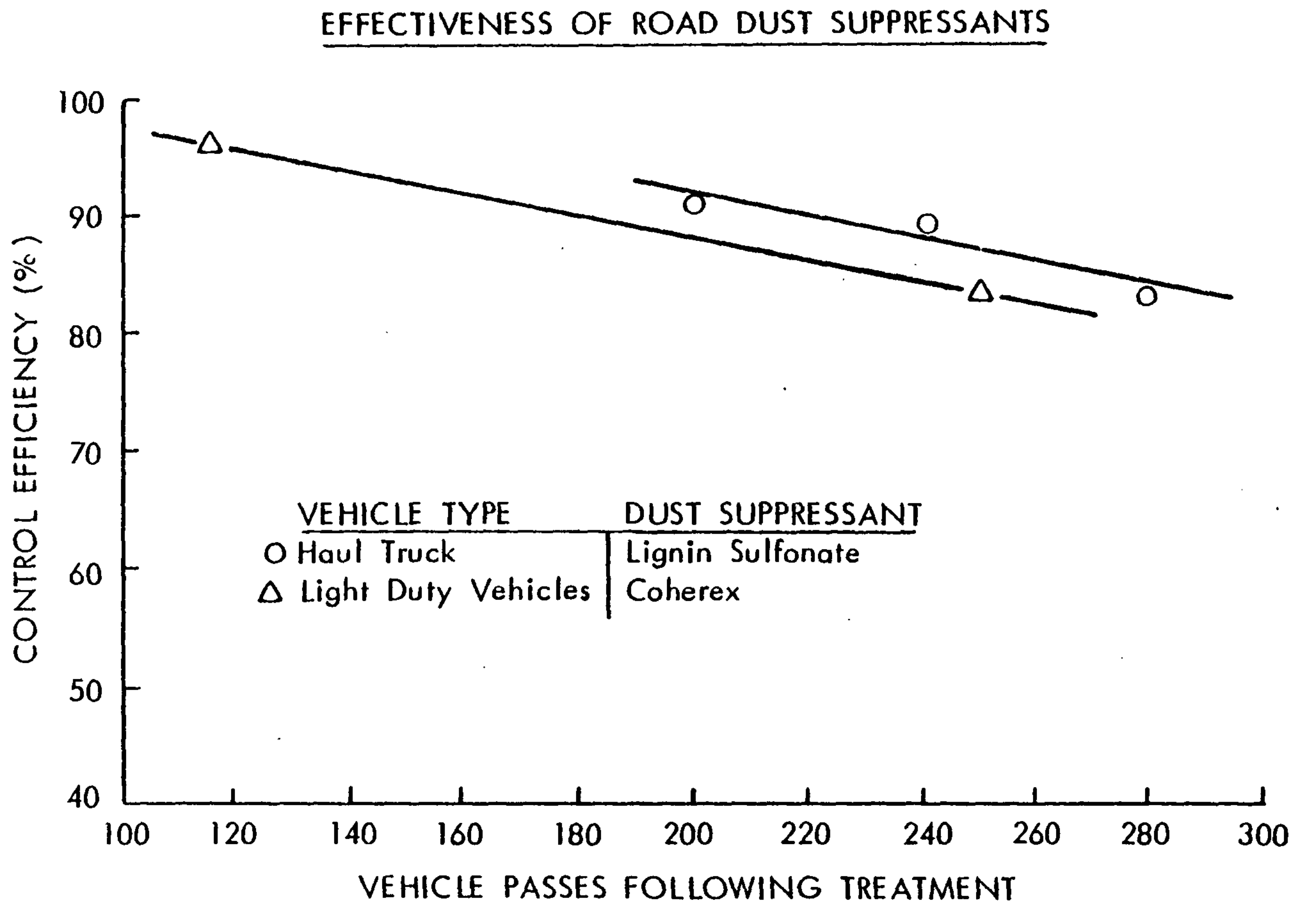

Figure 1. Effectiveness of road dust suppressants.

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

2.2 METHODOLOGY FOR MORE EXTENSIVE PLANT SURVEYS

In order to gather more extensive and reliable data on source extents, correction parameters and control practices for open dust sources within integrated iron and steel plants, a questionnaire was designed in the form of materials handling flow charts to be completed for specific plants.

The flow charts displayed several alternate handling schemes for the following materials:

1. Coal
2. Iron ore pellets
3. Unagglomerated iron ore
4. Limestone/dolomite
5. Sinter, nodules, and briquettes
6. Coke
7. Sinter input (flue dust, iron ore, and coke fines)
8. Slag

The completed flow charts for a specific plant provides information on: (a) the materials handling routes used at the plant, (b) the amount of material passing through each handling step, (c) physical characteristics of the handling equipment (e.g., bucket size, drop height, etc.), and (d) the handling steps that are controlled and the type of control utilized.

Through the assistance of the American Iron and Steel Institute (Mr. John Barker, Chairman of the AISI Fugitive Emissions Committee, and Mr. William Benzer), the following companies agreed to complete the materials handling flow charts for the indicated plants:

Armco Steel, Incorporated

- Middletown Works
- Houston Works

Interlake, Incorporated

- Chicago Plant (coke ovens and blast furnace)
- Works at Riverdale (BOFs)

Bethlehem Steel Corporation

- Burns Harbor
- Sparrows Point

National Steel Corporation

- River Rouge Plant (coke ovens and blast furnaces)
- Works at Ecorse (BOFs and EAFs)
- Works at Granite City

U.S. Steel Corporation

- Geneva Works
- Gary Works

Republic Steel Corporation

- Cleveland District Plant

Jones and Laughlin Steel Corporation

- Aliquippa Works
- Indiana Harbor Works

At the time of the writing of this report, most of the completed flow charts had been received. Appendix A gives an example of materials handling data compiled from the charts for two plants.

2.3 UPDATED EMISSIONS INVENTORY

The completed materials handling flow charts for the 14 plants will provide input data for a more representative industry-wide emissions inventory of open dust sources. Pending the compilation of data from the flow charts, the preliminary inventory developed earlier was updated by using the revised emission factors for unpaved roads, paved roads, and continuous drop operations, as developed in Reference 2.

The updated inventory, shown in Table 2, has the same features as the inventory published earlier. Vehicular traffic on unpaved surfaces accounts for over 71% of the total open dust source emissions while batch and continuous drop operations combine for less than 5% of the total. This inventory will be further refined by incorporation of the results of the 14 plant surveys.

Because the data base on the field performance of control measures for open dust sources is so small as to be insignificant, control measure testing should be distributed in relation to the magnitude of uncontrolled emissions. According to Table 1, testing should focus on control measures applicable to:

- Unpaved roads
- Paved roads
- Storage pile maintenance
- Storage pile wind erosion
- Unpaved parking lots
- Conveyor transfer stations
- Exposed area wind erosion

TABLE 2. PRELIMINARY INVENTORY OF OPEN DUST SOURCE CONTRIBUTIONS TO SUSPENDED PARTICULATE EMISSIONS

Source	1976 Nationwide suspended particulate emission rate for the iron and steel industry Uncontrolled[a/] (tons/yr)	Percent of total emissions
. Vehicular traffic on unpaved surfaces		
Unpaved roads	50,100	71.5
Storage pile maintenance	9,270	
Unpaved parking lots	3,350	
. Vehicular traffic on paved surfaces	11,300	12.9
. Batch drop operations		0.1
Loaders	13	
Railcars	35	
Trucks	9	
Gantry/clamshell	26	
. Continuous drop operations		4.5
Stackers	122	
Conveyor transfer stations	3,840	
Bucket wheels	38	
. Wind erosion		11.0
Storage piles	6,500	
Exposed areas	3,110	
	87,700	

a/ Except that natural control due to precipitation is included.

Based on preliminary analysis of the materials handling flow charts, uncontrolled emissions from conveyor transfer stations are probably larger than the value given in Table 1 because the number of transfer stations exceeds the average value of two per material that was assumed in the calculations.

2.4 SAMPLING AND ANALYSIS METHODS

Fugitive emissions are especially difficult to characterize for the following reasons.

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

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

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

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

Three basic techniques have been suggested.[9]

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

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

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

Of these techniques, only the upwind/downwind method is suitable for application to open dust sources.

As an alternative to the upwind/downwind method for quantification of source-specific emission factors for open dust sources, MRI developed the "exposure profiling" technique, which uses the isokinetic profiling concept that is the basis for conventional source testing.[10] Exposure profiling consists of the direct measurement of the passage of airborne pollutant immediately downwind of the source by means of simultaneous multipoint sampling over the effective cross section of the fugitive emissions plume. This technique uses a mass-balance calculation scheme similar to EPA Method 5 stack testing rather than requiring indirect calculation through the application of a generalized atmospheric dispersion model. Exposure profiling is compared with conventional upwind/downwind sampling in the subsections below.

2.4.1 Open Dust Source Quantification by Upwind/Downwind Method

The upwind/downwind method has frequently been used to measure fugitive particulate emissions from open (unconfinable) sources, although only a few studies have been conducted in the integrated iron and steel industry. Typically, particulate concentration samplers (most often high-volume filtration samplers) are positioned at a considerable distance from the source (for example, at the property line around an industrial operation) in order to measure the highest particulate levels to which the public might be exposed. The calculation of the emission rate by dispersion modeling is oftern treated as having secondary importance, especially because of the difficult problem of identifying the contributions of elements of the mix of open sources (and possibly fugitive emissions discharged from process installations).

While the above strategy is useful in characterizing the air quality impact of an open source mix, it has significant limitations with regard to control strategy development. The major limitations are as follows:

1. Overlapping of source plumes precludes the determination of source-specific contributions on the basis of particulate concentration alone.

2. Air samplers with poorly defined intake flow structure (including the conventional high-volume sampler) exhibit diffuse cutoff size characteristics for particle capture, which tend to be affected by wind conditions.[11]

3. Uncalibrated atmospheric dispersion models introduce the possibility of substantial error (a factor of three[12]) in the calculated emission rate, even if the stringent requirement of unobstructed dispersion from a simplified source configuration is met.

The first two limitations are not a direct consequence of the upwind/downwind method but of the way it is used. These limitations could be removed by using samplers designed to capture all or a known size fraction of the atmospheric particulate, and by designing sampler placement to isolate the air quality impact of a well defined source operation.

However, there would remain the need to improve method accuracy by calibration of the dispersion model for the specific conditions of wind, surface roughness, and so on, which influence the near-surface dispersion process. This need is evident from the significant size of the variation in model-calculated emission rates for aggregate process operations, based on data from individual samplers operated simultaneously at different downwind locations.[13] The suggested use of tracers for this purpose is complicated by the characteristically diffuse and variable nature of an open dust source and the need for a polydisperse tracer test dust approximating the particle size distribution of the source emissions.

2.4.2 Open Dust Source Quantification by Exposure Profiling Method

As stated above, 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 on 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.

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 parallel to the direction of the minimum dimension of the area source.

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 calculationof plume dispersion. Grid size adjustments may be required based on the results of preliminary testing.

Particulate sampling heads should be symmetrically distributed over the concentrated portion of the plume containing about 90% of the total mass flux (exposure). For example, if the exposure from a point source is normally distributed, as shown in Figure 2, 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.

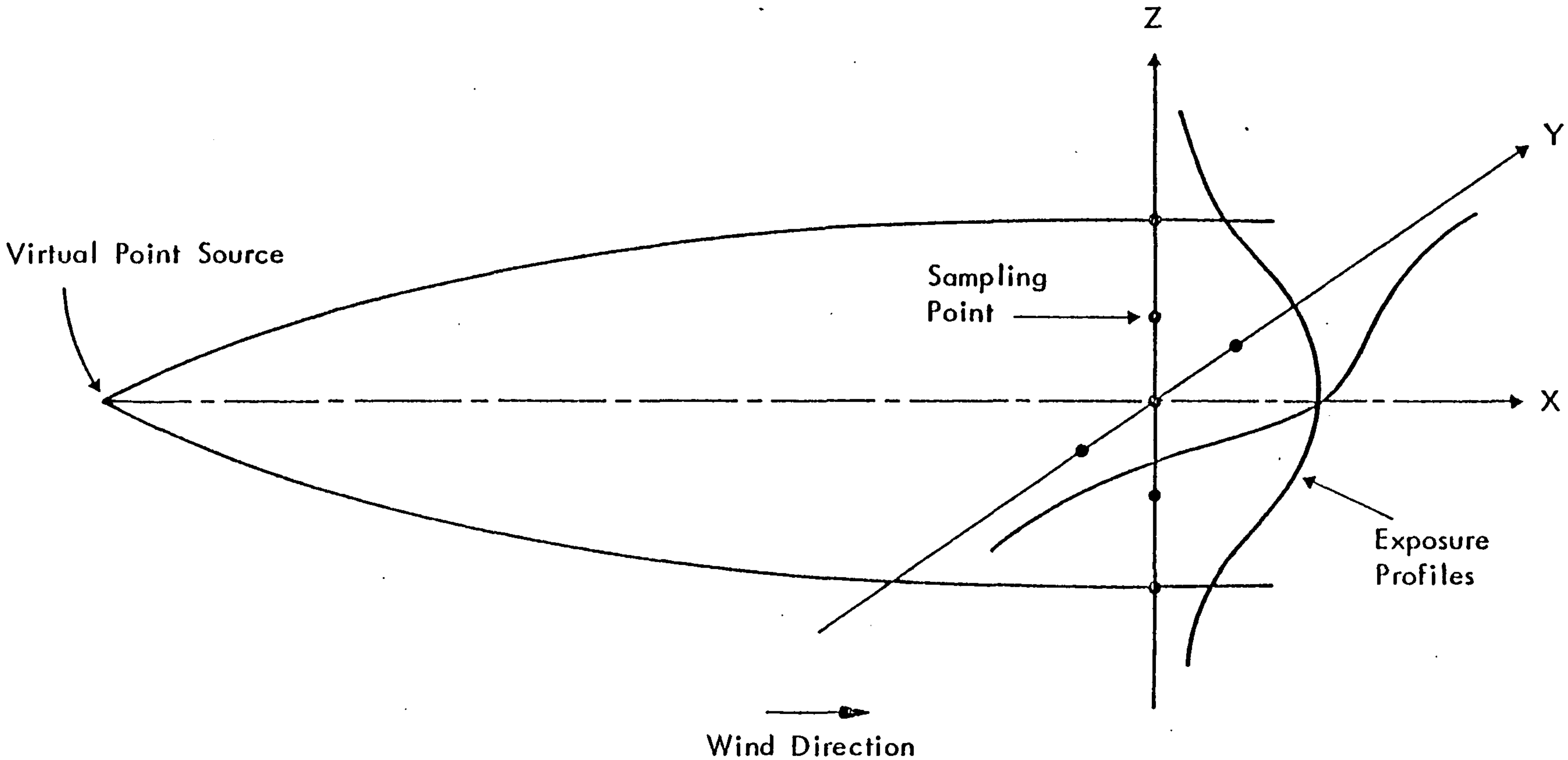

Figure 2. Example exposure profiling arrangement.

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.

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.

Based on replicate exposure profiling of open dust sources under varying conditions of source activity and properties of the emitting surface, emission factor formulae have been derived that successfully predict test results with a maximum error of 20%.[3] These formulae 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. Based on the above results, the accuracy of exposure profiling is considerably better than the ± 50% range given for the upwind/downwind method with site-specific dispersion model calibration.[9]

2.4.3 Methods for Particle Sizing

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.[14] Once again, the sampling intake should be pointed into the wind and the sampling velocity adjusted to the mean local wind speed by fitting the intake with a nozzle of appropriate size.

The recently developed EPA version of the dichotomous sampler,[15] which is virtually free of particle bounce problems is useful for quantification of fine particle mass concentrations. However, this device operates at a low flow rate (1 cu m/hr) yielding only 0.024 mg of sample in 24 hr for each 10 $\mu g/m^3$ of TSP concentration. Thus, an analytical balance of high precision is required to determine mass concentrations below and above the fine particulate (2.5 μm) cutpoint (the minimum in the typical bimodal size distribution of atmospheric particulate). In addition, the dichotomous sampler was designed to have a 15 μm cutpoint for capture of airborne particles (the upper size limit for inhalable particulate based on unit density); however, recent wind tunnel studies have shown that this cutpoint is wind sensitive.[16]

The size-selective inlet for a standard high-volume sampler[9] is also designed to capture particles smaller than 15 μm in aerodynamic diameter. This unit is much less wind sensitive than the dichotomous sampler[16] but it does not provide a cutpoint at 2.5 μm. However, it can be adapted for use with a high volume cascade impactor to obtain an IP size distribution.

3.0 CONTROL TECHNOLOGY FOR OPEN DUST SOURCES

A number of publications are available which describe in some level of detail the various control techniques which have been applied to open dust sources. A bibliography of such literature resources is presented in Appendix B.

3.1 TYPES OF CONTROL TECHNIQUES

Standard preventive techniques for the control of open dust sources may be divided into three basic types:

1. Maintenance of high moisture levels in the exposed surface.

2. Chemical stabilization of the exposed surface.

3. Protection of the exposed surface by physical emplacements.

Each of these control method types is discussed briefly below.

Decades of research on the physical principles of soil loss by wind erosion have quantified the dependence of dust generation on moisture content.[17,18] This may be approximated as an inverse square relationship. Maintenance of high moisture levels in exposed surfaces associated with open dust sources is very effective in controlling dust emissions. This may be accomplished by periodic or continuous watering using fixed or mobile spray systems. Moisture penetration and.or retention may be enhanced by the use of: (a) chemical wetting agents or foams, or (b) dessicant materials such as calcium chloride.

Chemical stabilization of an exposed dusty surface to control dust emissions is accomplished by the direct application of chemical agents to the surface. These agents bind the loose surface particulate which otherwise would be subject to entrainment into the atmosphere by the forces of wind or machinery. If the surface is subject to large mechanical stresses (for example, as would be the case for an unpaved haul road), it is important that the base below the surface be strong enough to absorb the stresses. Otherwise, the surface crust may be broken and become uneffective in controlling dust emissions.

Because the rate of dust generation by wind erosion increases substantially with wind speed (above the "threshold" value), control of wind erosion can be effected by reducing the wind speed near the exposed surface in relation to the ambient wind. This may be accomplished by enclosures or other forms of windbreaks.

Nonpreventive control of emissions from open dust sources entails the capture of emissions usually by some combination of hooding and enclosures. Water sprays are not very effective for this purpose, although recent research efforts have shown that charged fogs are substantially more effective. Table 3 lists current research studies dealing with control technology for open dust sources.

3.2 EFFICIENCY AND COST OF CONTROL

Ideally, the selection of "best" controls for a particular open dust source should be based on cost-effectiveness evaluation of each of the potentially applicable control techniques. Unfortunately, the data for these evaluations are sparce and generally do not reflect the wide variability of source conditions.

Cost and estimated efficiency data on open dust source controls for the integrated iron and steel industry have been compiled by Bohn et al.[1] These costs included initial and annual operating costs of several control

TABLE 3. RECENT AND CURRENT INVESTIGATIONS OF CONTROL TECHNOLOGY APPLICABLE TO OPEN DUST SOURCES

1. Paved and unpaved road emissions, Midwest Research Institute, Dr. Chatten Cowherd, EPA Contract No. 68-02-2814.

2. Improved street sweepers for paved roads, Air Pollution Technology, Dr. Richard Parker, EPA Contract No. 68-02-3148.

3. Road carpet for unpaved roads, Monsanto, Mr. Keith Tackett, EPA Contract No. 68-02-3107.

4. Windscreening and chemical additives for area sources, The Research Corporation of New England, Mr. Dennis Martin, EPA Contract No. 68-02-3115.

5. Charged fog for construction sight activity and front-end loaders, Aerovironment, Mr. John Kinsey, EPA Contract No. 68-02-3145.

6. Dust control for haul roads, Midwest Research Institute, Mr. Russel Bohn, BuMines Contract No. J0285015.

7. Emission factors and control technology for fugitive dust from coal mining sources, PEDCo/MRI, Mr. Ken Axetell/Dr. Chatten Cowherd, EPA Contract No. 68-02-2585.

8. Fugitive emissions from integrated iron and steel plants, Midwest Research Institute, Mr. Russel Bohn, EPA Contract No. 68-02-2120 (see EPA-600/2-78-050, March 1978).

options applied to each source. As part of the same study, cost-effectiveness evaluation was performed for a typical process source of fugitive emissions (electric arc furnace) and for several open dust sources (see Table 4).

Recently, Cooper et al.[19] have compiled cost-effectiveness data for the control of emissions from unpaved roads by paving, oiling, watering, calcium chloride, and speed control. However, details on the application frequency and intensity of dust suppressants is sketchy.

Another recent compilation of cost-effectiveness data for the control of emissions from unpaved mining haul roads and access roads has been prepared by Bohn et al.[20] As shown in Table 5, the product control efficiencies, although largely estimates, are properly tied to prescribed levels of application density and frequency.

As illustrated in the above examples, the most serious data gap affecting cost-effectiveness evaluation is the nearly total lack of actual field data on control method performance, especially for the preventive control techniques. Table 6 illustrates this point by summarizing the reported efficiencies for control of wind erosion from storage piles; all but one of the efficiency values are estimates.

Because of the finite durability of all control techniques, ranging from hours (watering) to years (paving), it is essential to tie an efficiency value to a frequency of application (or maintenance). For measures of lengthy durability, such as paving of unpaved roads, the maintenance program required to sustain control effectiveness should be indicated. One likely pitfall to be avoided is the use of field data on a freshly applied control measure to represent the lifetime of the measure.

3.3 CURRENT INDUSTRY CONTROL PRACTICES

Analysis of the materials handling flow charts for the 14 integrated iron and steel plants indicate that a number of control techniques are being

TABLE 4. COST EFFECTIVENESS OF FUGITIVE EMISSIONS CONTROL METHODS

Source	Control method	Estimated control efficiency (%)	Annualized investment cost ($/lb)[a]	Ranking order [ ]	Annual operating cost ($/lb)[a]	Ranking order [ ]
Process						
EAF	Canopy hoods	70	1.44	[8]	NA	-
Open dust						
Storage pile activities Load-in/load-out	Utilize mobile stacker/reclaimer combination rather than front-end loader activity for pellet piles	80	8.68	[9]	NA	-
Wind erosion from storage piles (lump iron ore)	Watering	80	0.02	[4]	NA	-
	Chemical stabilizers (Coherex 20% solution)	97	0.02	[4]	0.008	[1]
Vehicular traffic						
Unpaved roadways	Watering	50	0.006	[2]	0.06	[5]
	Road oil	75	0.006	[2]	0.4	[7]
	Oil and double chip	80	0.02	[4]	0.03	[3]
	Chemical stabilizers (Coherex)	90	0.02	[4]	0.08	[6]
	Paving	90	0.08	[5]	0.08	[6]
Paved roadways	Broom sweeping	70	0.005	[1]	0.05	[4]
	Vacuum sweeping	75	0.01	[3]	0.06	[5]
	Road flushing	80	0.006	[2]	0.05	[4]
Wind erosion from exposed areas	Watering	50	0.21	[7]	0.01	[2]
	Chemical stabilizers[b]	70	0.16	[6]	0.05	[4]
	Oiling	80	0.02	[4]	NA	-
	Paving with cleaning	95	0.01	[3]	NA	-

NA = Not available.

a/ Dollar per pound reduction of fine particulate per year.

b/ No specific chemical stabilizer given; 70% control efficiency is assumed to be the average of all available chemical stabilizers for this control purpose.

TABLE 5. CONTROL EFFICIENCIES OF ROAD DUST SUPPRESSANTS

Parameter	Lignin sulfonate	Coherex®	Calcium chloride	Road watering	Wetting agents
Control efficiency					
Haul road	75%	75%	75%	75%	75%
Access road	70%	70%	70%	70%	70%
Application density					
Haul road					
Initial	2 gal./yd^2 of 15% solution	2 gal./yd^2 of 1:4 dilution	1 gal./yd^2 of 30% solution	0.05 gal./yd^2	0.05 gal./yd^2
Subsequent	Same	0.5 gal./yd^2 of 1:10 diultion	0.3 gal./yd^2 of 30% solution	Same	Same
Access road	2.4 gal./yd^2 of 12% solution	1 gal./yd^2 of 1:7 dilution	0.6 gal./yd^2 of of 30% solution	0.05 gal./yd^2	0.05 gal./yd^2
Application Frequency/Year					
Haul road	6	6	6	Summer: Hourly Spring and Fall: Every 2 hr Winter: Once per day	Summer: Daylight hr Spring and Fall: Every 2 daylight hr Winter: Every other day
Access road	1	1	1	Summer: Every 2 hr Spring and Fall: Every Winter: Once every 2 days	Summer: Every 2 daylight hr Spring and Fall: Every 3 daylight hr Winter: Once per week

TABLE 6. REPORTED EFFICIENCIES FOR CONTROL OF WIND EROSION OF STORAGE PILES

Control method	Reported efficiency (%)	Reference (year)*	Method of determination
Watering - periodic sprinkling	50	22 (1976) 23 (1977)	Ref. 21 (1973) - estimate Ref. 22 (1976) - estimate
Watering - wind-activated sprinkler system	80	1 (1978)	Estimate
Chemical wetting agents or foam	90	23 (1977)	Estimate
Continuous chemical spray onto input material	90	22 (1976) 23 (1977)	Vendor brochure - estimate
Surface crusting agents	Up to 99	1 (1978)	Ref. 24 (1974) - wind tunnel tests
Enclosure	95 to 99	23 (1977)	Estimate
Storage silos	100	1 (1978)	Estimate
Vegetative windbreak	30	1 (1978)	Estimate
Low pile height	30	1 (1978)	Estimate

* Reference 25 cites References 23 and 1.

applied to open dust sources at one or more locations. These are summarized in Table 7.

In addition, plans are underway at one plant to apply Coherex® to unpaved roads and to the shoulders and berms of paved roads and to vegetate bare ground areas. Presumably some form of cost-effectiveness analysis was undertaken in the selection and implementation of these control measures.

3.4 SELECTION OF BEST CONTROLS

The selection of best controls was based on the extent of use within the industry and on the results of the preliminary cost-effectiveness evaluations cited above. The "best" controls are reviewed for each source category in the paragraphs below.

The best control methods selected for unpaved roads are: application of Coherex®, watering, and application of calcium chloride. All three of these techniques have been used in the integrated iron and steel industry. These techniques have favorable cost-effectiveness ratios, although recent increases in the price of calcium chloride have made it less competitive.

The best control methods selected for paved roads are flushing and vacuumings. These techniques are used in combination within the steel industry. Preliminary evaluation based on estimated control efficiencies shows that these two methods have similar cost-effectiveness ratios. At one plant, Coherex® is being applied to unpaved shoulders and berms of paved roads to reduce emissions from these areas and to prevent the rapid build-up of surface loadings on the paved road.

Watering (possibly with the addition of wetting agents) has been selected as the best method to control emissions from storage pile maintenance and wind erosion. Because of the active nature of the surfaces involved, chemical stabilization is not effective. Also, the use of physical windbreaks characteristically prevents the freedom of access to the pile which is necessary to maintain adequate material flows into and out of storage.

TABLE 7. SUMMARY OF FUGITIVE EMISSION CONTROLS (BY PLANT)

Source	Control practice	Plant(s)
I. Unpaved roads	A. Watering	Armco-Houston Works
	B. Oiling	J&L Steel-Aliquippa Works
II. Paved roads	A. Flushing	None reported
	B. Sweeping	Armco-Houston Works (also watering)
III. Storage pile (maintenance and wind erosion)	A. Watering	1. Armco-Houston Works 2. Bethlehem Steel-Burns Harbor 3. U.S. Steel-Gary Works 4. U.S. Steel-Geneva Works
	B. Chemical sprays	1. Bethlehem Steel-Burns Harbor 2. National Steel-Great Lakes Division
IV. Unpaved parking lots	None indicated	
V. Conveyor transfer station	A. Enclosures	1. Armco-Middletown Works 2. Bethlehem Steel-Burns Harbor 3. Interlake Steel-Chicago 4. J&L Steel-Aliquippa Works 5. U.S. Steel-Geneva Works
	B. Water sprays	1. Armco-Middletown Works 2. Bethlehem Steel-Burns Harbor 3. U.S. Steel-Geneva Works
	C. Chemical sprays	1. Bethlehem Steel-Sparrows Point
VI. Exposed Area Wind Erosion	Vegetation	None reported

The best method to control emissions from unpaved parking lots and other exposed areas subject to traffic disturbance is through the application of a chemical stabilizer. Such areas usually have a well compacted subsurface to allow for mechanical stress absorbance without break up of the stabilizing agent. Moreover, it is usually not practical to water large areas that are poorly accessible.

Conveyor transfer stations are best controlled by enclosure and ducting of the captured dust to a removal device prior to recycle or disposal. Water sprays on conveyed material is a preventive method for controlling dust. Both of these method are widely used in the integrated iron and steel industry.

4.0 RECOMMENDATIONS FOR PHASE II

This section presents our recommendations for a field testing program to supply the data needs for cost-effectiveness evaluation of the best controls for open dust sources within the integrated iron and steel industry.

4.1 DATA NEEDS

The data needs for control cost-effectiveness evaluation fall into the following categories:

- Emission factors for total suspended particulate (TSP), inhalable particulate (IP), and fine particulate (FP) with and without application of the control technique.

- Emission factor correction parameters (see Table 8) for uncontrolled and controlled test source segment.

- Control application density and time after application for which controlled testing was performed.

- Investment and operating costs of dust control measure.

The procedures for development of size specific emission factors for open dust sources are outlined in the next section, as are procedures for on-site correction parameter determination. Control application density should be expressed in units similar to that found in Table 5.

Cost data for the control technique being tested should be obtained from the steel plant where testing is performed. These data should include: (a) annualized costs of equipment purchase and installation, and (b) annual

TABLE 8. PARAMETERS AFFECTING EMISSION FACTORS FOR OPEN DUST SOURCES

Generic source category	Material	Equipment	Climate
Vehicular traffic on unpaved surfaces	Surface silt content	Vehicle speed Vehicle weight Number of wheels	
Vehicular traffic on paved surfaces	Surface silt content Surface loading	Vehicle weight	
Wind erosion of storage piles and exposed areas	Surface erodibility Surface silt content Surface moisture content		Wind speed

operating costs. The annualized investment costs should take into account the initial costs, the life time of the equipment, interest and taxes. To calculate the total annualized cost, the average annual cost of operation is added to the product of the initial capital investment and the capital recovery factor. The capital recovery factor is the percentage of the initial investment which would be paid yearly on a loan or mortgage.

4.2 SAMPLING AND ANALYSIS PROCEDURES

This section describes the field sampling and laboratory analysis procedures that will be used to quantify (a) particulate emission rate and particle size distribution, (b) meteorological conditions, and (c) process conditions. The quality assurance program is also discussed.

4.2.1 Mechanically Generated Particulate Emissions

Table 9 lists the equipment that will be used to sample particulate emissions from unpaved roads, paved roads, storage pile maintenance, and unpaved parking lots. Equipment locations and intake heights are specified. The primary tool for quantification of emission rate will be the exposure profiler, operated in the moving point source mode.

The exposure profiler (Figure 3) consists of a portable tower (4 to 6 m height) supporting an array of four sampling heads. Each sampling head is operated as an isokinetic exposure sampler directing passage of the flow stream through a settling chamber (trapping particles larger than about 50 μm in diameter) and then upward through a standard 8 by 10 in. glass fiber filter positioned horizontally. Sampling intakes are pointed into the wind, and sampling velocity of each intake is adjusted to match the local mean wind speed, as determined prior to each test. Throughout each test, wind speed is monitored by recording anemometers at two heights, and the vertical profile of wind speed is determined by assuming a logarithmic distribution. Normally, the exposure profiler is positioned at a distance of 5 m from the downwind edge of the road.

TABLE 9. SAMPLING EQUIPMENT FOR OPEN DUST SOURCES

Location	Distance from source (m)	Equipment	Intake height (m)
Upwind	5-10	1 Standard Hi-Vol	2.0
		1 Hi-Vol with 15 μm inlet[a]	2.0
		1 Hi-Vol with 15 μm inlet[b]	4.0
		1 Continuous wind monitor	4.0
Downwind	5	1 MRI exposure profiler with four sampling heads	1.0 2.0 3.0 4.0
		1 Standard Hi-Vol	2.0
		2 Hi-Vol cascade impactors with 15 μm inlet or cyclone precollector	1.0 3.0
		2 Warm wire anemometer	1.0 3.0

a A particle sizing unit will be operated in place of this unit for one run in each 3-run test series.

b This unit will be used only on tests of controlled emissions.

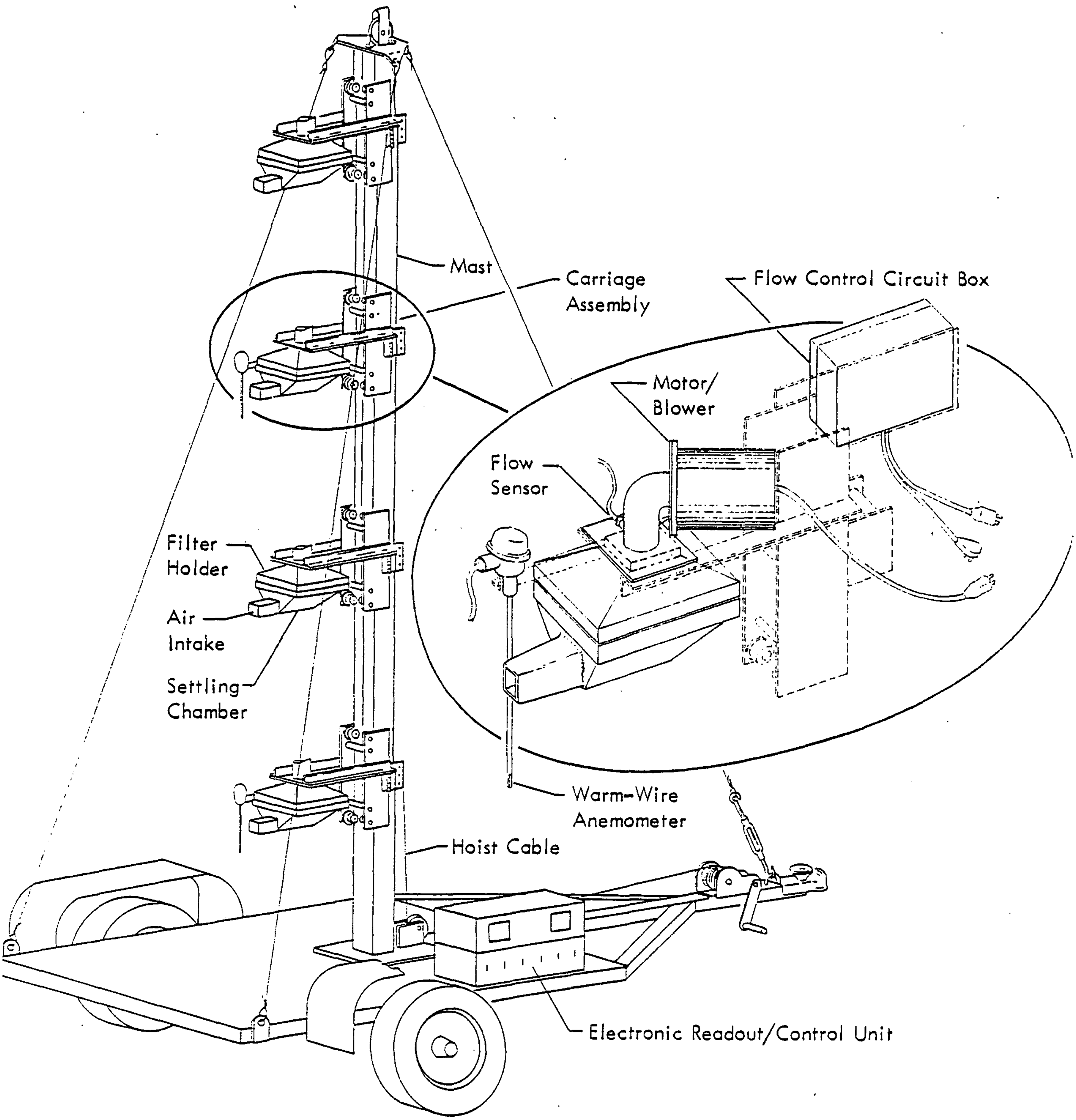

Figure 3. MRI exposure profiler.

Particle size distribution will be measured using a high volume cascade impactor preceeded either by a size-selective intake (15 µm cutpoint) or a cyclone preseparator (10 µm cutpoint). The first option provides for direct measurement of inhalable particulate, but requires total (isokinetic) particulate concentrations from the exposure profiler for the calculation of the particle size distribution of total airborne particulate matter in the emission plume. The second option provides for direct isokinetic measurement of the total particle size distribution but requires extrapolation from the cyclone cutpoint (10 µm) to determine IP concentrations. In either case, particle sizing samplers will be operated along side of the exposure profiler at two heights (usually the first and third profiler levels) in the fugitive dust plume.

Also, a high-volume sampler with a size-selective inlet (Hi-Vol/SSI) will be operated at the upwind monitoring station to determine the IP fraction of the background particulate. This will be replaced with a particle sizing sampler for one run in each 3-run test series. For tests of controlled emissions, a second Hi-Vol/ SSI will be operated at a higher elevation to determine the change of background IP concentration with height. Conventional high-volume samplers will be operated at one height both upwind and downwind of the source.

Table 10 lists the critiera for suspending or terminating an exposure profiling test. Some of these criteria address the wind conditions in relation to the requirements for isokinetic sampling. Testing may also cease if rainfall ensues (reducing emissions to negligible levels) or if light is insufficient for safe operation. The final criterion deals with an unacceptable change in source condition.

Sampling time will be sufficient to provide sufficient particulate mass and to average over several units of cyclic fluctuation in the emission rate, e.g., vehicle passes on an unpaved road. Because of the proximity of the sampling grid to the source, the first condition is easily met for testing of uncontrolled sources. However, testing of controlled sources may require a sampling period of up to 4 hours to provide sufficient sample mass.

TABLE 10. CRITERIA FOR SUSPENDING OR TERMINATING AN EXPOSURE PROFILING TEST

A test will be suspended or terminated if:[a/]

1. Rainfall ensues during equipment setup or when sampling is in progress.
2. Mean wind speed during sampling moves outside the 4 to 20 mph acceptable range for more than 20% of the sampling time.
3. The angle between mean wind direction and the perpendicular to the path of the moving point source during sampling exceeds 45 degrees for more than 20% of the sampling time.
4. Mean wind direction during sampling shifts by more than 30 degrees from profiler intake direction.
5. Mean wind speed approaching profiler sampling intake is less than 80% or greater than 120% of intake speed.
6. Daylight is insufficient for safe equipment operation.
7. Source condition deviates from predetermined criteria (e.g., occurrence of truck spill).

a/ "Mean" denotes a 15-min average.

Emissions from conveyor transfer stations will be measured by standard stack sampling methods using the quasi-stack method as described in Reference 9. This will necessitate the testing of a well enclosed station with an adequate run of ducting. The uncontrolled emission rate will be determined by sampling the ducted conveyor emissions upstream of the particulate removal device.

4.2.2 Wind-Generated Particulate Emissions

A portable wind tunnel fabricated by MRI (Figure 4) will be used to measure emissions from wind erosion of storage piles or other exposed areas. The wind tunnel consisted of a two-dimensional 5:1 contraction section, an open-floored test section, and a roughly conical diffuser. The test section of the tunnel is placed directly on the surface to be tested (30 cm x 2.4 m), and the tunnel centerline air flow is adjusted to predetermined velocities up to 18 m/sec (40 mph), as measured by a pitot tube at the downstream end of the test section.

An emissions sampling module[2] has been designed and fabricated for use with the pull-through wind tunnel in measuring particulate emissions and particle size distributions generated by wind erosion. As shown in Figure 4, the sampling module is located between the tunnel outlet hose and the fan inlet. The sampling train, which is operated at 34 m^3/hr (20 cfm), consists of a tapered probe, cyclone precollector, parallel-slot cascade impactor, back-up filter, and high volume motor. Interchangeable probe tips are sized for isokinetic sampling at predetermined cross-sectional average velocities within the tunnel test section.

4.2.3 Site/Process Conditions

In addition to the measurements of wind speed obtained at two heights on the profiling tower, a meteorological instrument will also be located at the background monitoring station. Continuous measurements of wind speed and direction at a height of 4 m will be recorded at the upwind site.

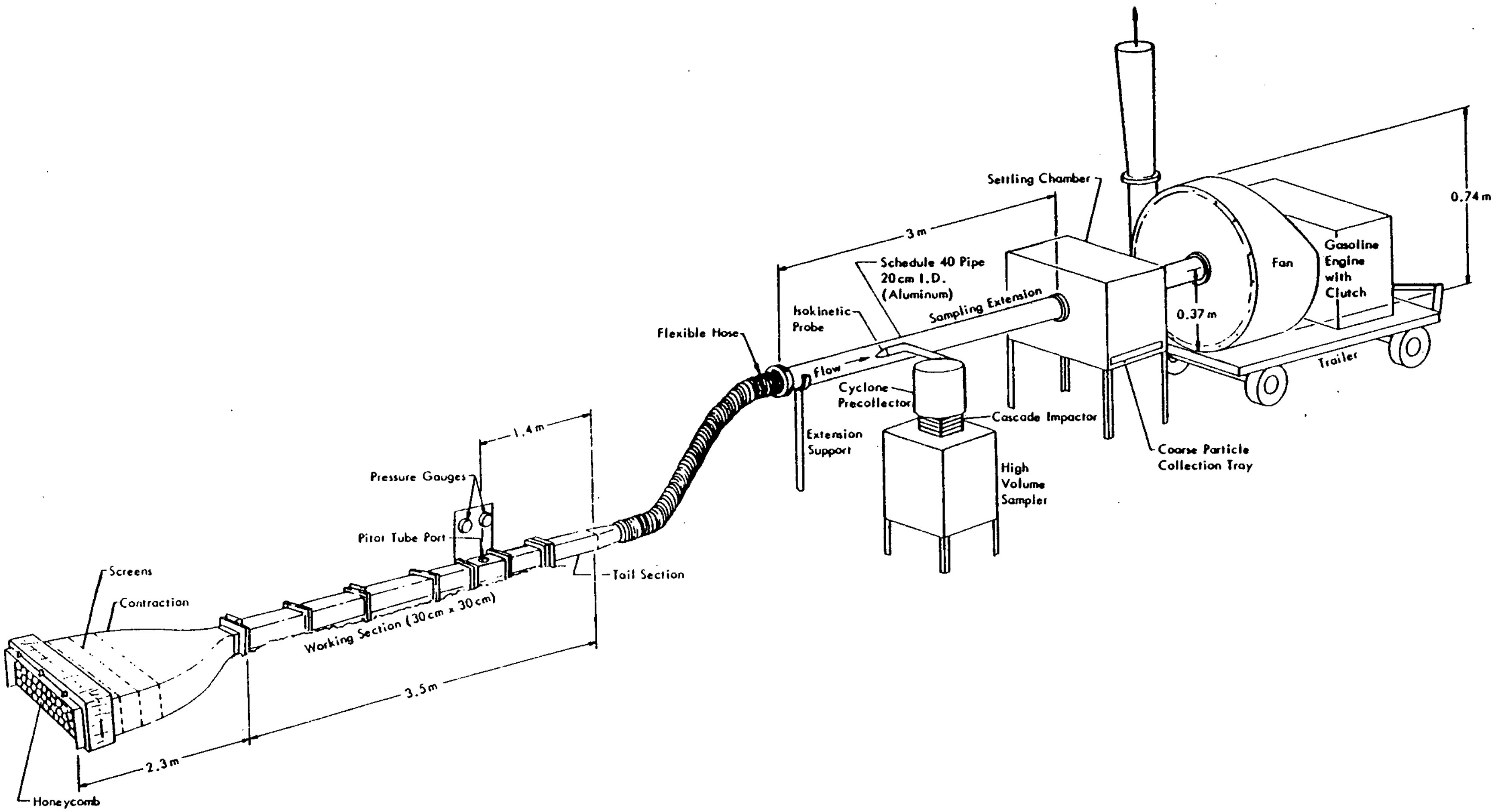

Figure 4. MRI portable and tunnel.

In order to determine the properties of aggregate materials being distrubed by the action of machinery or wind, representative samples of the materials will be obtained for analysis in the laboratory. Unpaved and paved roads will be sampled by vacuuming and broom sweeping to remove loose material from lateral strips of road surface extending across the traveled portion. Storage piles will be sampled to a depth exceeding the size of the largest aggregate pieces. If possible, samples of conveyed material will be taken directly from the conveyer upstream of the transfer station being tested. Additional detail on the sampling methods is provided elsewhere.[2]

Throughout a test of traffic-generated emissions, a vehicle count will be maintained by a pneumatic-tube traffic counter. Periodically (e.g., during 15 min of each hour) vehicle mix will be determined by compiling a log of vehicles passing the test point segregated by vehicle type (usually the number of axles and wheels). Vehicle speeds will be measured with a radar gun. Data on vehicle weight will be obtained from plant personnel.

4.2.4 Sample Handling and Analysis

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

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

After the gross samples of surface particulate are taken to the laboratory, they are prepared for moisture and silt analysis. The first step consists of reducint the sample to a workable size. A riffle sample splitter should be used for this purpose, following ASTM Method D2013-72, "Standard Method of Preparing Coal Samples for Analysis." The final split should produce a sample mass not exceeding 1,000 g.

The reduced samples of surface particulate will be dried to determine moisture content and screened to determine the weight fraction passing a 200 mesh screen, which gives the silt content. A conventional shaker will be used for this purpose. That portion of the material passing through the 200 mesh screen will be analyzed to determine the density of potentially suspendable particules. The procedures for moisture and silt analysis, which comform to ASTM Method C136-76, are summarized in Tables 11 and 12.

4.3 QUALITY ASSURANCE PROGRAM

4.3.1 Sampling and Analysis of Airborne Particulate

The quality assurance program for particulate sampling and analysis will include (a) activities designed to demonstrate that measurements are made within acceptable control conditions, and (b) assessment of sampling and analysis data for precision and accuracy. The QA program for quantification of fugitive particulate emissions meets or exceeds requirements specified in "Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II -Ambient Air Specific Methods" (EPA 600/4-77-027a) and "Ambient Monitoring Guidelines for Prevention of Significant Deterioration" (EPA 450/2-78-019).

A variety of particulate sampling devices will be utilized in the study to quantify fugitive emissions by exposure profiling. Sampling devices include: standard Hi-Vol air sampling units (with and without 15 µm inlets), exposure profiling systems, and Hi-Vol cascade impactors. These sampling devices utilize filter media, impaction substrates, and cyclone catch chambers to collect the sampled particulate. A certain amount of particulate

TABLE 11. 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.

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.

TABLE 12. SILT ANALYSIS PROCEDURES

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

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

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

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

5. Tare sieves and pan. Check the zero before every weighing. Record weights.

6. After nesting the sieves in decreasing order with pan at the bottom, dump dried laboratory sample (probably immediately after moisture analysis) into the top sieve. Brush fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.

7. Place nested sieves into the mechanical device and sieve for 20 min. Remove pan containing minus No. 200 and weigh. Replace pan beneath the sieves and sieve for another 10 min. Remove pan and weigh. When the difference between two successive pan sample weighings (where the tare of the pan has been subtracted) is less than 3.0%, the sieving is complete.

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

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

is also collected on interior surfaces of the sampling probe and connect tubing which must be rinsed and filtered.

There are six main categories which a QA program for fugitive particulate sampling must address. They are:

* Calibration of equipment
* Filter and impaction substrate selection and preparation
* Sampling procedures
* Sampling equipment maintenance
* Laboratory analysis procedures
* Calculations and data reporting

A series of tables in EPA 600/4-77-027a presents a matrix of activities which should be performed to satisfy the QA aspects within each of the above categories.

Tables 13 through 16 list the adaptations of the EPA requirements which will be adopted to improve the QA aspects above minimum EPA requirements. For example, electronic flow controllers will be used in all air sampling devices to minimize excursions from preset flow rates.

As part of the QA program for the study, routine audits of sampling activities will be performed. The purpose of the audits will be to demonstrate that measurements are made within acceptable control conditions for particulate source sampling and to assess the source testing data for precision and accuracy. Examples of items to be audited include filter weighing, flow rate calibration, data processing and calculations. The mandatory use of specially designed reporting forms for sampling and analysis data obtained in the field and laboratory aid in the auditing procedure.

TABLE 13. QUALITY ASSURANCE PROCEDURES FOR SAMPLING FLOW RATES

Activity	QA Check/Requirement
Calibration	
. Profilers, hi-vols, and impactors	Calibrate flows in operating ranges using calibration orifice every two weeks at each regional site prior to testing.
. Dichotomous samplers	Calibrate flows in operating ranges with displaced volume test meters every two weeks at each regional site prior to testing.
Single-Point Checks	
. Profilers, hi-vols, and impactors	Check 25% of units with rotameter calibration orifice or electronic calibrator once at each site prior to testing (different units each time). If any flows deviate by more than 7%, check all other units of same type and recalibrate non-complying units. (See alternative below.)
. Dichotomous samplers	Check 25% of unit with calibration orifice once at each site prior to testing (different units each time). If any flows deviate by more than 5%, check all other units and recalibrate noncomplying units.
. Alternative	If flows cannot be checked at test site, check all units every two weeks and recalibrate units which deviate by more than 7% (5% for dichots).
Orifice Calibration	Calibrate against displaced volume test meter annually.

TABLE 14. QUALITY ASSURANCE PROCEDURES FOR SAMPLING MEDIA

Activity	QA Check/Requirement
Preparation	Inspect and imprint glass fiber media with ID numbers. Inspect and place teflon media (dichot filters) in petri dishes labeled with ID numbers.
Conditioning	Equilibrate media for 24 hr in clean controlled room with relative humidity of less than 50% (variation of less than ± 5%) and with temperature between 20 C ± and 25 C (variation of less than ± 3%).
Weighing	Weigh hi-vol filters and impactor substrates to nearest 0.1 mg and weigh dichot filters to nearest 0.01 mg.
Auditing of weights (Tare and Final)	Independently verify weights of 7% of filters and substrates (at least 4 from each batch). Reweigh batch if weights of any hi-vol filters or substrates deviate by more than ± 3.0 mg or if weights of any dichot filters deviate by more than ± 0.05 mg.
Correction for Handling Effects	Weigh and handle at least one blank for each 1 to 10 filters or substrates of each type for each test.
Prevention of Handling Losses	Transport dichot filters upright in filter cassettes placed in protective petri dishes.
Calibration of Balance	Balance to be calibrated once per year by certified manufacturer's representative check prior to each use with laboratory Class S weights.

TABLE 15. QUALITY ASSURANCE PROCEDURES FOR SAMPLING EQUIPMENT

Activity	QA Check/Requirements
Maintenance	
. All samplers	Check motors, gaskets, timers, and flow measuring devices at each regional site prior to testing.
. Dichotomous samplers	Check and clear inlets and nozzles between regional sites.
Equipment Siting	Separate colocated samplers by 3 to 10 equipment widths.
Operation	
. Timing	Start and stop all samplers during time spans not exceeding 1 minute.
. Isokinetic sampling (profilers only)	Adjust sampling intake orientation whenever mean (15 min. average) wind direction changes by more than 30 deg.
	Adjust sampling rate whenever mean (15. min. average) wind speed approaching sampler changes by more than 20%.
. Prevention of Static Mode Deposition	Cap sampler inlets prior to and immediately after sampling.

TABLE 16. QUALITY ASSURANCE PROCEDURES FOR DATA PROCESSING AND CALCULATIONS

Activity	QA Check/Requirements
Data Recording	Use specially designed data forms to assure all necessary data are recorded. All data sheets must be initialed and dated.
Calculations	Independently verify 10% of calculations of each type. Recheck all calculations if any value audited deviates by more ± 3%.

4.3.2 Meteorological Monitoring

The primary meteorological parameters to be monitored during source testing are wind speed and direction. Precipitation (important in open source fugitive assessments), temperature, and relative humidity will also be observed. Atmospheric stability will be determined from wind direction fluctuations. Raw field data will be recorded on a continuous strip chart and stored on magnetic tape at the site. Parameters will be sampled at intervals no longer than 60 sec. The magnetic tape will be used primarily for data analysis, with the strip chart as back-up.

QA procedures to be used during meteorological sampling follow federal EPA guidelines. Each instrument will be sited to produce representative samples of the meteorological parameters observed. For instance, wind monitors will be sited away from buildings, trees, and other substantial obstacles. Rainfall measurements will be made to avoid the effects of wind on precipitation catch.

Wind speed and direction sensors will exhibit a starting threshold of less than 0.5 m/sec. Anemometers will be accurate to ± 0.25 m/sec at speeds below 5 m/sec. At high velocities, the error will not exceed ± 5% of the speed, with no errors greater than 2.5 m/sec. The wind vane damping ratio will be between 0.4 and 0.65. Wind vane errors will not exceed 3 degrees for 10-min averages.

Temperature will be measured to ± 1.0°C. Relative humidity error will not exceed an equivalent dew point error of 1.0°C. The rain guage will have an accuracy of 0.25 mm/hr at a precipitation rate of 7.6 cm/hr.

Each instrument will be calibrated at least every 6 months at MRI facilities and weekly in the field. Field calibration will also be employed whenever the instrument is tranported long distances.

Wind speed monitors (cup and warm wire anemometers) will be calibrated at least every 6 months against known flows in a wind tunnel. In the field, the instruments will be calibrated either by visual observation of wind speed or by comparison with co-located anemometers. Field calibration will also include adjustment of the zero and span levels on the cup anemometer signal processor.

Correct operation of the wind direction sensor will be determined in the field and at MRI by observing the instrument output while manually adjusting the vane heading. In addition, zero and span settings for the wind vane signal processor will be set at every field and MRI calibration.

Temperature and relative humidity sensors will be calibrated, in-house and in the field, by comparison with measurements from a sling psychrometer. Adjustments to the signal processor will be made by setting zero and span levels.

Rain gauge calibrations will be made by pouring specified volumes of water into the intake funnel. The signal processor for this instrument will be calibrated by setting zero and span levels.

4.4 STATISTICAL BASIS FOR SAMPLING PLAN

This section presents statistical analysis to determine the expected reliability of the emission factors developed from replicate sampling at each site. For purposes of this analysis, it is assumed that in the absence of significant precipitation or other events which might irreversibly alter the source condition, particulate emission rates vary about a constant mean for a given test site during the period of replicate testing (usually less than 1 week).

Based on the detailed error analysis for the exposure profiling method, it is shown that a typical emission rate can be expected to have a random 1 σ error of ± 10%. An additional error due to linear extrapolation of the particle size distribution will be encountered in calculating emission rates for particles larger than 15 μm diameter. This factor may contribute an additional ± 10% random 1 σ error to a typical emission rate for suspended particulate. A combination of these two errors with the natural variability of the daytime source condition ($\sigma = \pm 10\%$) gives an estimate of the standard deviation, σ, of the total population of possible measured values, expressed as a percentage:

$$\sigma = \quad (10)^2 + (10)^2 + (10)^2 = 17.3\% \qquad (7)$$

The sample size, n, needed to achieve an expected standard deviation of the sample mean, S_d, that is less than 10% of the mean of the population, is given by:

$$n = \left(\frac{\sigma}{S_d}\right)^2 = \left(\frac{17.3}{10}\right)^2 = 3.0 \qquad (8)$$

Consequently, a sample of three replicate tests will achieve an expected 1 σ error of less than 10% for the sample emission rate mean in relationship to the true emission rate.

4.5 DISTRIBUTION OF TESTS

The proposed distribution of tests over the source categories of interest is based on the following considerations:

1. The number of control measures tested for a particular source type should reflect the importance of the source based on uncontrolled emissions, but may be limited by the number of candidate "best controls" that are available.

2. All control measures must be referenced to an uncontrolled condition.

3. Triplicate tests are needed to characterize an uncontrolled or controlled condition at any point in time.

4. Long-term control measures must be tested at least twice after application to establish control efficiency decay curve.

5. Short-term control measures (e.g., watering) will usually show loss of efficiency during back-to-back testing.

6. Testing of wind erosion must quantify decay of emission rate with time so that loss potential can be quantified.

The proposed distribution of tests is shown in Table 17.

4.6 PROPOSED TEST SITES

Test sites with established control programs are preferable to those where control must be applied for the first time. This helps to provide credibility that the program for application of the control technique is realistic. For the same reason, chemical dust suppressants and watering will be tested at typical application densities rather than those which may be purported to improve performance. All of this will ensure that the historical cost and performance data which have been compiled at a particular site apply to the control measure as tested.

At the time of this writing, it is envisioned that the first plant to be tested will be Armco's Middletown Works. The sources proposed for testing at Middletown are given in Table 18. The remainder of the field test program, which is targeted for completion by the end of October 1980, will take place at two additional sites, yet to be selected.

The schedule proposed for testing is as follows:

Testing of uncontrolled sources at Armco's Middletown Works	Late June/early July
Pre-test survey of second and third plant sites	Late July

TABLE 17. PROPOSED DISTRIBUTION OF TESTS

Source	Control measure	Test method*	Number of tests
Unpaved roads (heavy duty)	Coherex	EP	12
	Lignin sulfonate or calcium chloride	EP	12
	Watering	EP	12
Paved roads	Flushing	EP	9
	Vacuuming	EP	9
Storage pile maintenance	Watering	EP	9
Storage pile wind erosion (active piles)	Watering	WT	
• Moderate winds			9
• High winds			9
Unpaved parking lots	Chemical	EP	12
Conveyor transfer stations	Enclosure	D	9
Exposed area wind erosion (moderate winds)	Chemical	WT	9

* EP = Exposure profiling
WT = Wind tunnel testing
D = Duct sampling

TABLE 18. SOURCES PROPOSED FOR TESTING AT ARMCO'S MIDDLETOWN WORKS

Source	Control measure
Unpaved road	Coherex application
Paved road	Flushing/vacuuming
Coal stockpile - maintenance	Watering
Coal stockpile - wind erosion	Watering

Testing of controlled sources at Armco's Middletown Works	Early August
Testing of uncontrolled and controlled sources at second plant	Late August/early September
Testing of uncontrolled and controlled sources at third plant	Late September/early October

In addition, it is also recommended that two or three additional plants with active control programs be visited during this period to gather additional data on the cost and performance of control techniques for open dust sources.

The total effort (technical person-hours) required for the testing program and subsequent evaluation of cost-effectiveness of control techniques may be estimated from the number of field test performed. For this purpose, the number of test should be multiplied by 80 person-hours. This estimate should be refined based on final definition of the scope of the program.

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APPENDIX A

EXAMPLE DATA COMPILATION FROM MATERIALS HANDLING FLOW CHARTS

TABLE A-1. RAW AND INTERMEDIATE MATERIAL HANDLING AT THE INTERLAKE CHICAGO PLANT IN 1978

Material	Handling Method and Amount of Material Handled						
	Origination Mode	Transfer Station	Storage Load-in	Storage	Storage Load-out	Transfer Station	Screening
Coal	Truck unloaded (26,000 ST) Railcar unloaded by rotary dump (495,000 ST)	9 transfer stations (521,000 ST)	Scraper (495,000 ST)	Open storage pile (505,000 ST)	Scraper (521,000 ST)	21 transfer stations (521,000 ST)	None
Coke	Coke Ovens (345,000 ST)	2 transfer stations (345,000 ST)	Conveyor stacker (17,000 ST)	Open storage pile (17,000 ST)	Front-end loader dump into conveyor hopper/feeder (17,000 ST)	2 transfer stations (345,000 ST)	Screened - 90% to coke oven; 10% to sinter plant (345,000 ST)
Iron Ore Pellets	Ship unloaded by clamshell (1,203,000 ST)	None	Same clamshell used to unload ships (1,203,000 ST)	Open storage pile (1,203,000 ST)	Bucket wheel reclaimer onto underground conveyor (1,203,000 ST)	2 transfer stations (1,203,000 ST)	None
Dolomite	Truck unloaded at storage pile (35,300 ST)	None	Same truck used to deliver material to plant (35,300 ST)	Open storage pile (35,300 ST)	Crane-Clam-shell bucket transfer to conveyor (35,000 ST)	2 transfer stations (35,300 ST)	None
Limestone	Ship unloaded by clamshell (123,000 ST)	None	Same clamshell used to unload ships (123,000 ST)	Open storage pile (123,000 ST)	Crane-Clam-shell bucket transfer to conveyor (123,000 ST)	2 transfer stations (123,000 ST)	None
Sinter, Nodules and Briquette	Sinter Plant (302,000 ST)	1 transfer station (302,000 ST)	None	None	None	1 transfer station (302,000 ST)	Screened - 82% to blast furnace; 18% recycled (272,000 ST)
Sinter Input (Flux, Iron ore and Coke fines)	Truck unloaded at storage pile (398,000 ST)	2 transfer stations (199,000 ST)	Same truck used to deliver material to plant (199,000 ST) Conveyor stacker (199,000 ST)	Open storage pile (498,000 ST)	Front-end loader dump into conveyor hopper/feeder (398,000 ST)	3 transfer stations (398,000 ST)	None

TABLE A-2. RAW AND INTERMEDIATE MATERIAL HANDLING AT THE J&L STEEL ALIQUIPPA PLANT IN 1978

	Handling Method and Amount of Material Handled						
Material	Origination Mode	Transfer Stations	Storage Load-in	Storage	Storage Load-out	Transfer Stations	Screening
Coke	Railcar unloaded by bottom dump (1,465,000 ST)	None	Conveyors (1,465,000 ST)	Storage bins (1,465,000 ST)	Conveyors (1,465,000 ST)	None	Screened - 95% to blast furnaces; 5% to sinter plants
Coal for boilers and storage	Barge unloaded by clamshell (34,600 ST) Barge unloaded by bucket-ladder conveyor (1,678,000 ST) Railcar unloaded by bottom dump (17,300 ST)	None	Conveyor to temporary storage area to coal yard pile via clamshell (623,000 ST)	Open storage pile (623,000 ST)	Clamshell to conveyor (623,000 ST)	None	None
Coal for Coke Oven	Barge unloaded by bucket-ladder conveyor and fed into bins (2,358,000 ST) Railcar unloaded via rotary dump (73,000 ST)	22 transfer stations (2,358,000 ST)	Conveyors to crusher to bins (2,431,000 ST)	Storage bins (2,431,000 ST)	Bins to conveyor to crusher to bins (2,431,000 ST)	None	None
Iron Ore Pellets	Railcar unloaded to transfer car via rotary dump (1,184,000 ST) Railcar unloaded to conveyor via bottom dump (1,184,000 ST)	None	Transfer car to temporary storage area to ore yard pile via clamshell (1,184,000 ST) Conveyors to cast-house storage bins (1,184,000 ST)	Open storage pile (1,184,000 ST) Casthouse storage bins (1,184,000 ST)	Clamshell to transfer car (1,184,000 ST)	Transfer car to cast house storage bin (1,184,000 ST)	Screened (1,018,000 ST)
Unagglomerated Iron Ore	Railcar unloaded to transfer car via rotary dump (62,200 ST)	None	Transfer car to temporary storage area to ore yard via clamshell (62,200 ST)	Open storage pile (62,200 ST)	Clamshell bucket to transfer car (62,200 ST)	Transfer car to bin (62,200 ST)	Screening (27,700 ST)

(continued)

TABLE A-2. (concluded)

Material	Handling Method and Amount of Material Handled: Origination Mode	Transfer Stations	Storage Load-in	Storage	Storage Load-out	Transfer Stations	Screening
Limestone/Dolomite	Railcar unloaded to transfer car via rotary dump (71,000 ST) Railcar unloaded to conveyor via bottom dump (30,000 ST)	None	Transfer car to temporary storage area to main storage area via clamshell (71,000 ST) Conveyor to bins (30,000 ST)	Open storage pile (71,000 ST) Bins (30,000 ST)	Clamshell bucket to transfer car (71,000 ST)	Transfer car to bin (71,000 ST)	None
Sinter	Sinter Plant (1,548,000 ST)	5 transfer stations (1,548,000 ST)	Conveyor to bins (1,548,000 ST)	Bins (1,548,000 ST)	Bins to transfer car (1,548,000 ST)	Transfer car to casthouse bins to skip cars (882,000 ST) Transfer car to casthouse bins to 3 transfer stations (666,000 ST)	Screening (666,000 ST)
Sinter Input (Flux, Iron ore and Coke Fines)	Railcar unloaded to conveyor via rotary dump (1,527,000 ST) Railcar unloaded to conveyor via bottom dump (655,000 ST)	2 transfer stations (2,182,000 ST)	Conveyor to bins (2,182,000 ST)	Bins (2,182,000 ST)	Bins to conveyor (2,182,000 ST)	15 transfer stations (2,182,000 ST)	None

APPENDIX B

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