UNCONTROLLED

Appendix A

Emission Measurements from Controlled Construction Activities

Site-Specific Test Plan
Revision 1

Prepared for
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711
Office of Research and Development
Air Pollution Prevention and Control Division
(MD-61)

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Under Subcontract to
Pacific Environmental Services, Inc.

EPA Contract No. 68-D-70-002
Work Assignment No. 2-04
MRI Project No. 4813-02

October 6, 1999

Preface

This test plan was prepared for the U.S. Environmental Protection Agency by Midwest Research Institute (MRI) under Subcontract No. 68D7002-MRI, Work Assignment No. 2, from Pacific Environmental Services, Inc. The prime contract for this effort is EPA Contract 68-D-70-002, Work Assignment 2-04. Under this work assignment, MRI is providing assistance in characterizing construction-related particulate matter emissions and controls in terms of mass and particle size distribution.

Questions concerning this plan should be addressed to Dr. Chatten Cowherd, Work Assignment Leader, at (816) 753-7600, Ext. 1586.

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Document Control

This is an internally controlled document in accord with MRI's Standard Operating Procedures (SOPs) MRI-0055. Requests for controlled documents are to be made through Ms. Judy Kozak, MRI Document Control Coordinator.

Revision History

Revision 0: This site-specific test plan was prepared as a companion to the QAPP produced for the work assignment.

Revision 1: "October 6, 1999" Revised to incorporate corrections and changes in the text requested by EPA and PES.

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Section 1. Introduction

1.1 Summary

This test plan presents the testing approach that Midwest Research Institute (MRI) will use to characterize the amount and particle size distribution of particulate matter (PM) emissions from certain controlled construction-related activities. Specifically, the activities under consideration are those related to (a) the movement of large off-road construction equipment along temporary unpaved travel routes and (b) mud/dirt trackout from unpaved areas onto paved roads that border a construction site.

To address logistical difficulties, field testing of construction emissions will occur at “captive” operations in the sense that operations can be largely controlled during testing. Tests will be conducted at two locations:

- North Central Kansas (NCK) Technical College. This is a heavy equipment vocational training facility located in Beloit, Kansas. The effectiveness of watering as a control measure for unpaved travel routes will be tested at this site.

- Deramus Field Station. This 80-acre MRI facility is located in Grandview, Missouri. The effectiveness of two to four trackout controls on two soil types will be tested at this site.

Testing under this work assignment is planned for the period from August to October 1999. Testing of uncontrolled particulate emissions from construction-related activities was recently performed by MRI at both of these sites under a prior work assignment.

Past studies have found that a substantial fraction of PM emissions from construction activities is related to transport of earth and other materials around the site. Because of the generally short-term nature of travel routes at construction sites, operators throughout the United States commonly employ water to control PM emissions rather than relying on more expensive chemical dust suppressants.

Although PM emissions from watered unpaved roads has attracted attention since at least the early 1980s, only two watering tests have been conducted at construction sites. In addition to the simple scarcity of data specifically referenced to construction sites, there are concerns about how well watering tests of unpaved roads in other settings can be applied to the construction sites. Because temporary routes are not nearly as well constructed as conventional unpaved roadways, available data may not accurately reflect the efficiency afforded by watering at construction sites.

Mud/dirt trackout from construction sites constitutes a large component of construction dust emissions in urban areas, where tracked mud/dirt substantially raise the silt loadings on adjacent paved roadways. Trackout is observed to increase as soil moisture increases, but this effect has not been quantified. There are a variety of candidate methods for decreasing the accumulation of mud/dirt on tires or removing accumulated mud/dirt as vehicles exit a construction site. However, the control efficiency test data for these measures are limited.

1.2 Test Program Organization

Figure 1-1 presents the test plan organization, major lines of communication, and names/phone numbers of responsible individuals.

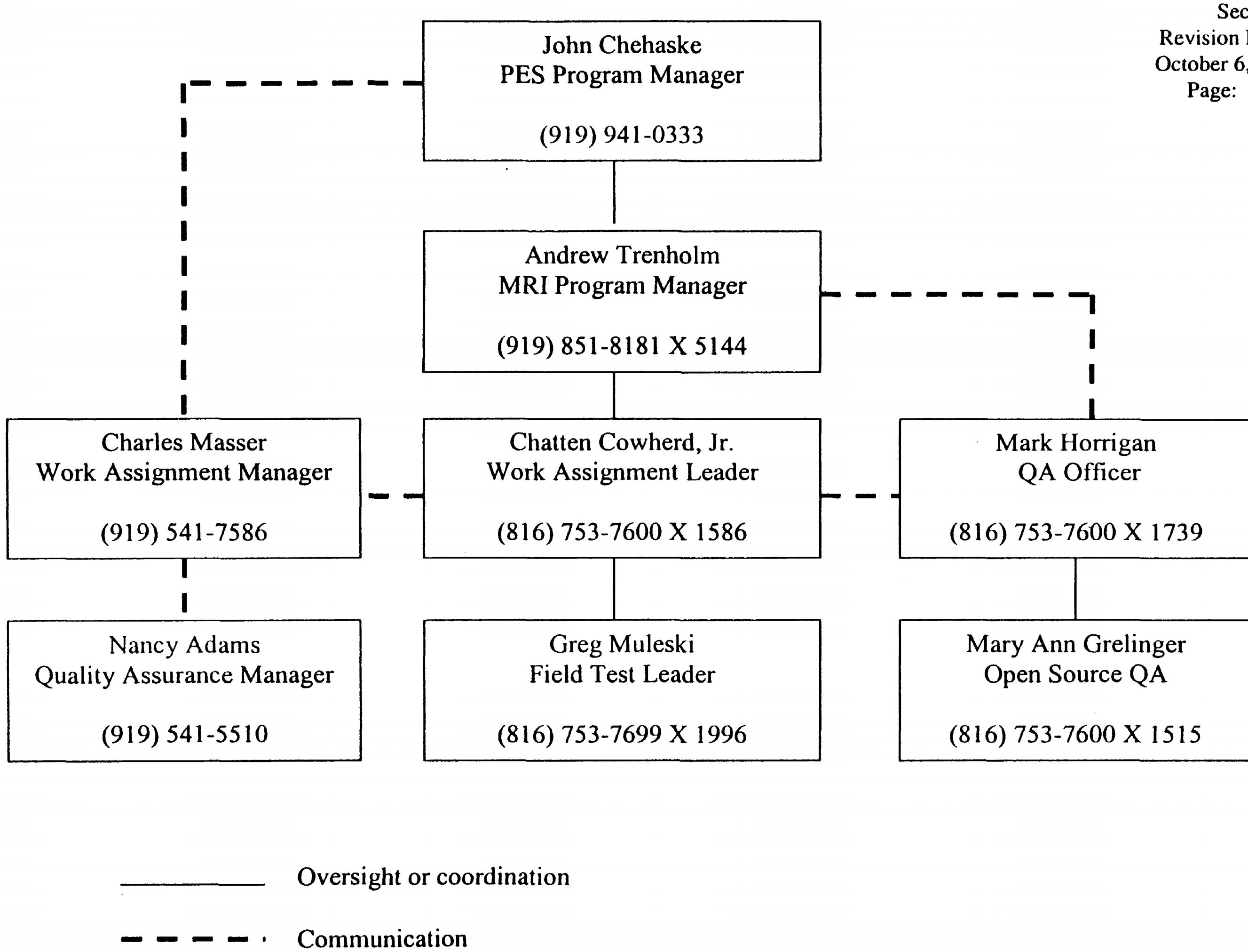

Figure 1-1. Project Organization Chart

Section 2. Source Description

2.1 Process Description

Earthmoving operations constitute a large, if not dominant, source of particulate emissions at heavy construction sites. Numerous process "systems" are available for the purpose of earthmoving, and these systems often combine different machines. The *Caterpillar Performance Handbook*[3] lists the following options:

- Bulldozing with track-type tractors
- Load-and-Carry with wheel loaders
- Scrapers self-loading with elevator, auger, or push-pull configurations, or push-loaded by track-type tractors
- Articulated trucks loaded by excavators, track loaders or wheel loaders
- Off-highway trucks loaded by shovels, excavators or wheel loaders

Selection of a "spread" of equipment for use at a construction site depends on numerous factors, not the least of which includes the number and size of equipment readily available to the earthmoving contractor. The need to transport material into or out of the site also restricts what type of equipment can be used.

When different machine options are available, the most important consideration by the contractor involves the typical operating distance. General haul distances for earthmoving systems are shown in Figure 2-1, as found in the Caterpillar handbook.[3] As can be seen, scrapers can be economically operated over a wide range of haul distances and are the primary equipment used for alternating cuts and fills. Scrapers have important advantages in that they are highly mobile; can be operated under wide variety of underfoot conditions; and can accomplish the entire operation of digging, transporting, and unloading in a single cycle.

Figure 2-2 provides a schematic illustration of the earthmoving cycle for scrapers. During the loading or "cut" operation, a scraper generally travels approximately 100 to 200 ft while material is being loaded.[4] Once loaded, the scraper travels a haul route to a "fill" or a stockpiling location, where the material is unloaded. The scraper again travels approximately 100 to 200 ft during the unloading operation. The unloaded scraper then returns to the cut location along a haul route to repeat the loading/unloading cycle.

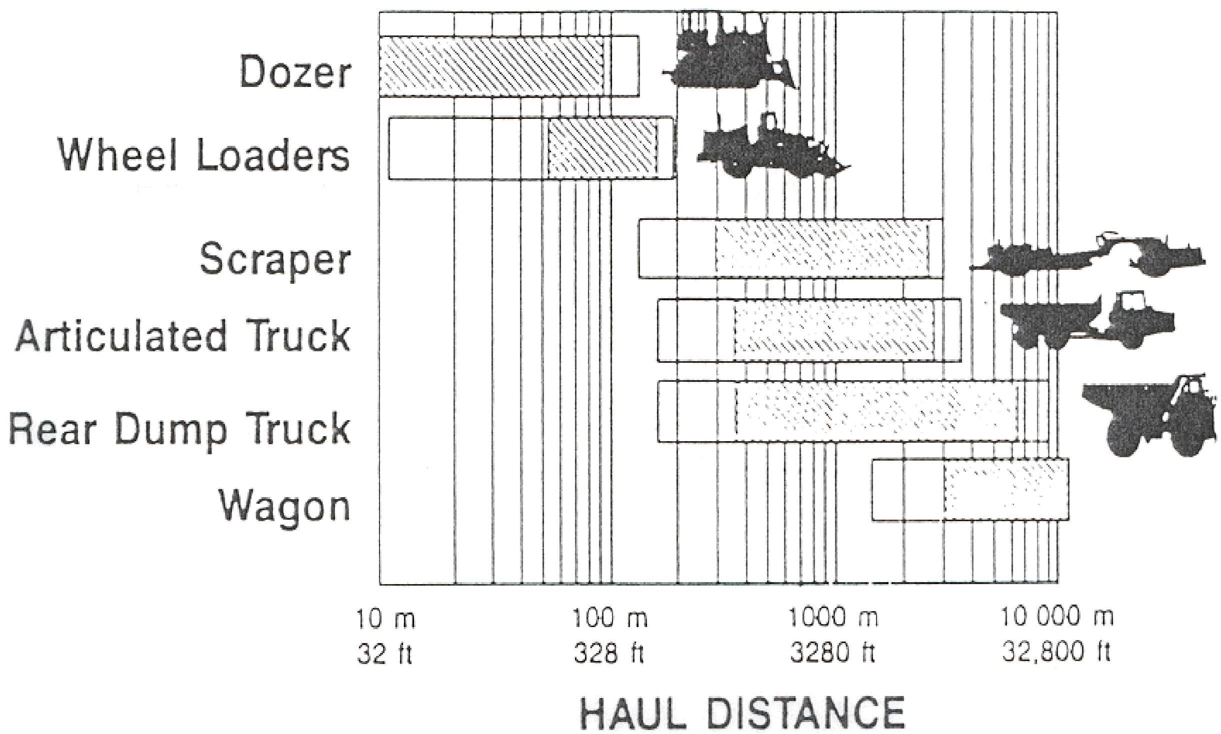

Figure 2-1. Typical Operating Distances for Earthmoving "Systems" Described in Reference 3

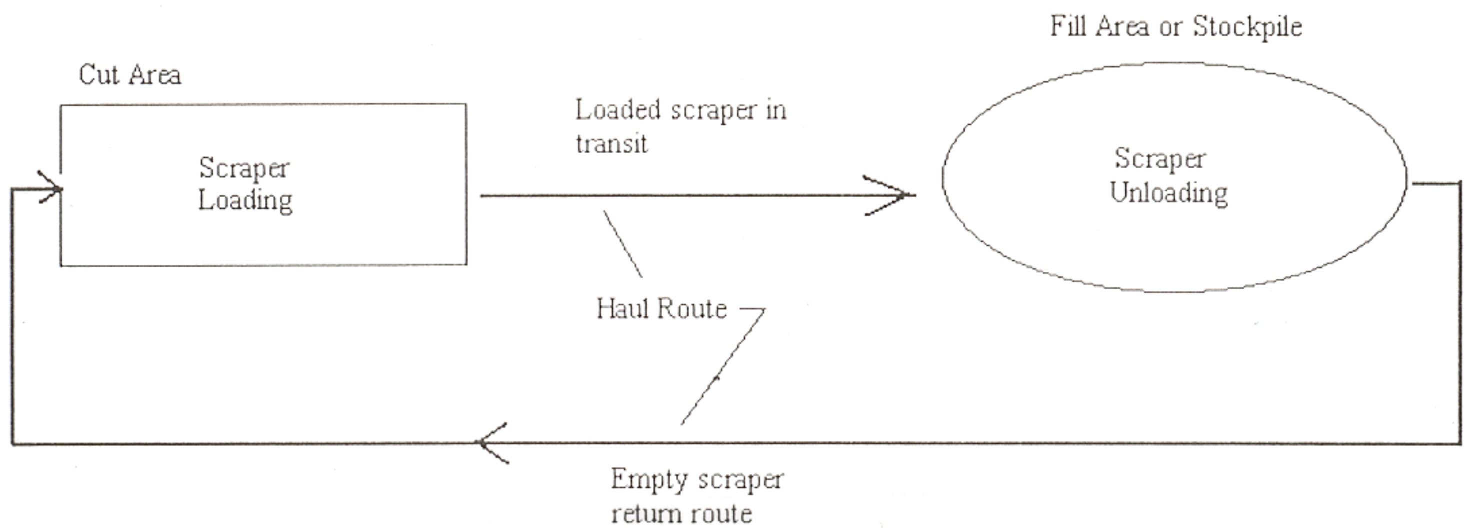

Figure 2-2. Schematic Operation of Scrapers for Earthmoving Activities

If the transported material is unloaded at a fill location, it can be compacted by bulldozers and other equipment. Should the unloading instead occur at a stockpile location, the material ultimately must be moved again. This typically involves a scraper again transporting the material to on-site fill location; however, the stockpile may require loading into trucks for transport to an off-site location.

Mud/dirt trackout constitutes a large component of construction dust emissions in urban areas. The mud/dirt that is tracked by vehicles exiting construction sites raises the silt loading on adjacent paved roads. This, in turn, causes elevated emissions from the paved roads as the mud/dirt is pulverized and resuspended by vehicular traffic. In some cases, surface watering for on-site control of construction dust may enhance trackout emissions.

2.2 Control Equipment Description

Because the construction-related PM sources under consideration are open emission sources, traditional pollution control devices such as cyclones and baghouses are not applicable. In general, water applied by gravity or pressurized trucks is the most commonly used dust control technique at construction sites. Water is frequently applied to the haul routes within a site.

Because temporary routes traveled by scrapers are not nearly as well constructed as conventional unpaved roadways, data from temporary routes will more accurately reflect the efficiency afforded by watering at construction sites. The frequency and amount of water added to the travel route per unit time will be varied to develop the basis for cost-effective strategies for dust control of unpaved travel routes within the construction industry.

Control measures for mud/dirt trackout usually consist of aprons or mechanical devices at the vehicle exit points. These measures are intended to remove the mud/dirt accumulations from tires as the vehicles exit the site onto adjacent paved roads.

Section 3. Test Program

3.1 Objectives

This test program will develop particulate control efficiency for (a) watering of scraper travel routes and (b) application of two to four controls for mud/dirt trackout. Specific objectives, in descending order of priority, are:

- Develop uncontrolled and controlled PM-10 emission factors for watering of unpaved scraper travel routes.
- Determine the PM-2.5 fraction of the PM-10 emissions from scraper travel routes, with and without watering.
- Determine mud/dirt trackout rates from uncontrolled, unpaved soil surfaces onto a paved roadway.
- Determine mud/dirt trackout rates after application of each control measure (to include a gravel access apron and at least one stationary metallic device).

3.2 Test Matrix

Table 3-1 presents the overall design of the testing program. In the table, "mass flux profiling" refers to the method for determination of an individual emission factor/rate. The exposure profiling test method is discussed in detail in Section 5. The term "particle size profiling" is used to denote a test designed to characterize the particulate size distribution at two heights. Because of the need to collect adequate mass of the smaller size fractions, a single particle size test spans several mass flux tests. The particle sizing technique is also discussed in Section 5.

Emission tests at NCK Technical College will be conducted under a variety of meteorological conditions (e.g., temperature, wind speed, cloud cover) and operating conditions (e.g., weight and speed of vehicle equipment, number of vehicle passes per unit time, and time of day). Of particular interest is on-site collection of pan evaporation measurements so control efficiency decay rates for watering can be referenced to readily available meteorological data. Because control efficiency is greatest immediately after water is applied to the roadway and decays as the surface dries, testing will span a broad range of times after watering, so reliable average control efficiency data are obtained.

Table 3-1. Test Design

Operation	Travel surface	Pollutant	No. of tests	Test method	Approx. time (min) per test
NCK Tech. College					
Transit–Native Soil	Uncontrolled	PM-10 PM-2.5	3 1	Mass flux profiling Particle size profiling	15 75
	Watered: Appl. 1	PM-10 PM-2.5	3 1	Mass flux profiling Particle size profiling	30-60 120
	Watered: Appl. 1a	PM-10 PM-2.5	3 1	Mass flux profiling Particle size profiling	30-60 120
	Watered: Appl. 2	PM-10 PM-2.5	3 1	Mass flux profiling Particle size profiling	30-60 120
	Watered: Appl. 2a	PM-10 PM-2.5	3 1	Mass flux profiling Particle size profiling	30-60 120
Deramus Field Station					
Trackout–Native Soil	Uncontrolled • Moisture 1 • Moisture 2	Surface loading	 3 3	Manual cleaning	60 min
	Control 1	Surface loading		Manual cleaning	60 min
	• Moisture 1 • Moisture 2		3 3		
	Control 2 • Moisture 1 • Moisture 2	Surface loading	 3 3	Manual cleaning	60 min
	Control 3 • Moisture 1 • Moisture 2	Surface loading	 3 3	Manual cleaning	60 min
Trackout–Sandy Soil	Uncontrolled • Moisture 1 • Moisture 2	Surface loading	 3 3	Manual cleaning	60 min
	Control 1 • Moisture 1 • Moisture 2	Surface loading	 3 3	Manual cleaning	60 min
	Control 2 • Moisture 1 • Moisture 2	Surface loading	 3 3	Manual cleaning	60 min
	Control 3 • Moisture 1 • Moisture 2	Surface loading	 3 3	Manual cleaning	60 min

At the Deramus Field Station, trackout from bare soil areas on to a paved roadway will be studied as a function of soil type, soil moisture and control method. The technique for trackout quantification is discussed in Section 4.

Section 4.
Sampling Locations

4.1 Sampling Locations

As noted earlier, testing will employ captive construction-related operations at two different facilities. The first set of tests will take place at the North Central Kansas Technical College (NCK Technical College) location near Beloit, Kansas. Figure 4-1 presents a general plant layout of the facility. Testing will be performed in conjunction with the "hands-on" training of students at NCK Technical College. During the captive earthmoving operation, students operating up to 5 scrapers will form a cut of approximate dimensions 300 ft long, 100 ft wide and 8 ft deep. When that cut is completed, the stockpiled material will be recovered and replaced.

AT NCK Technical College, there are seven scrapers available, as show below:

No. of units	Caterpillar model no.	Capacity (cu yd)	Type
3	621	21	Pan-type, single engine tractor
1	623	23	Elevating (paddle) type
3	613	11	Elevating (paddle) type

This test site affords an opportunity to examine the effect that different types of scrapers have on emission levels. To the extent practical, MRI will work with NCK Technical College staff to isolate individual scraper types during the testing. That is, if only three teams (two students each) are to train on scrapers on any given day, MRI will request that on one day the three pan scrapers be used and on the next day, the three Model 613 units be used. If NCK Technical College plans call for four teams, MRI will request that four elevating models be used.

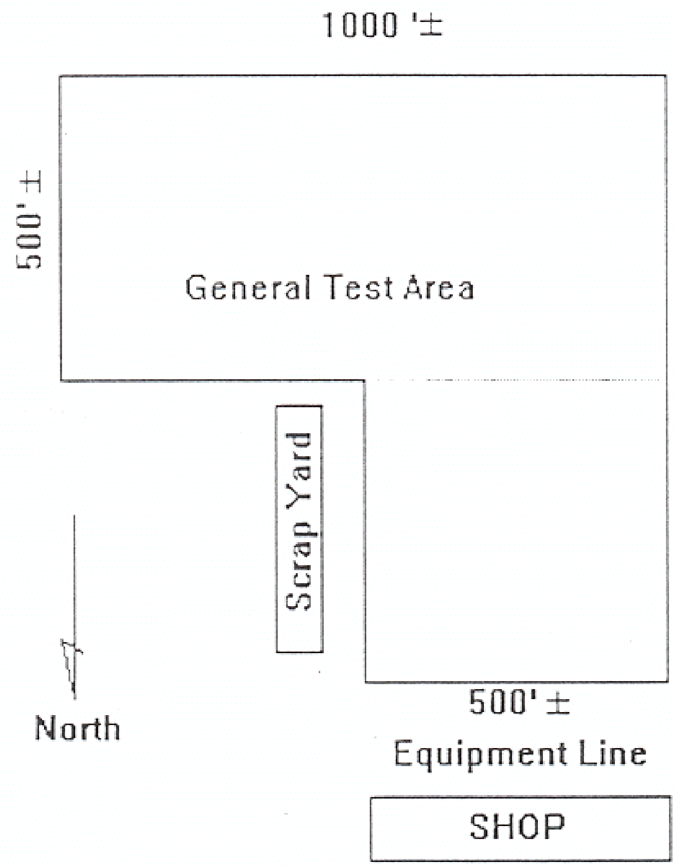

Figure 4-1. General Layout of Training Facility at North Central Kansas Technical College

The scraper in transit represents a "moving point" source that can be treated as a "line" source. Figure 4-2 shows not only a schematic of the operation but also the basis for the line source test methodology.

As long as the distance traveled during the transit operation is substantially greater than the downwind distance from the path to the sampling array, then only a single vertical array of samplers ("tower") is necessary to characterize the PM plume. In other words, because the source is considered as uniformly emitting over the length of the operational pass, a vertical array is sufficient to characterize the vertical distribution of concentration and wind speed in the plume.

A captive test site at MRI Deramus Field Station (Grandview, Missouri) will be used to test mud/dirt trackout controls, in order to stage site conditions and trackout vehicles during the study. An asphalt-paved (or otherwise improved) linear test strip approximately 200 feet in length will be used to determine the amount of material that is tracked from the adjacent egress area (unpaved travel route at right angles to the paved test strip). The unpaved travel route will include two soil types (one high and one low clay content) for characterization of uncontrolled trackout (at varying moisture levels). In addition, from two to four trackout control methods will be investigated. They will include a gravel access apron and at least one stationary metallic device for removing the mud/dirt from vehicle tires.

4.2 Process Sampling Locations[a]

In addition to the particulate concentrations and wind speed measurements necessary (as described in Section 5) to determine emission rates, two other broad classes of information will be collected during the field exercise at NCK Technical College. The first class comprises operational features, such as the speed of the scraper. Because of the "captive" nature of the earthmoving being tested, the operational parameters will be established prior to the start of testing and will be controlled by the operators during test periods.

The second supplementary class consists of aggregate material properties of the unpaved travel surfaces. Of particular interest are the moisture and silt contents of the surface material. Up to six composite samples (edge-to-edge) will be collected to characterize the scraper transit surface soil at the NCK Technical College training facility. During watering tests, a composite sample for moisture analysis will be collected every 30 min. Each composite sample will consist of 10 increments, each 12 in by 12 in in area.

[a] The process is defined in terms of the operational parameters of the construction equipment and the properties of the travel surface which constitutes the source of entrained dust.

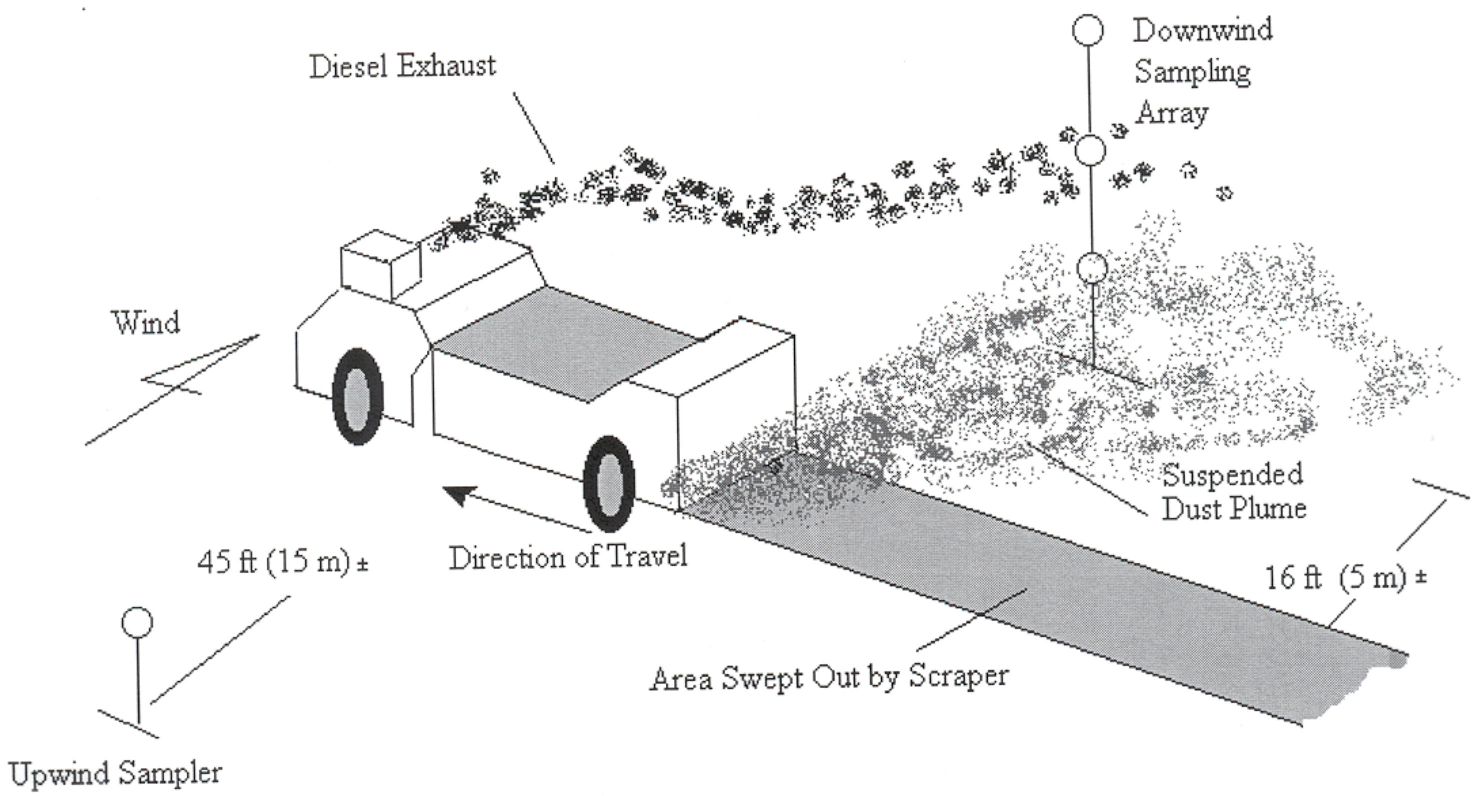

Figure 4-2. Schematic Illustration of Test Procedure for Moving Point Source

Sample collection and analysis will follow procedures contained in Appendices C.1 and C.2 in EPA's Compilation of Air Pollutant Emission Factors (AP-42).[5]

At the trackout test site at the Deramus Field Station, no emission testing will be performed, but the operational features of trackout vehicles (primarily a full-size pickup truck) will be documented. In addition, the aggregate material properties of the test soil surfaces, from which trackout originates, will be characterized, together with the silt loadings on the paved test strip. For each test soil, a composite sample consisting of six 12 in by 12 in increments will be collected for silt and moisture analysis. For "point" measurement silt loading on the paved test surface, each surface sample will be obtained by cleaning a lateral strip (edge-to-edge) of the surface. A combination of sweeping with a small broom and a vacuum cleaner (depending on surface loading) will be used to collect each surface sample.

Section 5. Sampling and Analytical Procedures

5.1 Test Methods

The exposure profiling test method will be used to quantify emissions from scrapers in transit under different watering cycles. This method has been recognized by EPA as the characterization technique most appropriate for the broad class of open anthropogenic dust sources, such as moving point sources. Because the method isolates a single emission source while not artificially shielding the source from ambient conditions (e.g., wind) , the open source emission factors with the highest quality ratings in EPA's emission factor handbook AP-42[5] are typically based on this approach.

The exposure profiling technique for emission testing of open particulate matter sources is based on an isokinetic profiling concept. The passage of airborne pollutant immediately downwind of the source is measured directly by means of simultaneous multi-point sampling of mass concentration and air flow (advection) over the cross section of the emission plume. Because both the emission rate and the air flow are non-steady, simultaneous multipoint sampling is required. This technique uses a mass flux measurement scheme testing rather than requiring indirect emission rate calculation through the application of a generalized atmospheric dispersion model. As noted in the previous section, the emission source—scrapers in transit—can be represented as a line source.

As applied to line sources, the "exposure profiling" test method requires a vertically oriented array of sampling points. A vertical network of samplers (Figure 5-1) is positioned just downwind and upwind from the edge of the source. The downwind distance of approximately 5 m is far enough that interference with sampling due to vehicle-generated turbulence is minimal but close enough to the source that the vertical plume extent can be adequately characterized with a maximum sampling height of 5 to 7 m. In a similar manner, the approximate 15-m distance upwind from the source's edge is far enough from the source that (a) source turbulence does not affect sampling, and (b) a brief wind reversal would not substantially impact the upwind samplers. The 15-m distance is, however, close enough to the line of the moving point source to provide the representative background concentration values needed to determine the net (i.e., due to the source) mass flux.

The primary air sampling device in the exposure profiling portion of the field program will be a standard high-volume air sampler fitted with a cyclone preseparator (Figure 5-2).

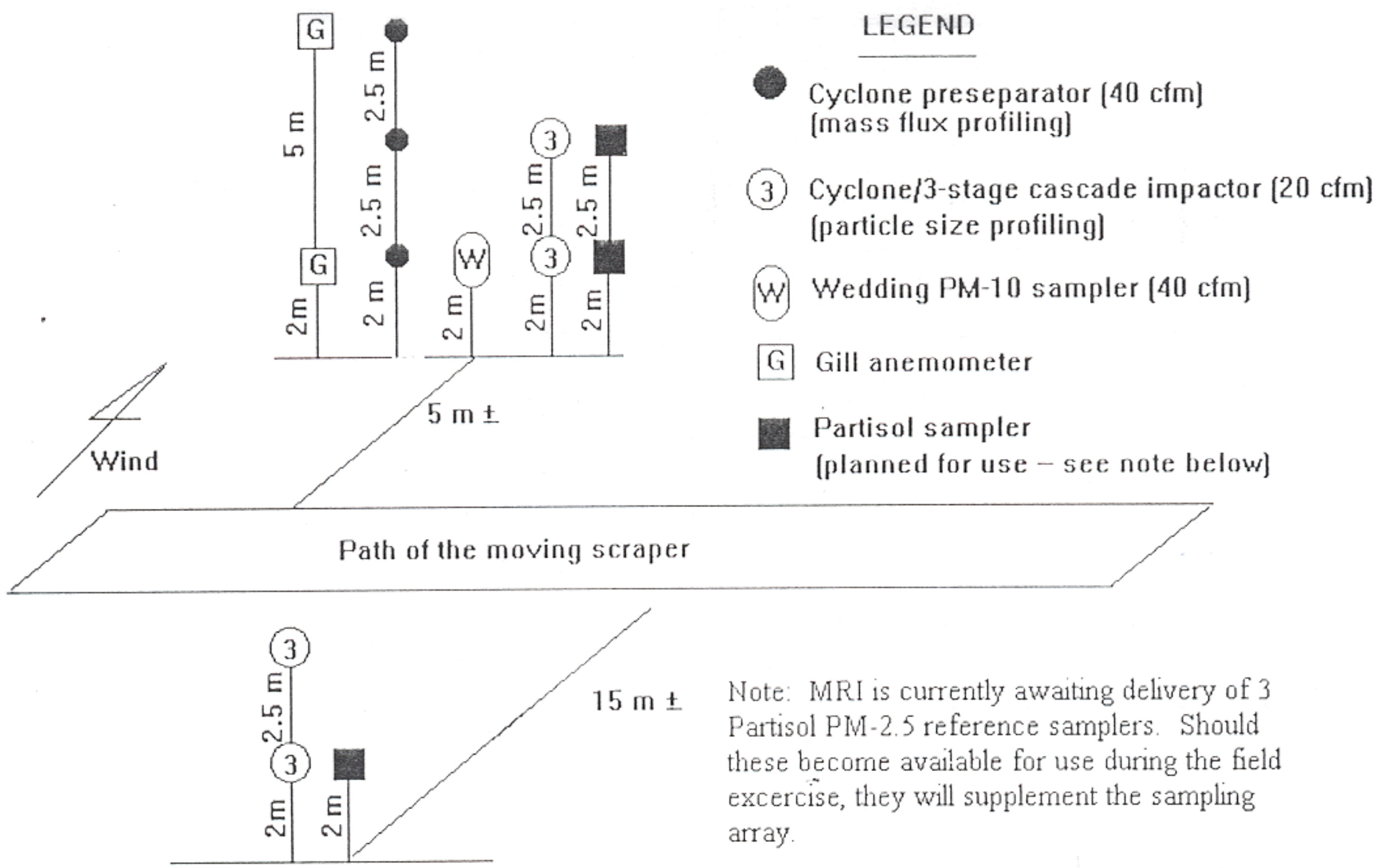

Figure 5-1. Sampling Equipment Deployment for Scraper Transit Tests

The cyclone exhibits an effective 50% cutoff diameter (D_{50}) of approximately 10 µmA when operated at a flow rate of 40 cfm (68 m^3/h).[6] Thus, mass collected on the 8- by 10-in backup filter represents a PM-10 sample. During each mass flux profiling test, a Wedding and Associates high-volume PM-10 reference sampler will be colocated with one cyclone sampler for comparison purposes.

As noted in connection with the test matrix given in Table 3-1, "mass flux profiling" describes tests that will be used to characterize mass emissions from scrapers in transit. In this technique, samplers of the type shown in Figure 5-2 are distributed over the effective height of the dust plume to determine the mass concentration of particulate at different heights in the plume. In this way, the shape of the emission plume is defined and the PM-10 emission factor is found by integrating the mass flux over the height of the plume in the manner described in Section 5.2.

The test matrix given in Table 3-1 also references "particle size profiling" tests to determine vertical profiles of particle size distribution data. This second sampling system supplements the mass exposure profiling system described above. The second system also uses a high-volume cyclone preseparator but in a different sampling configuration. Here, the cyclone is operated at a flow rate of 20 acfm over a 3-stage cascade impactor (see Figure 5-3). At that flow rate, the cyclone and 3 stages exhibit D_{50} cut points of 15, 10.2, 4.2, and 2.1 µmA. Particulate matter is collected on 4- by 5-in glass fiber impactor substrates and the 8- by 10-in glass fiber backup filter. To reduce particle "bounce" through the impactor, the substrates are sprayed with a grease solution that improves the adhesion of the impacted particles. To determine the sample weight of particulate collected on the interior surface, the interior surface is washed with distilled water into separate jar which is then capped and taped shut. Upon return to MRI's main laboratories, the entire wash solution will be passed through a Büchner-type funnel holding an 47-mm glass fiber filter under suction to ensure collection of all suspended material on the filter.

As noted in Section 3, a particle size profiling test will span three mass flux profiling tests. This recognizes that, because a cyclone/impactor combination samples at a slower flow rate and collects mass on more media, this type of sampler must be operated much longer than the 40-cfm cyclones used to define the plume shape in the mass flux profiling tests.

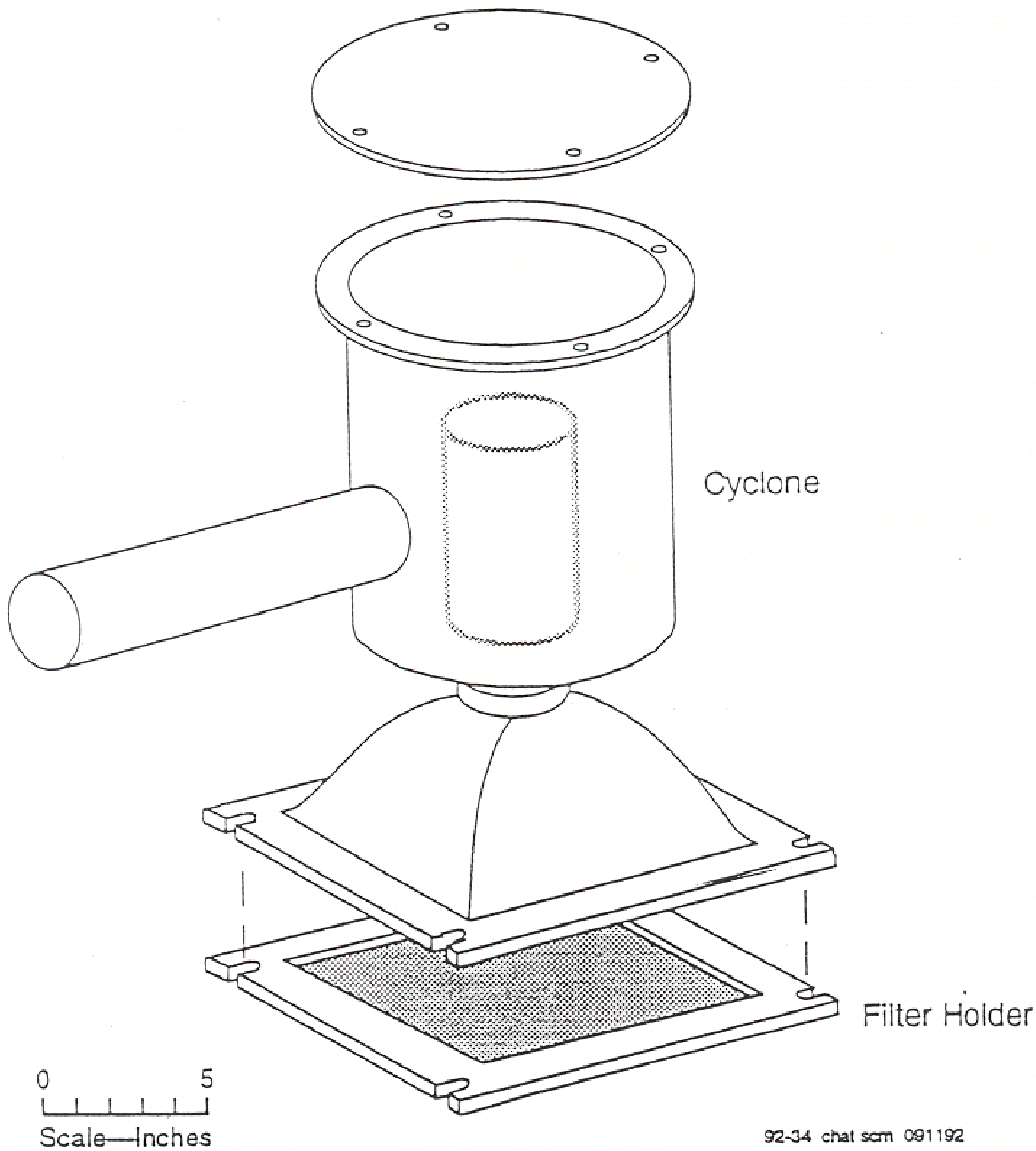

Figure 5-2. Cyclone Preseparator Operated at 40 cfm

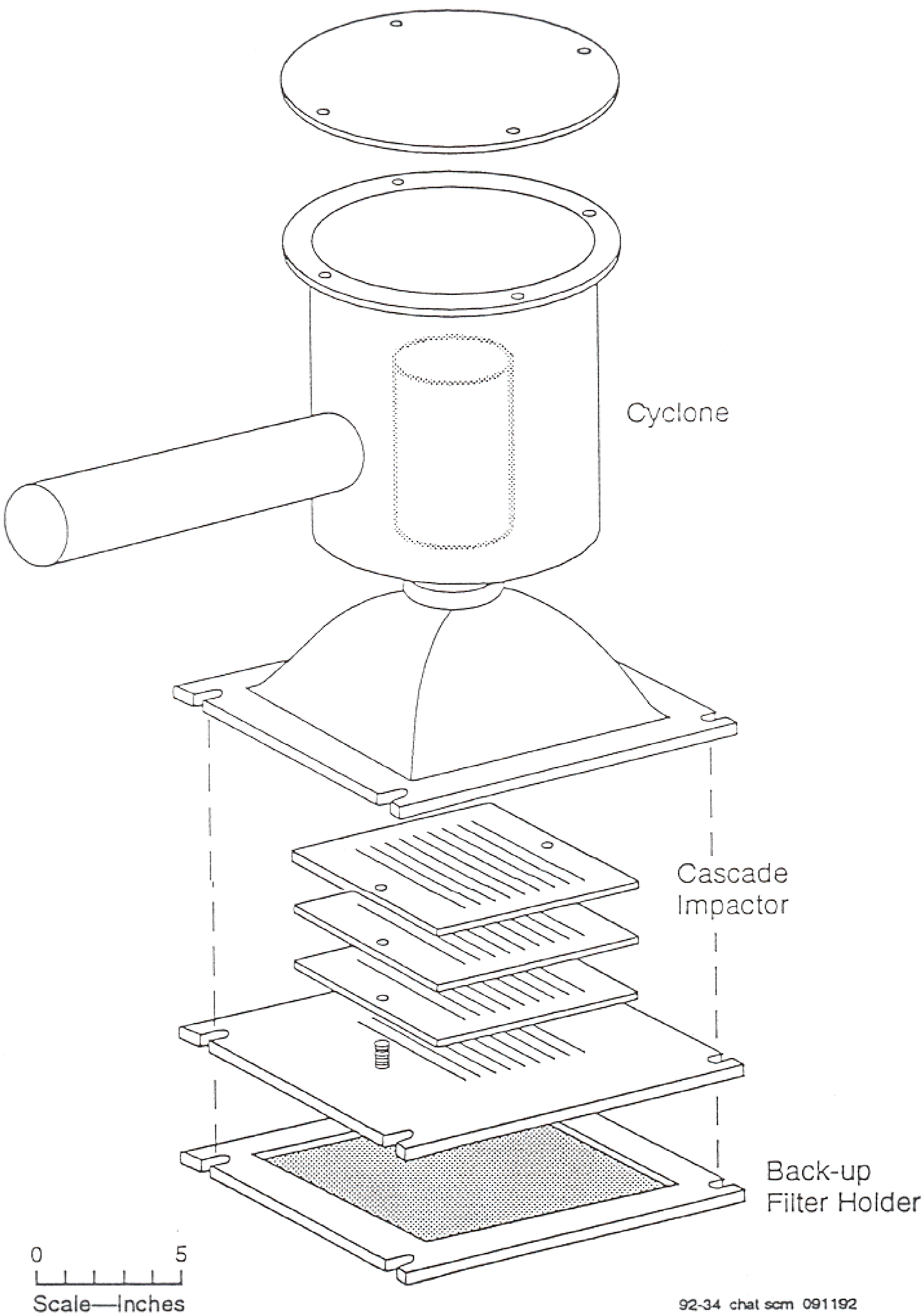

Figure 5-3. Cyclone Preseparator-Cascade Impactor Operated at 20 cfm

Besides the air sampling equipment, Figure 5-1 also shows that, throughout each test of scrapers in transit, wind speed will be monitored at two heights using R. M. Young Gill-type (model 27106) anemometers. Furthermore, an R. M. Young portable wind station (model 05305) will be used to record wind speed and direction at the 3.0 m height downwind. All wind data are to be accumulated into 5- to 15-min averages logged with a 26700 series R. M. Young "programmable translator."

Additional measurements are necessary to characterize the service environment for the watering tests of scrapers in transit. These measurements will include:

- volume of water applied per unit area of travel surface
- solar radiation
- cloud cover
- relative humidity
- pan evaporation

Note that these measurements are intended to provide a field representation of water application and evaporative conditions during testing. These are viewed as second tier, semi-quantitative measurements to assess how the primary variable (moisture content) relates to environmental conditions. It should be noted that the evaporation rate from a travel surface is strongly enhanced by the movement of scrapers or other mobile equipment over the surface.

To determine the volume of water applied per unit area, a series of tared sampling pans will be placed across the test surface. These will consist of lightweight aluminum pans with an opening of approximately 32 square inches. The bottom of the pan will be lined with absorbent material to avoid splashing of the water. Once the water is applied, the sampling pans will be retrieved and reweighed. The volume of water will be determined by assuming water density of 1 g/cm^3. The application rate is found by dividing the volume of water by the top area of the pan.

Solar radiation during the test period will be monitored by a Weathertronics Model 3010 mechanical polygraph. This device produces a hard copy record of the intensity of direct and scattered solar radiation. Hourly visual observations of cloud cover (to the nearest tenth) will supplement the pyranograph results.

Dry and wet bulb temperatures (from which relative humidity is determined) from a sling psychrometer will be recorded hourly.

The standard "Class A" evaporation measurement procedure requires that 7.5 inches of water be maintained in a pan with very specific dimensions (10 inch high by 47.5 inch inside diameter), construction details (material, welding, etc.), and operational features (leveling, etc.). Given the goal to provide a semi-quantitative measure of ambient conditions, MRI will make use of a galvanized steel tank with approximately the same dimensions as a Class A pan and will fill the tank with water to the same relative height (i.e., to 2.5 inch from the top). The tank will be deployed at the start of the testing exercise, and the water level will be measured each morning and evening during the sampling trip. A rain gauge will also be deployed in the immediate vicinity of the tank, and its contents will be read each morning and evening as well.

Trackout emissions of PM-10 and PM-2.5 will be projected from the quantity of mud/dirt per vehicle which passes from the egress area to the paved test strip, and its contribution to silt loading. The method for collection and analysis of surface loading (total and silt fraction) is described in Reference 5.

For the baseline (dry soil) uncontrolled condition (one series of tests for each soil type), the trackout quantity will be measured by collecting surface samples from the paved test strip at five regular distance intervals from the access end to the opposite end (200 ft length). The total trackout will be determined by integrating the measured surface loadings over the full length of the test strip.

For the other uncontrolled tests (with higher moisture levels on the unpaved travel route) and for tests of trackout controls, the total trackout quantity will be based on collection of surface materials in the immediate vicinity (within about 25 feet) of the trackout point, with a scaling factor for extrapolation. Reducing the paved area to be sampled will allow multiple access points for more effective back-to-back testing of several uncontrolled/controlled conditions. As stated in Section 3.1, the trackout control measures will include a gravel access apron and a stationary metallic device that spreads the tire tread to remove mud/dirt accumulations.

5.2 Data Reduction

To calculate emission rates in the exposure profiling technique, a conservation of mass approach is used. The passage of airborne particulate (i.e., the quantity of emissions per unit of source activity) is obtained by spatial integration of distributed measurements of exposure (mass/area) over the effective cross section of the plume. Exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement, or equivalently, the net particulate mass passing through a unit area normal to the mean wind direction during the test. The steps in the calculation procedure are described below.

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

$$C = m / QT$$

where C = particulate concentration (mass/volume)
m = net mass collected on the filter or substrate (mass)
Q = volumetric flow rate of the sampler (volume/time)
T = duration of sampling (time)

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

$$IFR = Q / aU$$

where Q = volumetric flow rate of the sampler (volume/time)
a = sampler intake area (area)
U = approach wind speed (length/time)

This ratio is of interest in the sampling of total particulate, since isokinetic sampling ensures that particles of all sizes are sampled without bias. As such, the ratio is of greatest interest in the particle size profiling tests. Specially designed nozzles are available to maintain ±20% isokinetic sampling for wind speeds in the range of approximately 5 to 20 mph (when the samplers are operated at 20 acfm). Because the primary interest in this program is directed to PM-10 and PM-2.5 emissions, sampling under moderately nonisokinetic conditions should pose little difficulty. It is readily recognized that 10 µm (aerodynamic diameter) and smaller particles have weak inertial characteristics at normal wind speeds and therefore are relatively unaffected by anisokinesis.[7]

Nozzles are used on both the 20- and 40-cfm directional sampler units. However, because of the lower intake speed, the 20-cfm cyclone/impactors have more favorable isokinetic rations under typically encountered wind speeds. For this reason, only the total particulate results based on the samples collected in 20-cfm units will be reported and associated with an IFR value.

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

$$E = (C - C_b)\ U\ T$$

where E = net particulate exposure (mass/area)
C = downwind particulate concentration (mass/volume)
C_b = background particulate concentration (mass/volume)
U = approach wind speed (length/time)
T = duration of sampling (time)

Because background concentrations are much smaller than source contributions to downwind concentrations (except when control efficiency is very high), linear interpolation and extrapolation are sufficient to characterize the vertical profile of background concentration for application to all downwind sampling heights.

The 4.5-m wind speed will be interpolated from the 2-m and 7-m measurements. The interpolation assumes a logarithmic wind profile of the form:

$$U(z) = K \ln (z/z_0)$$

where
U = wind speed (length/time)
z = height above ground (length)
K = proportionality constant (length/time)
z_o = roughness height of ground surface (length)

Exposure values vary over the spatial extent of the plume. If exposure is integrated over the plume effective cross section, then the quantity obtained represents the total passage of airborne particulate matter due to the source. For a line source, a one-dimensional integration is used:

$$A1 = \int_{O}^{H} E \; dh$$

where
A1 = integrated exposure for a line source (mass/length)
E = net particulate exposure (mass/area)
h = height above ground (length)
H = vertical extent of the plume (length)

Because exposures are measured at discrete point within the plume, a numerical integration is necessary to determine the integrated exposure. For moving point (line) sources, exposure must equal zero at the vertical extremes of the profile (i.e., at the ground where the wind velocity equals zero and at the effective height of the plume where the net concentration equals zero). However, the maximum exposure usually occurs below a height of 1 m, so that there is a sharp decay in exposure near the ground. To account for this sharp decay, the value of exposure at the ground level is set equal to the value at a height of 1 m. The 1-m value of exposure is obtained by extrapolating the 2-m and 4.5-m values. The effective height H is found by vertically extrapolating the net (i.e., downwind minus upwind) concentrations to a value of zero.[b] Finally, the integration is performed using the trapezoidal rule.

The emission factor for particulate matter is determined from the integrated exposure by normalizing the emissions against some measure of source activity. For the tests of scrapers in transit, the integrated exposure will be divided by the number of equipment passes to obtain an emission factor in terms of mass emitted per equipment per unit distance traveled during the operation. For tests of loading and unloading, the "operational distance" traveled by the scrapers will be found by multiplying the total number of scraper passes by the mean distance traveled (see Sections 4.2 and 5.3) during loading or unloading. Both the operational distance and the total volume of earth loaded/unloaded will be used to normalize the emission factor. Both sets will be reported.

5.3 Process Data

As noted in connection with Section 4.2, operational features, such as the speed of the scraper, will be controlled by the "captive" nature of the earthmoving at the NCK Technical College test site.

[b] Because past testing at the Beloit site has shown that most of the dust plume lies below the 7 m sampling height, only minor uncertainties result from vertical extrapolation of the downwind concentration profile from the value at 7 m to the background (upwind value) above 7 m.

Section 6.
QA/QC Activities

6.1 QC Procedure

The Quality Assurance Project Plan (QAPP) prepared for this test program is a separate document that describes all the QA/QC activities for the project.

6.2 QA Audits

As part of the QA program for this study, routine audits of sampling and analysis procedures are to be performed. The purpose of the audits is 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 audited include gravimetric analysis, flow rate calibration, data processing, and emission factor calculation. The mandatory use of specially designed reporting forms for sampling and analysis data obtained in the field and laboratory aids in the auditing procedure.

Requirements for high-volume (hi-vol) sampler flow rates rely on the use of secondary and primary flow standards. The Roots meter is the primary volumetric standard and the BGI orifice is the secondary standard for calibration of hi-vol sampler flow rates. The Roots meter is calibrated and traceable to a NIST standard by the manufacturer. The BGI orifice is calibrated against the primary standard on an annual basis. Before going to the field, the BGI orifice is first checked to assure that it has not been damaged. In the field, the orifice is used to calibrate the flow rate of each hi-vol sampler. (For samplers with volumetric flow controllers, no calibration is possible and the orifice is used to audit the nominal 40 acfm flow rate.) Table 6-1 specifies the frequency of calibration and other QA checks regarding air samplers.

A second pre-test activity is the preparation of the hi-vol filters for use in the field. In this preparation, the filters are weighed under stable temperature and humidity conditions. After they are weighed and have passed audit weighing, the filters are packaged for shipment to the field. Table 6-2 outlines the general requirements for conditioning and weighing sampling media. Note, the audit weighing is performed by a second, independent analyst.

Table 6-1. Quality Assurance Procedures for Sampling Equipment

Activity	QC check/requirement
Maintenance • All samplers	Check motors, brushes, gaskets, timers, and flow measuring devices at each plant prior to testing. Repair/replace as necessary.
Calibration Volumetric flow controller	Prior to start of testing at each regional site, ensure that flow determined by orifice and the look-up table for each volumetric flow controller agrees within 7%. For 20 acfm devices (particle size profiling), calibrate each sampler against orifice prior to use at each regional site and every two weeks thereafter during test period. (Orifice calibrated against displaced volume test meter annually.)
Operation Timing	Start and stop all downwind samplers during time span not exceeding 1 min.
Isokinetic sampling (cyclones)	Adjust sampling intake orientation whenever mean wind direction changes by more than 30 degrees for 2 consecutive 5-min averaging periods. Suspend testing if mean wind direction (for two consecutive 5-min averaging periods) is more than 45 degrees from perpendicular to linear path of the moving point source. Change the cyclone intake nozzle whenever the mean wind speed approaching the sampler falls outside of the suggested bounds for that nozzle for two consecutive 5-min averaging periods. Suspend testing if wind speed falls outside the acceptable range of 3 to 20 mph for two consecutive 5-min averaging periods.
Prevention of static deposition	Cover sampler inlets prior to and immediately after sampling.

Table 6-2. Quality Assurance Procedures for Sampling Media

Activity	QA check/requirement
Preparation	Inspect and imprint glass fiber media with identification numbers.
Conditioning	Equilibrate media for 24 h in clean controlled room with relative humidity of 40% (variation of less than ±5% RH) and with temperature of 23°C (variation of less than ±1°C).
Weighing	Weigh hi-vol filters to nearest 0.05 mg.
Auditing of weights	Independently verify final weights of 10% of filters and substrates (at least four from each batch). Reweigh entire batch if weights of any hi-vol filters deviate by more than ±2.0 mg. For tare weights, conduct a 100% audit by a second analyst. Reweigh any high-volume filter whose weight deviates by more than ±1.0 mg. Follow same procedures for impactor substrates used for sizing tests. Audit limits for impactor substrates are ±1.0 and ±0.5 mg for final and tare weights, respectively.
Correction for handling effects	Weigh and handle at least one blank for each 1 to 10 filters of each type used to test.
Calibration of balance	Balance to be calibrated once per year by certified manufacturer's representative. Check prior to each use with laboratory Class S weights.

As indicated in Table 6-2, a minimum of 10% field blanks will be collected for QC purposes. This involves handling at least 1 blank filter for every 10 exposed filters in an identical manner to determine systematic weight changes due to handling steps alone. These changes are used to mathematically correct the net weight gain due to handling. A field blank filter is loaded into a sampler and then immediately recovered without any air being passed through the media. Cyclone wash blanks are obtained by washing the devices after they have been cleaned. Blanks have been successfully used in many MRI programs to account for systematic weight changes due to handling.

After the particulate matter samples and blank filters are collected and returned from the field, the collection media are placed in the gravimetric laboratory and allowed to come to equilibrium. Each filter is weighed, allowed to return to equilibrium for an additional 24 h, and then a minimum of 10% of the exposed filters are reweighed by a second analyst. If a filter fails the audit criterion, the entire lot will be allowed to condition in the gravimetric laboratory an additional 24 h and then reweighed. The tare and first weight criteria for filters (Table 6-2) are based on an internal MRI study conducted in the early 1980s to evaluate the stability of several hundred 8- x 10-in glass fiber filters used in exposure profiling studies.

6.3 QA/QC Checks for Data Reduction and Validation

Whenever practical, all data collected in the study will be entered directly into bound laboratory notebooks and standard data forms. All data are to be recorded in notebooks or on standard data forms (examples are provided in the Appendix) using permanent black ink and signed/dated by sampling personnel. Notebooks and data forms are to be inspected for completeness and accuracy by the appropriate field supervisor at the end of each test. At that time, data forms are grouped by test number and bound into 3-ring binders.

The data analysis procedures to be used for this project are procedures that have been through several layers of validation in substantiating the performance of the method. It should be noted that blank-corrected sample mass is considered quantifiable (and usable for concentration calculation) only if it equals or exceeds three times the standard deviation for the net weight gain of the field blanks. The procedures for conversion of particulate concentrations to final end products are presented in Section 5.2.

The Field Team Leader or his/her designee will perform an independent check of the calculations in any computer data reduction program. The Field Team Leader or his/her designee will conduct an on-site spot check to assure that data are being recorded accurately. After the field test, the QA officer or his/her designee will check data input to assure accurate transfer of the raw data.

For this project, all records will be evaluated for the adherence to all procedures and requirements. The items that will be reviewed include:

- Gravimetric audit weighing for the assessment of the particulate data,
- Calibration and calibration criterion checks,
- The results of all blanks, and
- The validation of data process systems or procedures.

Selected data will be reconstructed, including tracing the calibration back to the primary standards. Any software (spreadsheets) used to determine numerical values will be checked by hand calculating all intermediate and final results for one run by referring to original sources of data (i.e., field filter logs, filter weight logs, run sheets, sampler look-up tables).

6.4 Sample Identification and Traceability

To maintain sample integrity, the following procedure will be used:

- Each filter will be issued a unique identification number. SOP MRI-8403 describes the numbering system that is employed to identify filter type, project, and other information.

- The sample number will be recorded in a sample logbook along with the date the sample is obtained. The sample number will be coded to indicate the sample location and test series.

- Other pertinent information to be recorded includes short descriptions of sample type or location, storage location, condition of sample, any special instructions, and signatures of personnel who receive the sample for analysis.

- In order to conduct traceability, all sample transfers will be recorded in a notebook or on forms. The following information will be recorded: the assigned sample codes, date of transfer, location of storage site, and the name of the person initiating and accepting the transfer.

All documented work will be reviewed by the project leader for completeness. The field technical coordinator and crew chief are responsible for assuring that all samples are accounted for and that proper traceability/tracking procedures are followed.

Section 7.
Reporting and Data Reduction Requirements

7.1 Report Format

The table of contents for the test report will be as shown in Table 7-1.

7.2 Data Reduction and Summary

Table 7-2 illustrates the summary format for the emission and particle size data collected during the field testing.

Table 7-1. Table of Contents for the Test Report

Table of Contents

Table 7-2. Summary Formats for Test Data

		PM-10 Emission Factor based on travel distance		PM-10 Emission Factor based on volume loaded/unloaded	
Scraper Operation	No. of Tests	Range	Mean	Range	Mean
Transit				NA	NA

		PM-2.5 to PM-10 Ratio	
Scraper Operation	No. of Tests	Range	Mean
Unloading			
Transit			

Section 8. Plant Entry and Safety

8.1 Safety Responsibilities

The work assignment leader (C. Cowherd) and the field test leader (G. Muleski) are both responsible for ensuring compliance with plant entry, health, and safety requirements. The facility coordinator has the authority to impose or waive facility restrictions.

8.2 Safety Program

MRI has a comprehensive health and safety program that satisfies OSHA requirements. The Technical Safety and Security Manual, Chemical Hygiene Plan, and Field Operations Safety Manual include written procedures that cover: emergency procedures, safe work practices, material safety data sheets, employee information and training, medical monitoring, and use of personal protective equipment.

8.3 Safety Requirements

All MRI personnel will adhere to the host facility's procedures and safety requirements. In particular, MRI personnel will:

1. confine activities to the test area to the extent possible

2. obtain a daily pass, as required by the host facility

3. wear hard hat, safety shoes, and safety glasses at all times in accordance with host facility and MRI policy

4. have readily available first aid equipment and fire extinguisher

5. eat only in designated areas

Section 9.
Personnel Responsibilities and Test Schedule

9.1 Test Site Organization

The key tasks and task leaders for MRI and the host facilities are as follows:

- Facility coordinator (L. Dietz for NCK Technical College)
- MRI work assignment leader (C. Cowherd)
- MRI field test leader (G. Muleski)

9.2 Test Preparation

Table 9-1 lists the preparations and responsibilities that are required for the field program. A schedule is also presented.

9.3 Test Personnel Responsibilities and Detailed Schedule

MRI personnel will arrive at the host facility or at DFS by 8 am during each potential test day during the field exercise. Upon arrival, the MRI field test leader will meet with the facility coordinator (only at NCK Technical College) and then with the test team to: review test plans for the day; communicate all necessary information ; and notify each other of any problem or delay. Table 9-2 provides a detailed test schedule.

Table 9-1. Test Preparations and Assignments

Preparation/Assignment	Responsibility
Preparation of sampling media	Field test leader
Transportation of sampling media and equipment to initial test site	Field test leader
On-site calibration of sampling equipment	Field test leader
Sample traceability (air and material samples)	Field test leader
Compilation of data forms by test number	Field test leader
Transportation of sampling media and equipment to second test site or MRI	Field test leader
Analysis of air and material samples	Field test leader
Data reduction and reporting formats	Field test leader
QA review	Senior QA officer or his designee
Report to management	Senior QA officer or his designee
Report preparation	Work assignment leader

Table 9-2. Testing Schedule

Date	Activity	Comments
7/26/99 - 7/30/99	Perform filter (tare) analysis	
	Prepare sampling equipment/supplies	
9/9/99 - 9/10/99	Load equipment and transport equipment to NCK Technical College	Schedule to coordinate with start of hands-on training fall semester
9/13/99	Establish on-site laboratory at NCK Technical College	
9/13/99 - 9/14/99	Conduct baseline uncontrolled tests at NCK Technical College	
9/14/99 - 9/24/99	Conduct controlled tests at NCK Technical College	
9/25/99	Return equipment and NCK Technical College samples to main MRI laboratories	
10/15/99	Establish test area at DFS	
10/18/99-10/25/99	Conduct baseline uncontrolled tests at DFS	
11/8/99 - 12/3/99	Conduct controlled tests at DFS	
12/13/99	Complete sample analyses	
12/23/99	Complete data reduction	

Section 10. References

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4. Nichols, H. L, Jr. *Moving the Earth: The Workbook of Excavation*. Third Edition. McGraw-Hill, New York, NY. 1976.

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