Other Test Method – 32: Determination of Emissions from Open Sources by Plume Profiling

This method is designed to quantify particulate matter (PM) from open, roadside sources. This method utilizes plume profiling, which is an open source emission test method based on the exposure profiling concept, with exposure defined as the time-integrated mass flux of pollutant at a sampling point. The mass flux is the product of pollutant concentration and wind speed, which gives the pollutant mass passing the sampling point per unit cross-section of the plume per unit time. The total emissions from the source during the sampling period is found by spatial integration of the exposure over the cross-section of the plume, in the same manner as performed in standard emission testing of ducted sources based on the principle of conservation of mass.

This method was submitted by the Center for the Study of Open Source Emissions (CSOSE) to EPA's Office of Air Quality, Planning and Standards – Air Quality Assessment Division – Measurement Technology Group (MTG) for inclusion into the Other Test Method (OTM) category on EPA's Emission Monitoring Center (EMC) website at http://www.epa.gov/ttn/emc/tmethods.html#CatC/. In addition, the Midwest Research Institute (MRI), under contract to the EPA, had submitted an overview document that is a companion document to this Test Method. That overview document is attached to the method and is listed as Appendix A. The reader is encouraged to review the appendix to this method for additional information.

The posting of a test method on the OTM portion of the EMC is neither an endorsement by EPA regarding the validity of the test method nor a regulatory approval of the test method. The purpose of the OTM portion of the EMC is to promote discussion of developing emission measurement methodologies and to provide regulatory agencies, the regulated community, and the public at large with potentially helpful tools.

Other Test Methods are test methods which have not yet been subject to the Federal rulemaking process. Each of these methods, as well as the available technical documentation supporting them, have been reviewed by the EMC staff and have been found to be potentially useful to the emission measurement community. The types of technical information reviewed include field and laboratory validation studies; results of collaborative testing; articles from peer-reviewed journals; peer-review comments; and quality assurance (QA) and quality control (QC) procedures in the method itself. A table summarizing the available technical information for each method can be found at the link below. The EPA strongly encourages the submission of additional supporting field and laboratory data as well as comments in regard to these methods.

These methods may be considered for use in Federally enforceable State and local programs (e.g., Title V permits, State Implementation Plans (SIP)) provided they are subject to an EPA Regional SIP approval process or permit veto opportunity and public notice with the opportunity for comment. The methods may also be considered to be candidates to be alternative methods to meet Federal requirements under 40 CFR Parts 60, 61, and 63. However, they must be approved as alternatives under 60.8, 61.13, or 63.7(f) before a source may use them for this purpose. Consideration of a method's applicability for a particular purpose should be based on the stated applicability as well as the supporting technical information outlined in the

table. The methods are available for application without EPA oversight for other non-EPA program uses including state permitting programs and scientific and engineering applications.

As many of these methods are submitted by parties outside the Agency, the EPA staff may not necessarily be the technical experts on these methods. Therefore, technical support from EPA for these methods is limited, but the table contains contact information for the developers so that you may contact them directly. Also, be aware that these methods are subject to change based on the review of additional validation studies or on public comment as a part of adoption as a Federal test method, the Title V permitting process, or inclusion in a SIP.

Method History

Final – 6/5/2013

EPA advises all potential users to review the method and all appendices carefully before application of this method.

Determination of Emissions from Open Sources by Plume Profiling

OVERVIEW: An open source is defined as a release point of particulate or gaseous air pollutant into the ambient atmosphere by means other than a stack, vent, or duct. Open sources are also referred to as fugitive sources. Even though vehicle exhaust emissions originate from tailpipes, roadways are treated as open sources, because it is not feasible to capture emissions from each vehicle in motion.

Plume profiling is an open source emission test method based on the exposure profiling concept [1], with exposure defined as the time-integrated mass flux of pollutant at a sampling point. The mass flux is the product of pollutant concentration and wind speed, which gives the pollutant mass passing the sampling point per unit cross-section of the plume per unit time. The total emissions from the source during the sampling period is found by spatial integration of the exposure over the cross-section of the plume, in the same manner as performed in standard emission testing of ducted sources based on the principle of conservation of mass.

In effect, the terms plume profiling and exposure profiling should be considered synonymous, with exposure profiling providing a more technically rigorous name for the method, as evident in the method details below. Another name for the method is plume flux profiling, recognizing the simple relationship between flux and exposure, as noted above.

Plume profiling is suitable for measuring open source emissions of a pollutant consisting of either a particulate or gaseous constituent in a nonbuoyant plume. The method utilizes an array of samplers that are typically supported on one or more ground-based towers placed downwind of the source in a sampling plane oriented perpendicular to the mean wind direction at the time of sampling. The plume profiling method has been widely applied to open (fugitive) dust sources, as illustrated in the references to Section 13.2 of EPA's Compilation of Air Pollutant Emission Factors (AP-42) [2]. Examples are vehicle traffic on unpaved roads and transfer of aggregate materials from a storage pile to a haul truck. However, the plume profiling method is equally applicable to gaseous emissions, from vehicle exhaust or other sources.

This method describes procedures for (a) preparing the sampling equipment, (b) selecting a sampling location, (c) deploying the equipment, (d) sampling, and (e) analyzing the samples, and (f) calculating the results. Additional guidance for the application of the method is provided elsewhere [3].

1.0 Scope and Application

1.1 *Pollutant/Measured Parameters.* The measured parameters are pollutant concentration and ambient wind speed and direction. If the pollutant is present as particulate matter (PM), then a particle size range must be specified. Generally, it is recommended that time-integrated samples be collected so that test results represent average emissions during a test period of relatively consistent source activity and wind conditions, as described below. If continuous monitors are used to measure pollutant concentration or wind speed, then the electronic signal should be time-

integrated over periods when no significant time variations in near-source conditions are observed. The term substrate is used to convey a means (physical or electronic) for pollutant mass accumulation over the test period.

1.2 *Applicability.* This method uses the technique of exposure profiling to determine the total mass passing through the sampling plane in a given period of time. The exposure profiling method is applicable to any open source of emissions, provided that the following conditions are met: (a) sampling equipment can be placed sufficiently close to the source (see Sec. 8.4) such that the plume core can be characterized by a ground-based sampling array; (b) the contribution of the emission source can be isolated from upwind (background) levels of the pollutant; and (c) wind conditions are such that horizontal advection of the emitted pollutant is consistent enough to provide for transport across the sampling array.

1.2.1 The method is applicable to the following open source configurations: (a) moving point sources (often treated as line sources), and (b) fixed sources (volume or area). The most common example of a moving point source is a vehicle travelling on a roadway. A roadway with a high density of freely flowing traffic[1] can be modeled as a line source, which is considered to be uniformly emitting over the length of the source. The method is also applicable to fixed area or volume sources, as long as the downwind plume dimensions are small enough that the plume can be feasibly sampled with a ground-based, vertically oriented array of samplers. Because of the restricted dimensions of such area or volume sources, they are commonly referred to as (virtual) point sources.

1.3 *Data Quality Objectives.* Adherence to the requirements of this method will enhance the quality of the data obtained from measurement of open source emissions. In the planning process, specific data quality objectives are set for the accuracy, precision, and completeness of each measurement component of the method as described below.

2.0 Summary of the Method

The exposure profiling technique uses simultaneous multipoint measurement of both pollutant concentration (above background) and wind speed (advection) over the effective cross-sectional area of the emission plume. The measurement points are distributed across a plane normal to the wind direction at a downwind location. Typically, exposure profiling with ground-based sampling towers is suitable for quantifying emissions from line sources and small volume or area sources that emit at or near ground level. The technique incorporates a mass flux calculation scheme that utilizes spatial integration of point values of pollutant flux (concentration multiplied by wind speed). The exposure profiling method was first proposed for standardization in 2000 [3].

[1] "The mean time between vehicle passes is less than the mean time required for the plume to pass from a vehicle to the sampling array."

3.0 Definitions

3.1 Advection means the horizontal movement of an air pollutant by the wind.

3.2 Effective Plume Area refers to the portion of the vertical plane perpendicular to the direction of plume transport that contains at least 80 percent of the pollutant mass flux (as a guideline) based on preliminary testing at the site of interest.

3.3 Exposure is the point value of the net passage of emission mass through a unit area normal to the direction of plume transport (usually the wind direction). Exposure is calculated by multiplying together (a) the concentration (mass of pollutant per unit volume of air); (b) the wind speed (length per time); and (c) the duration (time) of sampling at an individual point.

3.4 Exposure Profiling is the test method that determines the point values of exposure within the effective plume area and integrates those values across the sampling plane to determine the total net passage of pollutant mass emissions.

3.5 Integrated Exposure refers to the integral of exposure over the effective cross-sectional area of the plume transport. The result is the total net pollutant mass emitted by the source during the test duration.

3.6 Line Source is an emission source with a downwind concentration field that is uniform with respect to the crosswind horizontal dimension. A series of moving point sources such as vehicles traveling a paved roadway can be represented as a line source under conditions of high traffic density. Compare to virtual point source.

3.7 Measurement Plane is the vertically oriented plane (at right angles to the wind direction) located in the near-field of the emission source over which the point values of exposure are characterized.

3.8 Near-Field and Near-Source are terms used to characterize the downwind distance regions where the concentration and wind fields are profiled. The downwind distance is usually on the order of 2 to 10 meters (m) from the downwind edge of the source.

3.9 Open source is a source of air pollutant emissions that enter the atmosphere by means other than a duct, vent, or stack. In particular, open source pollutant mass is transported by ambient winds.

3.10 PM-X denotes particles equal to or smaller than X microns in size, with likely cut-points of interest being 10 microns and 2.5 microns, based on current ambient air quality standards.

3.11 Source Activity is the suitable measure of the anthropogenic activity (such as vehicle-miles traveled on an unpaved road) that causes the pollutant emission. When the integrated exposure is divided by the source activity, the result is an emission factor. When no suitable measure of activity is available, then the integrated exposure should be divided by the duration of the sampling to obtain an emission rate.

3.12 Substrate is a medium for accumulating sample mass over the sampling period.

3.13 Virtual Point Source is a representation of a small area or volume source. The virtual point is located upwind of the actual source such that the cross-sectional dimensions of the plume approximate the dimensions of the actual area or volume source being represented. Compare to line source.

4.0 Interferences

4.1 Potential interferences to this method are background (upwind) concentrations and artifact effects of handling the sample collection medium. The exposure profiling measurement technique incorporates precautions against potential interferences.

4.2 The method subtracts background (upwind) concentrations from measured downwind concentrations to obtain net concentration values (i.e., directly attributable to the source under consideration).

4.3 Blank collection media/substrates (typically filters when characterizing PM sources) are used to account for the effects of media handling. A minimum of 10 percent of the collection substrates used in the field (with an absolute minimum of three blanks per test site on a given day) is the amount of collection substrates recommended for use as blanks. A blank test is conducted in exactly the same manner as an emission test except that no air is passed through or across the collection substrates between the time when they are loaded into and unloaded from the sampling devices.

5.0 Safety

5.1 *Disclaimer*. This method may involve hazardous materials, operations, and equipment. This test method may not address all of the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

5.2 It is the responsibility of the crew chief or program manager to ensure compliance with site entry, health, and safety requirements is maintained. All personnel should adhere to the site procedures and safety requirements including: confining activities to the test area to the extent possible, wearing personal protective equipment in accordance with site policies, and having readily available first aid equipment and fire extinguishers.

5.3 Because the exposure profiling technique requires measurements across the effective plume area including its vertical extent, sampling equipment is commonly positioned from a height of about 1 m up to a height of 7 m above the ground. This requires that the sampling crew take reasonable precautions regarding guying of masts, avoiding power lines and other energized sources, and securing equipment to masts or other supports. Additionally, the crew needs to

follow safety requirements (such as the use of steel-toed footwear, hardhats, eye, and ear protection) of the host facility.

6.0 Equipment and Supplies

6.1 *Sample Collection.* In the application of the exposure profiling test method, substrates are required for sample collection, unless direct-reading samplers are used as described below.

6.1.1 *Air Samplers.* Air samplers are required for the determination of time-averaged pollutant concentrations at points within the emission plume. Air samplers may either be direct reading (continuous) or may be fitted with a removable sample collection substrate that is transferred to the analytical laboratory for determination of pollutant mass collected. Each air sampler is typically equipped with a flow transducer and connections for a flow recorder, unless the sampler flow is controlled automatically by an electronic air mass flow meter. Air samplers are deployed in different arrays and numbers depending upon the configuration of the emission plume being sampled.

6.1.1.1 In the case of PM emissions, the particle size fraction of interest determines the type of sampler inlet. For the capture of airborne particles larger than 10 micrometers in aerodynamic diameter, isokinetic sampling is recommended to avoid biasing the apparent particle size distribution of the collected sample as compared with the true particle size distribution of the emission plume approaching the sampling intake. This entails two critical requirements: (a) directional inlets are pointed into the mean wind direction, and (b) the sampling speed within the intake matches the mean wind speed approaching the intake at the sampling point, within a specified tolerance (e.g., ±20 percent to achieve an estimated error of less than ±5 percent [4]).

6.1.1.2 For sampling of PM-X, two options are available: (a) removing particles larger than X micrometers in aerodynamic diameter (µmA) from the PM sampling stream (downstream of the sampling inlet) so that only PM-X passes to the sample collection medium or (b) preventing unwanted particles from entering the sampled air stream, by attaching a size-selective inlet (typically omni-directional) to the sampler.

6.1.1.3 In much of the historical application of the exposure profiling method to fugitive dust sources, the primary air sampling device has been a standard high-volume sampler fitted with a cyclone pre-separator having a directional inlet. The cyclone exhibits an effective 50 percent cutoff diameter (D_{50}) of 10 µmA when operated at a flow rate of 40 cubic feet per minute (cfm) (68 m^3/h) and a D_{50} of 15 µmA when operated at a flow rate of 20 cfm [5] to reduce particle bounce if used with a cascade impactor. Thus, at a flow rate of 40 cfm, the mass collected on the backup filter represents a PM-10 sample. The high-volume air sampler with a cyclone pre-separator is shown in Figure 9 of Section 17.

6.1.2 *Flow Measurement Device*. This device assures that the correct flow through the sampler is maintained. For traditional high-volume sampling systems, the flow measurement device usually consists of an orifice that is incorporated into the sampler such that the entire sample stream passes through the orifice. The pressure drop across the orifice indicates the airflow rate through high-volume sampler, on the basis of a previously developed calibration curve.

6.1.3 *Meteorological Equipment.* Meteorological monitors are required for the determination of time-averaged values of wind speed and direction. Typically the averaging time should range from 5 minutes to 15 minutes depending on the observed variability of the mean wind conditions. A variety of recording instruments for measurement of ambient wind speed and direction are suitable for this purpose. A thermometer and a relative humidity indicator are also used to record weather conditions during testing. The barometric pressure can be obtained from a local weather station or can be approximated from the elevation of the test site, in the unusual case that it is desired to report concentrations in standard conditions rather than actual conditions.

6.1.4 *Timepiece.* A clock is needed to determine the start time and stop time of each test so that the duration of sampling can be determined. It is recommended that both a watch and an elapsed time meter be used for this purpose.

6.2 *Sample Recovery.* For samplers that are not direct-reading and require retrieval and analysis of a collection substrate, sample recovery must be performed. The following items are required for sample recovery: (a) devices to remove the collection substrate from each air sampler, and (b) devices to package the collection substrate for shipment to the analytical laboratory. For fugitive dust applications, packaging for filters typically includes glassine envelopes, numbered file folders, heavy duty plastic bags, and a heavy-duty cardboard box with lid.

6.3 *Sample Analysis.* Laboratory equipment and protocols are required for determining the mass of sampled pollutant present on each collection substrate. Sample analysis for particulate matter and gaseous pollutants is discussed further in Section 11.0.

7.0 Reagents and Standards

7.1 Reagents and standards may be required for execution of laboratory analysis of pollutant mass on collection substrates that have been retrieved from exposure profiling systems. Typically two steps are required: (a) recovery of the pollutant from the collection substrate, and (b) analysis of the pollutant to determine the mass transferred from the substrate.

7.2 For fugitive dust applications the traditional collection substrate consists of a 20.3 cm × 25.4 cm (8 inch by 10 inch) rectangular filter. The filter material is glass fiber or other relatively inert, non-hygroscopic material. The minimum collection efficiency is 99 percent as measured by a dioctyplthalate oil (DOP) test, for particles of 0.3 mm diameter. The filter material must be sufficiently pliable so that there are no cracks or separations after the filter is folded (exposed face inward) creating a single midpoint crease. PM mass on exposed filters is determined by gravimetric analysis with no reagents required.

8.0 Sample Collection, Preservation, Storage, and Transport

8.1 Pre-test Preparation.

8.1.1 *Air sampling equipment.* Sampling equipment should be adequately maintained and calibrated according to manufacturer's recommendation before use.

8.1.2 *Sample Collection Media.* The procedures to be followed depend on the sampling system and the collection media used for the pollutant of interest. This step does not apply to direct-reading samplers. As an illustration, the procedures in Table 1 are used for preparation of filter media for open source (fugitive) dust emission testing.

Table 1. Preparation of Filter Media for Sample Collection in a PM Plume

1.	Preparation—Inspect to make sure that no defects are present and imprint filter media with identification numbers.
2.	Conditioning—Equilibrate filter media for 24 hours in a clean controlled room with relative humidity (RH) of 40 percent (variation of less than ±5% RH) and with temperature of 34°C (variation of less than ±1°C).
3.	Calibration of balance—Calibrate balance once per year by certified manufacturer's representative. Check prior to, during (as necessary), and after each use with laboratory Class S weights.
4.	Weighing—Tare weigh filter media to nearest 0.05 milligram (mg).
5.	Audit of weights—For tare weights, conduct a 100 percent audit by a second analyst. Reweigh any filter with an audit weight that deviates by more than ±1.0 mg from the first tare weight.
6.	Correction for handling effects—Weigh and handle at least one blank for each 1 to 10 filters of each type used to test. Use at least 3 blank filters of each type for each test day.
7.	Preparation for shipment—Carefully place each tare weighed filter into a glassine envelope and place the envelope into a separate numbered file folder. Place the folders in a heavy-duty cardboard box with lid.

8.2 *Site Selection Criteria.* If a sampling location is not already contractually selected, the following selection criteria are recommended: (a) unobstructed fetch of flat, open terrain should be at least 15 m and 10 m from the upwind and downwind edges of source, respectively; (b) height of the nearest downwind obstruction should be less than the distance from the source to the obstruction; (c) height of the nearest upwind obstruction should be less than one-third the distance from the source to the obstruction; (d) for moving point/line sources, a line drawn perpendicular to the source should form an angle of 0 to 45 degrees with the mean prevailing wind direction for the time period when testing is performed; (e) mean wind speed should be greater than 1.3 meters per second (m/s) [3 miles per hour (mph)] for the time period when testing is performed; and (f) source activity should be adequate to provide quantifiable pollutant mass on each air sampler over the period of testing. A portable weather station may be deployed to assess the acceptability of wind conditions. In the case of road dust sampling from traffic as a line/moving point source, the sampling should take place at a location where the road grade is near zero so that particulate emissions from vehicle exhaust are small compared to the fine particle component of dust emissions.

8.3 *Preloading of Substrates.* The procedures to be followed depend on the sampling system and the collection media used for the pollutant of interest. This step does not apply to direct-reading

samplers. As an illustration, the following procedures are used for preloading of filter media for fugitive dust emission testing. In a sheltered area near the field test site, transfer each filter from its folder and envelop into a filter cartridge assembly. Center the filter over the wire screen, place the holder on top of the filter, and tighten the wing-nuts just enough to prevent leakage. Excessive tightening may cause the filter to stick to the gasket. Finally, place the cover plates on the filter cartridge assembly. It is helpful to view pictures of equipment in Section 2.11 of EPA's QA handbook [6].

8.4 *Deployment of Air Sampling Equipment.* The exposure profiling technique relies on simultaneous multi-point measurement of both pollutant concentration and airflow (advection). These simultaneous measurements are made over the effective area of the emission plume in a sampling plane perpendicular to the direction of transport. However, because both the emission rate and the airflow are nonsteady, this requires simultaneous multi-point sampling of mass concentration and wind speed as the emission plume passes across the sampling array. Variations exist in sampler deployment based on the emission source being sampled.

8.4.1 *Moving Point/Line Sources.* A vertically oriented array of sampling points is required for the exposure profiling test method when applied to moving point or line sources such as vehicle traffic on roadways. As long as the length of the source segment (e.g., the vehicle travel distance) with uniform emission conditions is at least 10 times the downwind distance from the path of the source to the sampling array, only a single vertical array of samplers is required. The samplers may be evenly spaced on the support tower or the spacing may be reduced in the denser part of the plume near the ground. Sampling towers are positioned just downwind and upwind from the edge of the source. The downwind distance of 5 m from the edge of the source 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 7 m. In a similar manner, the 15-m upwind distance from the edge of the source is far enough from the source that (a) source turbulence does not affect sampling and (b) a brief wind direction reversal would not substantially impact the upwind samplers. The 15-m upwind distance is close enough to the line/moving point source to provide the representative background concentration values needed to determine the net mass flux (i.e., due to the source). The sampling configuration for moving point/line sources can be seen in Section 17.

8.4.2 *Fixed Volume/Area Sources.* A vertically oriented array of sampling points is required for the exposure profiling test method when applied to fixed sources. Because the emission plume from a fixed source produces pollutant concentrations that vary laterally across the effective area of the plume, a two-dimensional network of samplers consisting of at least three vertical arrays (towers) is required for sampling downwind of the source. The towers should be located at least 3 m downwind of the source to allow for adequate plume development. If the source is elevated, as in the case of a truck loading operation, the samplers are spaced across the elevated emission plume. A single vertical sampling array of at least two points should also be located 15 m upwind of the source to measure the background contribution to the emission plume. If there is reason to suspect that the background concentration varies with height, then more than two sampling heights should be used to measure the variation. The sampling configuration for fixed point sources can be seen in Section 17.

8.5 *Deployment of Meteorological Monitors.* Normally wind speed monitors are deployed at two heights within the plume, and a functional relationship is used to determine mean wind speeds at the other air sampler heights, recognizing that the wind speed at the ground surface equals zero (no-slip boundary condition). Typically because wind direction does not vary significantly with height within the plume, only one wind direction monitor is needed. For moving point/line sources, the monitor is deployed at a height of 2 to 3 m above ground level. Meteorological monitors may be located upwind of the source, for convenience.

8.6 *Operation of Air Samplers.* Sampling should not be planned if measurable precipitation is forecast. Acceptable sampling conditions are: (a) forecast wind speed between 1.3 and 8.9 m/s (3 and 20 mph) [7] at a measurement height of 7 m and (b) forecast wind direction that meets criterion d in Section 8.2, in the case of moving point/line sources. The acceptance criteria for wind speed/direction are necessarily based on the results of on-site wind monitoring conducted immediately before starting a test. Testing should not begin unless the mean conditions remain in the acceptable ranges for at least two consecutive 5-minute averaging periods. Similarly, testing is suspended if either the wind speed or the wind direction drift outside the acceptable ranges for two consecutive 5-minute averaging periods. Sampling may be restarted if acceptable conditions return. In that case, the same criterion of two consecutive acceptable 5-minute periods is followed to restart a test. If sampling conditions are acceptable, load a collection substrate (with cover plate removed) into each sampler and position each sampler in its proper deployment location. Start and stop all downwind samplers during a time span not exceeding 1 minute. Adjust sampling intake orientation whenever mean wind direction (10 ± 5-minute averaging time) dictates. For isokinetic sampling of fugitive dust, change the directional sampling intake nozzle whenever the mean (10 ± 5-minute averaging time) wind speed approaching the sampler falls outside of the suggested bounds for that nozzle. Cover sampler inlets prior to and immediately after sampling.

8.7 *Sample Recovery and Transport.* At the conclusion of an emission test, remove the exposed collection substrates from the air samplers. In the case of fugitive dust sampling (addressed here for illustrative purposes), proceed with the following steps. In an area protected from wind and dust deposition, transfer each exposed filter into an individual glassine envelope and then into a numbered file folder. Seal groups of up to 50 file folders within heavy-duty plastic bags and then place into a heavy-duty cardboard box fitted with a lid. Keep all exposed and unexposed filters separate to avoid any cross-contamination. When exposed filters and the associated blanks are returned to the laboratory, they are equilibrated under the same conditions as the initial weighing.

9.0 Quality Assurance and Quality Control

9.1 *Performance Audits.* Routine audits of sampling and analysis procedures should be performed 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. Performance audits of three individual portions of the total measurement are recommended: (a) flow rate calibration, (b) exposed substrate reanalysis, and (c) data processing. Performance audits are conducted by an independent operator/analyst. The use of standard field and laboratory data forms aids in the auditing procedure.

9.2 *Sample Identification and Traceability.* Recordkeeping is a critical part of quality assurance activities. To maintain sample integrity, the following procedure must be used: (a) each substrate must be issued a unique identification number; (b) the sample number must be recorded in a sample logbook or other data form along with the date the sample was obtained; (c) the sample number must be coded to indicate the sample location and test series; (d) other pertinent information that must be recorded includes short descriptions of sample type or location, condition of sample, any special instructions, and signatures of personnel who receive the sample for analysis; (e) in order to conduct traceability, all sample transfers must be recorded in a notebook or on forms including the following information: the assigned sample codes, date of transfer, location of storage site, and the name of the person initiating and accepting the transfer.

9.3 *Method Precision* For line or moving point sources, method precision can be determined either (a) by collocating profiling towers on a given road segment or (b) by repeating tests using a single tower under otherwise constant source conditions. For fixed point sources requiring multiple towers, the choices are to select different symmetrical arrays of sampling points or to repeat tests using a single array of sampling points under otherwise constant source conditions. In the latter case, there must be independent evidence that average source conditions are constant during the consecutive test periods. In all cases, a minimum of three sets of tests should be performed for use in estimating method precision. Because of the cost of erecting and operating multiple sampling towers for determination of method precision, prior studies are often used to support estimates of expected method precision for similar source configurations.

10.0 Calibration and Standardization

10.1 All instruments used in field testing should be checked before use for yearly manufacturer calibration records, if required, and calibrated before arriving at testing location by necessary measures. The same applies to analytical devices present in the laboratory environment. For example, in the case of gravimetric analysis of exposed filters from fugitive dust samplers, laboratory balances used should be calibrated once per year by certified manufacturer's representative and checked before each use with laboratory Class S weights or higher. Meteorological equipment should be adequately maintained and calibrated according to the manufacturer's recommendation before use. A flow transfer standard can be used to calibrate/verify all sampler flows. The transfer standard should be calibrated annually against a positive displacement standard volume meter (such as a Rootsmeter) that is NIST-traceable.

11.0 Analytical Procedure

11.1 *Pollutant Analysis.* The procedures to be followed depend on the nature of the pollutant and the collection media used. This step does not apply to direct-reading samplers. For purposes of illustration, the procedure for gravimetric analysis of exposed filters from the testing of a PM source is presented in Table 2.

11.2 *Gravimetric Analysis.* All analytical methods required for filter-based exposure profiling of PM sources are inherently gravimetric in nature. That is, the final and tare weights are used to determine the net mass of particulate captured on filters and other collection media. The tare and final weights of blank filters are used to account for the systematic effects of filter handling.

Table 2. Gravimetric Analysis Procedure for Filters from PM Plume Sampling

The gravimetric analysis of filters is performed in an environmental chamber with temperature and humidity control within the limits specified in Section 8.1.2. The following procedure should be used whenever a sample-related weighing is performed: (a) an accuracy check at the minimum of one level, equal to approximately the actual weight of the exposed filter(s) with standard weights of Class S, (b) the observed mass of the calibration weight must be within 0.1 percent of the stamped value on the calibration weight, (c) if the balance calibration does not pass this test at the beginning of the weighing, the balance must be repaired or another balance must be used. If the balance calibration does not pass this test at the end of the weighing, the samples or standards must be reweighed using a balance that can meet these requirements. The procedure for weighing of the exposed filters is the same as that described in Section 8.1.2. Independently verify final weights of 10 percent of sampling media (at least four from each batch). Reweigh entire batch if weights of any filter media deviate by more than ±3 times the standard deviation of reweighs of filter blanks.

12.0 Calculations and Data Analysis

12.1 *Nomenclature.*

A_1	=	Integrated exposure (mass/length) for a moving point/line source
A_2	=	Integrated exposure (mass) for a fixed point source
a	=	Cross-sectional area of sampler inlet (area)
C	=	Pollutant concentration (mass/volume)
C_b	=	Background concentration (mass/volume)
C_d	=	Downwind concentration (mass/volume)
E	=	Pollutant exposure (mass/area)
E(h)	=	Pollutant exposure (mass/area) at height h
E(y,h)	=	Pollutant exposure (mass/area) at crosswind distance y and height h
H	=	Effective height (length) of the plume in the measurement plane
h	=	Height (length)
m	=	Net mass collected on the filter or substrate (mass)
Q	=	Volumetric flow rate of the sampler (volume/time)
t	=	Duration (time) of sampling
U	=	Advection airflow speed (length/time)

Y = Horizontal crosswind extent (length) of the plume at the measurement plane

y = Crosswind horizontal coordinate (length)

12.2 *Concentration of Pollutant.* The concentration of pollutant is given by:

$$C = m/Qt \quad \text{(OS-1)}$$

12.3 *Isokinetic Flow Ratio (IFR).* The IFR is the ratio of a directional sampler's intake air speed to the mean wind speed approaching the sampler. It is given by:

$$IFR = Q/a*U \quad \text{(OS-2)}$$

12.4 *Exposure.* Exposure represents the net passage of mass through a unit area normal to the direction plume transport and is calculated by:

$$E = (C-C_b)* U*t \quad \text{(OS-3)}$$

12.5 *Integrated Exposure.* Exposure varies with height and (in the case of point sources) crosswind horizontal location over the extent of the plume. The integration of exposure over the effective cross-section of the plume represents the total passage of the pollutant mass during the test. This quantity is termed the integrated exposure and is calculated as follows:

12.5.1 Fixed "Point" Source:

$$A_2 = \int_{0}^{H - Y/2} \int_{-Y/2} E(y,h)dy,dh \quad \text{(OS-5)}$$

12.5.2 Moving Point/Line Source:

$$A_1 = \int_{0}^{H} E(h)dh \quad \text{(OS-6)}$$

12.5.3 The integration extends from zero to the effective height H and, for point sources, over the crosswind horizontal extent. The quantities H and Y are found by extrapolating the net concentration values to zero. Because exposures are measured at discrete points, a numerical integration is necessary to determine A_2 or A_1. The exposure must equal zero at the vertical and horizontal extremes of the profile (i.e., at the ground where the wind velocity equals zero and at the points at which the net concentration equals zero). However, it has been found that only a relatively small error results from assuming that the exposure at the lowest sampling point applies to the vertical extent of the plume from the lowest sampling point to the ground. Typically, the integration is performed using the trapezoidal rule (see example in Section 12.7 below).

12.6 *Emission Factor.* The emission factor is found by dividing the integrated exposure by the measure of the source activity.

12.7 *Example of the Integration Process.* An example of the integration process for a line source is given below. This was developed for a representative test an unpaved road traveled by large trucks at an open pit iron ore mine [8] where it was necessary to sample the plume up to a height of 9 m above the ground. Raw data forms for this test run are provided in Section 17.

In Table 3, point values of time integrated plume concentrations and mean wind speeds are used to calculate exposure values. The test period was 1 hour. The number of vehicle passes was 27.

Table 3. Exposure Values

Sampler height	PM-10 concentration (mg/m^3)	(Note 1) Net PM-10 concentration (mg/m^3)	(Note 2) Mean wind speed (mph)	(Note 3) Net PM-10 exposure (mg/cm^2)
Cyclone 9.0 m	0.031	0.021	6.1	0.0471
Cyclone 6.5 m	0.142	0.132	5.9	0.2881
Cyclone 4.0 m	0.142	0.132	5.6	0.2722
Cyclone 2.0 m	0.128	0.118	5.2	0.2255

NOTES:
1. Determined by subtracting a representative upwind value of 0.010 mg/m^3 for the upwind concentration as found by simultaneous monitoring.
2. The average wind speeds recorded at heights of 2 m and 6.5 m during test were fitted to a logarithmic profile.
3. Exposure represents the product of wind speed, concentration, and test duration.

A numerical integration scheme is used to determine the integrated exposure and emission factor. Because the concentration at the 9.0-m level was nonzero, the concentrations of the 6.5 m and 9.0 m levels were linearly extrapolated to determine the estimated plume height of 9.5 m. As noted above, the exposure at ground level is set equal to that found for the lowest sampler.

Figure 1 plots the exposure values and shows how the trapezoidal rule is applied to obtain the integrated exposure value:

$$A = 0.0111 + 0.4191 + 0.7005 + 0.4978 + 0.4511 \text{ m-mg/cm}^2$$

$$= 2.0795 \text{ m-mg/cm}^2 \times (100 \text{ cm/1 m})^2 \times (1609 \text{ m/1 mile}) \times (1 \text{ lb/454,000 mg})$$

$$= 73.70 \text{ lb/mile}$$

The emission factor [e] is found by dividing the integrated exposure by the number of vehicle passes:

$$e = 73.70 \text{ lb/mile/27 vehicles}$$

$$= 2.730 \text{ lb/VMT}$$

Where VMT denotes vehicle-mile traveled, i.e., the product of the vehicle count and the length of the road segment represented by the profiling data.

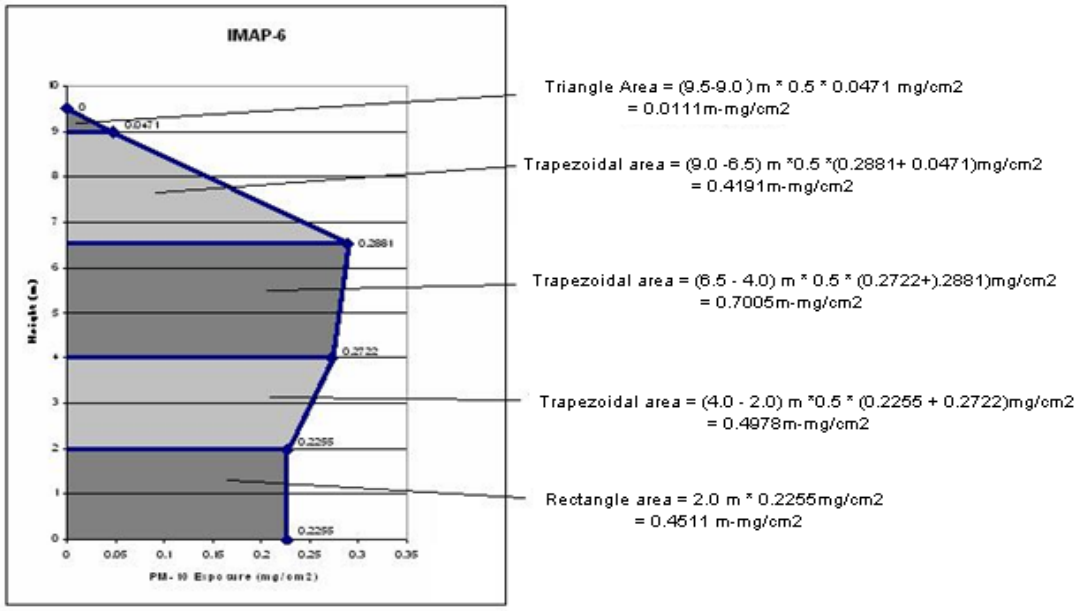

Figure 1. Integration of the Exposure Values over Plume Height

The effect of modifications to the method for extrapolating the exposure from the lowest sampling point to the ground is illustrated below. Three variations are shown:

- Set exposure at ground level equal to that found for the lowest sampler.
  - Emission Factor: **2.730 lb/VMT**
- Extrapolate exposure from the 2.0-m and 4.0-m samplers to a height of 1.0 m and set exposure at ground level equal to that found for the 1.0-m height.
  - Emission Factor: **2.711 lb/VMT**
- Extrapolate exposure from the 2.0-m and 4.0-m samplers to a height of 0.5 m, and then make a linear fit from the 0.5-m height to zero exposure at ground level.
  - Emission Factor: **2.636 lb/VMT**

It is clear that the resulting emission factor is relatively insensitive to the method used**.**

13.0 Method Performance

Method performance for plume profiling is addressed in Reference 9. An early analysis of uncertainties in the plume profiling method is presented in Reference 7. Typically method performance goals are given in terms of data quality objectives. For example, in profiling tests of road dust, collocated sampling towers may be used as a standard component of the quality assurance program, as described above in Section 9. However, the significant cost in erecting and operating additional profiling towers may necessitate that method precision be based on the results of prior testing of similar source configurations. In the case of roadway testing, data quality objectives for measurement precision are usually set at ±40 percent for PM10 mass flux and ±45 percent for PM10 emission factor [10]. The mass flux values reflect uncertainties in concentration and wind speed measurements coupled with uncertainties in graphical integration of profiles that require extrapolation from the lowest sampling point to ground level and from the highest sampling point to background (virtual top of plume). Regarding emission factors, additional uncertainties are attributable to variations in road surface conditions over short distances along the roadway. The data quality objectives for measurement accuracy are typically ±10 percent [10].

14.0 Pollution Prevention

Not applicable.

15.0 Waste Management

15.1 Any hazardous waste that is generated during the exposure profiling test method must be subjected to procedures that are approved for waste disposal. Disposal of general solid waste (e.g., unused bulk material samples obtained for soil characterization) must also follow approved procedures.

16.0 References

1. Cowherd, C., Jr., K. Axetell, Jr., C. M. (Guenther) Maxwell, and G. A. Jutze, “Development of Emission Factors for Fugitive Dust Sources,” EPA Publication EPA-450/3-74/037, NTIS Publication PB-238 262, (June 1974).
2. U.S. Environmental Protection Agency. “Compilation of Air Pollutant Emission Factors.” Research Triangle Park, North Carolina, 2005.
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4. Watson, H.H. “Errors Due to Anisokinetic Sampling of Aerosols.” *Am. Ind. Hig. Assoc. Quart.* 15:21, 1954.

5. Baxter, T. E., D. D. Lane, C. Cowherd, Jr., and F. Pendleton. "Calibration of a Cyclone for Monitoring Inhalable Particles." *Journal of Environmental Engineering*, 112(3), 468, 1986.

6. EPA's QA Handbook http://www.epa.gov/ttnamti1/files/ambient/qaqc/2-11meth.pdf

7. Axetell, K. and C.Cowherd, Jr., "Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources, Volume I—Sampling Methodology and Test Results." Prepared for USEPA Office of Research and Development, EPA-600/7-84-048, 1984.

8. Cowherd, C., Jr., Donaldson, J. Kies, R., and Murowchick, P. "Field Study of Emissions from Haul Roads." Prepared for the Iron Mining Association of Minnesota, Duluth MN, October 30, 2008.

9. ETV Program (4950-04-02-QAP) MRIGlobal. "Evaluation of a Mobile Sampler to Characterize Unpaved Road Dust Palliatives," Final Report prepared for the U.S. Army Construction Engineering Research Laboratory, CERL Order No. DACA42-01-F-0062, MRIGlobal Project No. 110144, August 5, 2002.

10. Muleski, G. and C. Cowherd, Jr., "Particulate Emission Measurements from Controlled Construction Activities." Prepared for USEPA Office of Research and Development, EPA-600/R-01-031, 2001.

17.0 Illustrations

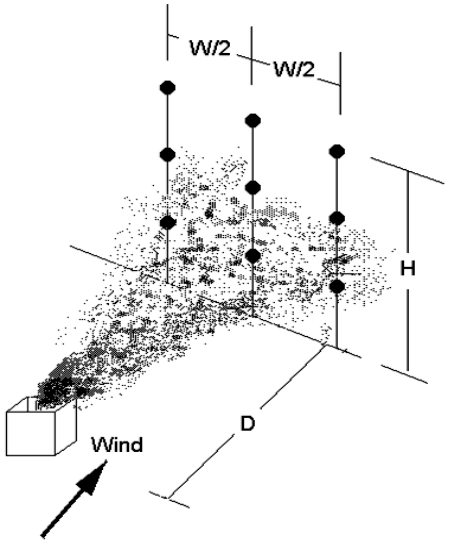

Figure 2. Illustration of Fixed Point Source Sampling Array

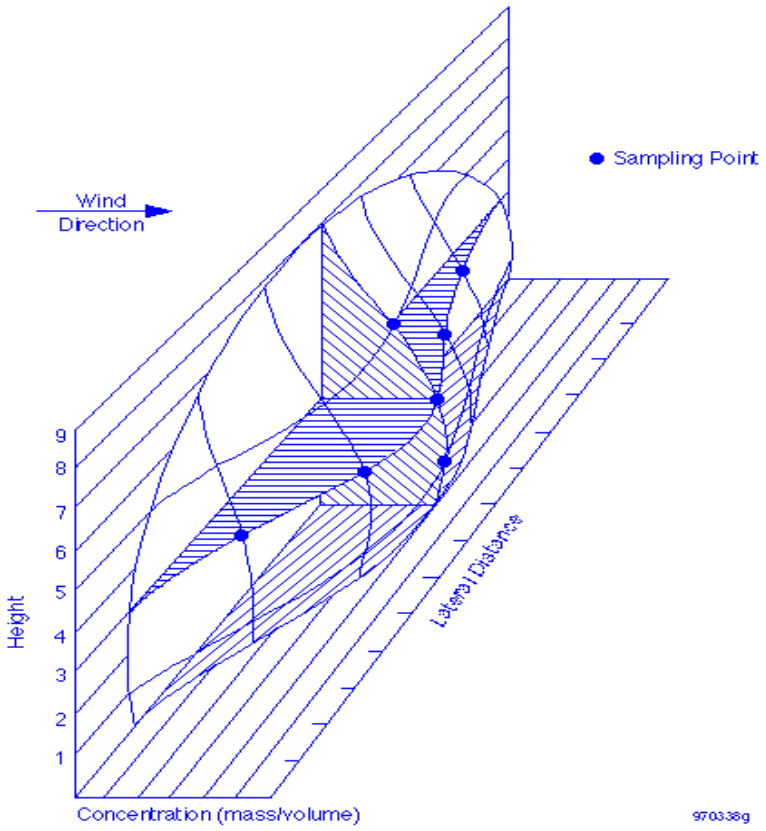

Figure 3. Illustration of Plume Concentration Profiles Downwind of a Fixed Point Source

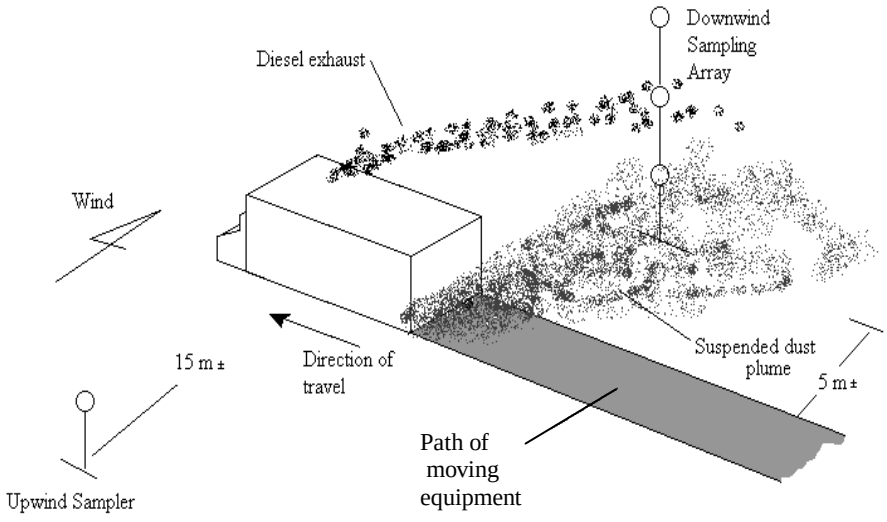

Figure 4. Illustration of Moving Point Source—Unpaved Road Dust Emissions

[exhaust emissions are typically negligible compared to uncontrolled road dust emissions]

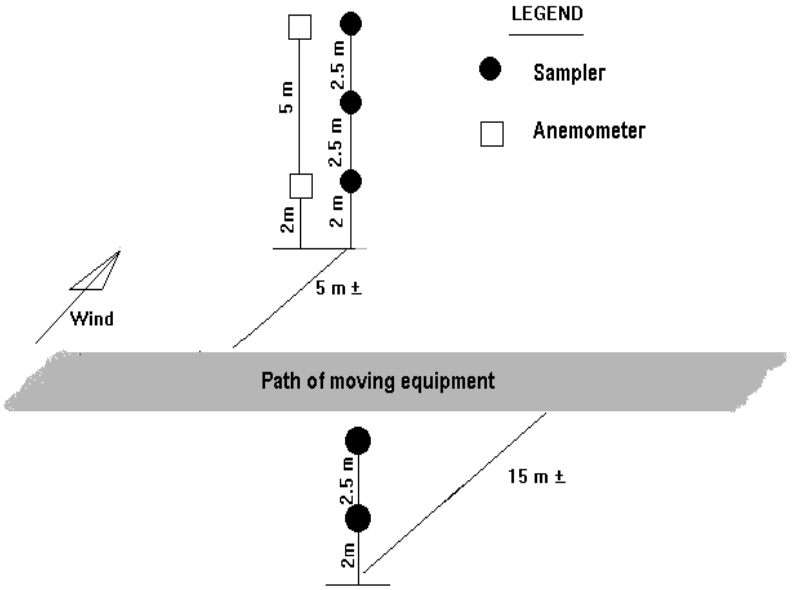

Figure 5. Example Sampling Array for Moving Point Source

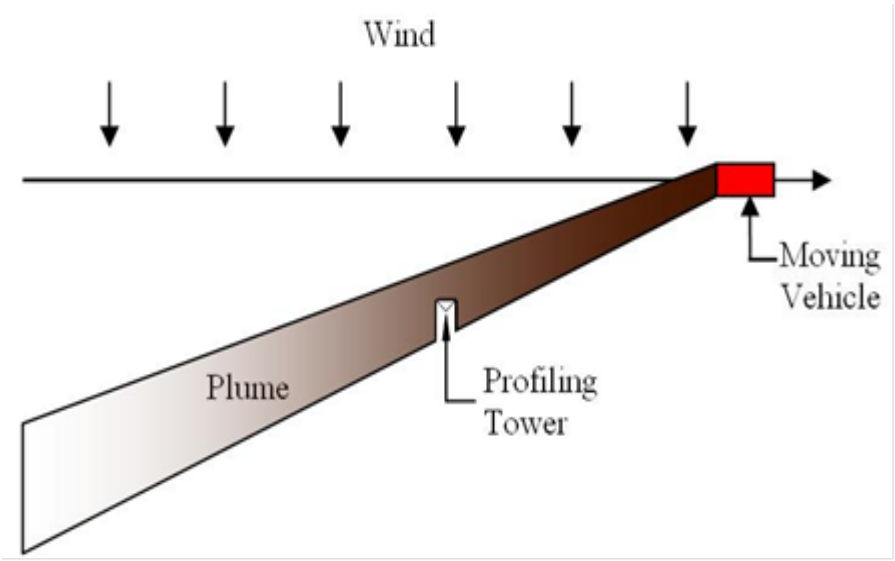

Figure 6. Illustration of Crosswind Plume Dynamics and Profiling Tower Location for Quantifying Emissions from Moving Point Source(s)

Figure 7. Deployment of Collocated Plume Profiling Towers at Roadside Location

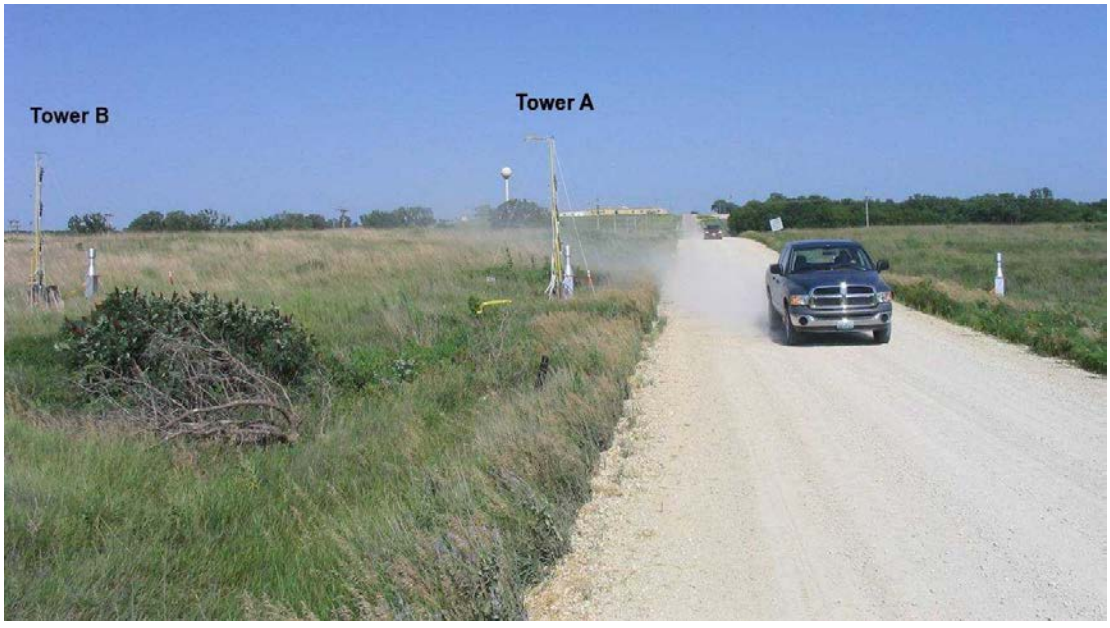

Figure 8A. Example deployment of plume profiling towers at distances of 5 m (Tower A) and 25 m (Tower B) from an unpaved road in tall grass area [7]

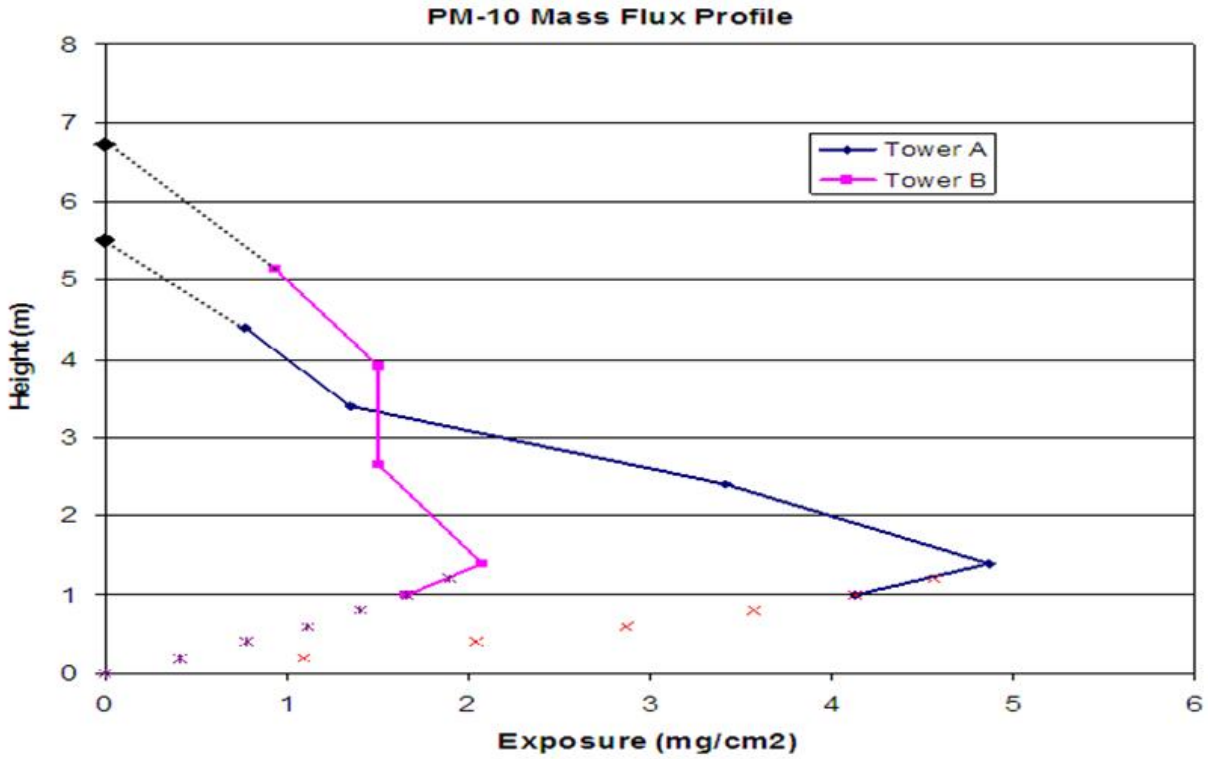

Figure 8B. Example PM-10 exposure profiles showing extrapolation points from lowest sampler to zero flux at ground level, and documenting consistent loss of PM-10 attributable to electrostatic agglomeration of dust particles [7]

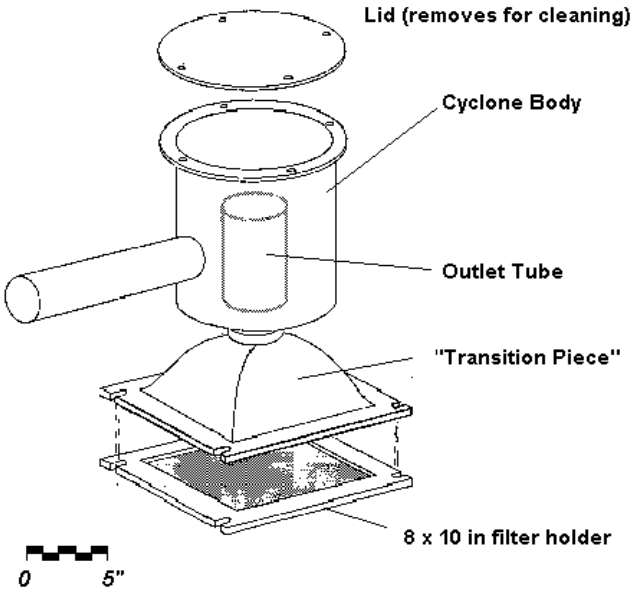

Figure 9. High-Volume Air Sampler with Cyclone Pre-Separator for Traditional Sampling of PM-10 from Dust Sources

MIDWEST RESEARCH INSTITUTE

Plume Profiling-
Fugitive Emission Testing

Run No. IMAP-6 Date 7/14/07

MRI Project No. 310700.1.003 Recorded by PMurawchick

Test Location: UTEC - East side of haul road between Shovel 18 and crusher (upper road above octopus junction)

	Sampler ID	Height	Filter Number / File Name	Start Time	Stop Time / Sampling Duration	Pressure (in. water) / Flow Readings
m Downwind	Cyclone 1 011928	9.0 m	0631110	1033	1251	16.6 @ 1035 16.5 @ 1132 16.7 @ 1216
	Cyclone 2 011931	6.5 m	0631108	1037	1251	15.8 @ 1035 15.8 @ 1132 16.0 @ 1216
	Cyclone 3 011920	4.0 m	0631100	1033	1251	16.6 @ 1035 16.7 @ 1132 16.8 @ 1216
	Cyclone 4 011929	2.0 m	0631101	1037	1251	16.9 @ 1035 17.0 @ 1132 17.1 @ 1216
Up-wind	Wedding 012096	1.9 m	0631080	1014	1302	@ @ @
m Downwind	Wedding 2098-1	1.9 m	0631079	1033	1251/	17.2 @ 1038 17.2 @ 1132 17.3 @ 1216
	DustTrak 1	4.0 m	PM_{10} Log1 File 5	1033	1254/2:21	Max: 3.83 Min: 0.001 Avg: 0.037
	DustTrak 2	4.0 m	$PM_{2.5}$ Log1 File 5	1033	1253/2:20	Max: 6.343 Min: 0.003 Avg: 0.011

Comments Hi Vol 1.2m 0631109 1033 1251 011605 2.3 @ 1038, 2.3 @ 1132, 2.2 @ 1216

Welding Blanks- 0631111, 0631105 1033 1251

Cyclone Blanks - 0631107, 0631106

7/5/2007

Figure 10A. Run Sheet Supporting Example Calculation

MIDWEST RESEARCH INSTITUTE

Page 1

Plume Profiling- Met. Data
Fugitive Emission Testing

Run No. IMAP-6 Date 7/4/07

MRI Project No. 310700.1.003 Recorded by C Cowherd

	Sampler ID	Height	Reading No.	Start Time	Stop Time / Sampling Duration	Reading (mph)	Comments
___m Downwind	Kestral 68	5.2 m	(1)	1037	1058/ 21	9.3	
			(2)	1058	1123/ 25	8.5	
			(3)	1124	1157/23	NR	
	Kestral 69	3.9 m	(1)	1037	1058/ 21	8.7	
			(2)	1058	1123 / 25	8.1	
			(3)	1124	1157/23	NR	
	Kestral ~~2.6~~ 71	2.6 m	(1)	1037	1058/21	8.7	
			(2)	1058	1123 / 25	8.0	
			(3)	1124	1157/23	NR	
	Kestral ~~1.3~~ 72	1.3 m	(1)	1037	1058/21	7.9	
			(2)	1058	1123 / 25	7.4	
			(3)	1124	1157 / 23	NR	

Observed Wind Directions:

Time	Direction	Comments

Observed Cloud Coverage:

Time	Observation

Comments NR = No Reading

7/6/2007

Figure 10B. Run Sheet Supporting Example Calculation

MIDWEST RESEARCH INSTITUTE

Page 2

Plume Profiling- Met. Data
Fugitive Emission Testing

Run No. INAP-6 Date 7/14/07

MRI Project No. 310700.1.003 Recorded by C Cowherd

	Sampler ID	Height	Reading No.	Start Time	Stop Time / Sampling Duration	Reading (mph)	Comments
___m Downwind	Kestral 68	5.2 m	(1)	1158	1223 / 25	7.6	
			(2)	1124	1254 / 30	7.3	
			(3)				
	Kestral 69	3.9 m	(1)	1158	1223 / 25	7.1	
			(2)	1124	1254 / 30	6.9	
			(3)				
	Kestral 71	2.6 m	(1)	1158	1223 / 25	7.0	
			(2)	1124	1254 / 30	6.7	
			(3)				
	Kestral 72	1.3 m	(1)	1158	1123 / 25	6.3	
			(2)	1124	1254 / 30	6.1	
			(3)				

Observed Wind Directions:

Time	Direction	Comments

Observed Cloud Coverage:

Time	Observation

Comments_____

7/6/2007

Figure 10C. Run Sheet Supporting Example Calculation

Appendix A

2002 Overview Document Written in Support for OTM -32

Overview for Measurements of Particulate Matter from Open Sources

June 2013

Overview for Measurement of Particulate Matter from Open Sources

U.S. Environmental Protection Agency

Office of Air and Radiation

Research Triangle Park, NC

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Acknowledgment

This document was prepared for the U.S. Environmental Protection Agency by Dr. Chatten Cowherd and Mr. John Hosenfeld of Midwest Research Institute (MRI) under Contract No. 68-D-027, Work Assignment No.4 for the contract year beginning October 1, 1999. Under this work assignment, MRI developed an open source (OS) emission test method. This document was prepared to assist the user in the understanding and application of the OS test method.

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Section 1 Introduction

Open source (OS) emissions contribute substantially to nationwide burdens of airborne particulate matter (PM), including PM-10 and PM-2.5. Examples of OS emissions are fugitive dust generated by (a) traffic on unpaved surfaces and (b) truck loading of excavated soil. The generic categories of open dust sources are listed in Table 1. OS emissions are defined as emissions that enter the atmosphere without first passing through a confined flow stream such as a duct or stack.

Table 1. Generic Categories of Open Dust Sources

1. Unpaved Travel Surfaces
   - Roads
   - Parking lots and staging areas
   - Storage piles
2. Paved Travel Surfaces
   - Streets and highways
   - Parking lots and staging areas
3. Exposed Areas (wind erosion)
   - Storage piles
   - Bare ground areas
4. Materials Handling
   - Batch drop (dumping)
   - Continuous drop (conveyor transfer, stacking)
   - Pushing (dozing, grading, scraping)
   - Tilling

In spite of the importance of open sources, no standard methods for emission testing of these sources have been published. The use of stack testing methods is seldom possible because of the impracticality of enclosing the source or otherwise capturing the entire emissions plume.

The challenges of open dust source emission quantification are further complicated by the diffuse and variable nature of the emissions, in comparison with ducted emissions. In addition, fugitive dust emissions contain a wide range of particle sizes, including particles which deposit immediately adjacent to the source.

In considering method applicability, it is important to note that OS categories entail a variety of physical configurations: line sources, moving point sources and fixed sources (volume or area). The most common example of a moving point source is vehicle travel on a roadway. Because of the restricted dimensions of fixed area or volume sources (such as truck loading of excavated soil), they are often treated as (virtual) point sources.

In the past, emission factor development for these sources has utilized two basic sampling approaches: exposure (plume) profiling, and upwind/downwind sampling (reverse dispersion modeling). The upwind/downwind method [1] relies on the application of a steady-state dispersion model to back calculate an emission rate from particulate concentrations measured at ground level. Conversely, the exposure profiling technique [2] is based on the same mass-flux plume-profiling concept that is used in conventional stack testing. The passage of airborne pollutant immediately downwind of the source is measured directly by means of a simultaneous multi- point sampling over the cross section of the open dust source plume.

The upwind-downwind method involves the measurement of airborne particulate concentrations both upwind and downwind of the pollutant source. The number of upwind sampling instruments depends on the degree of isolation of the source operation of concern (i.e., the absence of interference from other sources upwind). Increasing the number of downwind instruments improves the reliability in determining the emission rate by providing better plume definition. In order to reasonably define the plume emanating from a point source, instruments need to be located at a minimum of two downwind distances and three crosswind distances. The same sampling requirements pertain to line sources except that measurement need not be made at multiple crosswind distances.

Net downwind (i.e., downwind minus upwind) concentrations are used as input to atmospheric dispersion equations (normally of the Gaussian type) to back-calculate the particulate emission rate (i.e., source strength) required to generate the pollutant concentrations measured. Emission factors are obtained by dividing the calculated emission rate by the source extent. A number of meteorological parameters must be concurrently recorded for input to this dispersion equation. As a minimum, the on-site wind direction and speed must be recorded.

While the upwind-downwind method is applicable to virtually all OS emission categories, it has significant limitations with regard to the development of source-specific emission factors. The major limitations are as follows:

1. In attempting to quantify a large area source, overlapping plumes from upwind (background) sources may preclude the determination of the specific contribution of the area source.

2. Because of the impracticality of adjusting the locations of the sampling array for shifts in wind direction during sampling, it may be questionable to assume that the plume position is fixed in the application of the dispersion model.

3. The usual assumption that an area source is uniformly emitting may not allow for a realistic representation of spatial variation in source activity.

4. The typical use of an un-calibrated atmospheric dispersion model introduces the possibility of substantial error. According to Turner [4], the error in the calculated emission rate can be as much as a factor of three, even if the stringent

requirement of unobstructed dispersion from a simplified source configuration is met (e.g., constant emission rate from a single point).

As an alternative to conventional upwind-downwind sampling, the exposure-profiling technique utilizes the isokinetic profiling concept, which is the basis for conventional ducted source testing (EPA Method 5), except that, in the case of exposure-profiling, the ambient wind directs the plume to the sampling array. The passage of airborne particulate matter immediately downwind of the source is measured directly by means of a simultaneous, multipoint sampling of particulate concentration and wind velocity over the effective cross section of the fugitive emissions plume. Unlike the conventional upwind-downwind method, exposure profiling uses a mass-balance calibration scheme rather than requiring an indirect calculation through the application of a generalized atmospheric dispersion model.

Within certain constraints of acceptable source configuration, exposure profiling has been regarded as the preferred method for characterizing OS emissions. As such, it has been used in developing most of the fugitive dust emission factor equations currently contained in EPA's emission factor handbook (AP-42) [3]. 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 AP-42 are typically based on this approach. The method bears the closest resemblance to Method 5 stack emission testing and quantifies the full spectrum of particle size. As such, exposure profiling is the basis for the OS test method described in this document.

This document is provided as an overview document to accompany the exposure profiling method and includes (a) a summary of the method, its applicability on selected implementation aspects, (b) example calculations, and (c) a discussion of the reliability of the method. Appendix A contains examples of tests performed and data obtained using the exposure profiling method. Appendix B presents the OS emission test method based on exposure profiling.

Section 2 Method Overview

The exposure profiling technique was developed in 1973[2] for OS testing of fugitive dust emissions. Over the past 27 years, the profiling concept has been applied to numerous types of open dust sources in a variety of urban, industrial, and rural settings. Sources tested have included vehicular traffic on paved and unpaved surfaces, agricultural operations (such as harvesting, plowing, and land planing), batch and continuous material handling, and slag quenching. Industries in which testing has been conducted include iron and steel, construction, surface coal mining, agriculture, asphalt and cement batching, nonferrous smelting, sand and gravel, and taconite mining. Evaluations of controlled and uncontrolled sources have been performed.

Although each field site presents the possibility of complications in source testing, the fundamental basis of the profiling concept (that of horizontal mass flux measurements within the plume) has remained unchanged. However, various aspects of the method–such as techniques for isokinetic sampling, particle sizing and the like– have been refined in order to increase the accuracy of the method as the available measurement technology has advanced and as more experience has been acquired. Most of the early history of the modifications to the exposure profiling method was prepared for a Southern Research Institute study titled, "Critical Review of Open Source Particulate Emission Measurements."[5]

2.1 Summary of Method

For the measurement of non-buoyant fugitive emissions using exposure profiling, sampling heads are distributed over a vertical network positioned just downwind (usually about 5 m) from the source. Particulate sampling heads should be symmetrically distributed over the concentrated portion of the plume containing at least 80 percent of the total mass flux. A vertical line grid of at least three samplers is sufficient for the measurement of emissions from line or moving point sources, while a two-dimensional array of at least six samplers is required for quantification of fixed (virtual) point sources of emissions. At least one upwind sampler must be operated to measure the background concentration, and on-site wind speed must be measured concurrently.

The particulate emission rate is obtained by a spatial integration of the distributed measurements of exposure (accumulated mass flux), which is the product of mass concentration and wind speed:

$$R = \int_A C(h,w)\, u(h,w)\, dh\, dw \qquad (1)$$

Where:

R = emission rate, g/s
C = net particulate concentration, g/m^3
u = wind speed, m/s
h = vertical distance coordinate, m
w = lateral distance coordinate, m
A = effective cross-sectional area of plume, m^2

Usually a numerical integration scheme is used to calculate the emission rate.

Data quality objectives should be incorporated into a test plan in order to provide the specific parameters for testing and ensure a greater accuracy of the results obtained. The objectives should specify the desired accuracy, precision, and completeness of each measurement component of the method.

2.2 Applicability of Method

Except for large area sources (see size criteria below); virtually all OS categories can be characterized by the exposure profiling method. The necessary requirements for using the method are:

1. Sampling equipment can be placed sufficiently close to the source such that the plume core can be characterized by a ground based sampling array.
2. The contribution of the emission source can be isolated from upwind (background) levels of the pollutant
3. The horizontal wind advection of the emitted pollutant is sufficient to provide for consistent transport across the sampling array, but not so great as to increase background levels by resuspending exposed soils or other aggregate materials.

Figure 1 diagrams the decision process for determining whether exposure profiling is applicable and what kind of a sampling array is needed. Steps in this process are discussed in the subsections below.

2.3 Sampling Site Selection

If the sampling location is not already determined, the following criteria should be considered when deciding on a location that is suitable for application of the exposure profiling method:

1. There should be at least 10 m of flat, open terrain upwind and downwind of the source.

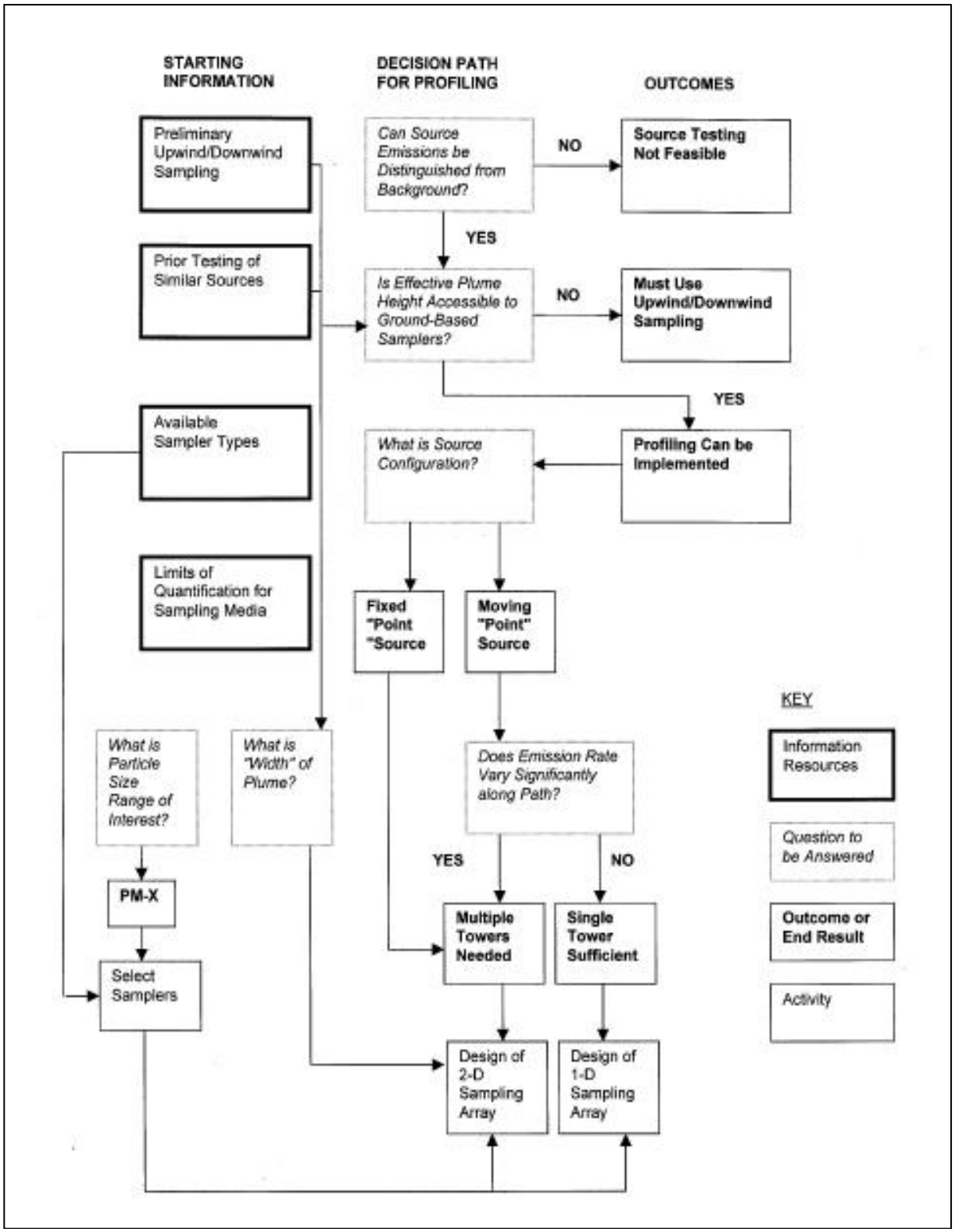

Figure 1. Decision Process for Profiling Applicability and Design

2. The height of the nearest downwind obstruction to wind flow should be less than the distance from the source to the obstruction.
3. The height of the nearest upwind obstruction to wind flow should be less than one-third the distance from the source to the obstruction.
4. A line drawn perpendicular to the lateral axis of the source should form an angle of 0 to 45 degrees with the mean daytime prevailing wind direction.
5. At the time of year when testing is anticipated, the mean daytime wind speed should be greater than 1.3 m/s (3 mph).
6. The source should have an adequate amount of emission-generating activity during the testing period.

There are many other factors that can be considered when selecting a location, mostly related to source representativeness and accessibility for emission testing.

2.4 Sampler Positioning and Placement

The exposure profiling method requires placement of samplers just downwind of the source. The downwind distance should be as small as possible such that (1) source turbulence (wind fluctuation) is not significant at the measurement plane and (2) plume development is sufficient so that a single plume core is observed across the lateral dimension of the plume.

The positioning of the samplers across a vertical measurement plane downwind of the source requires preliminary knowledge of the plume extent. The objective of the sampler positioning is to capture at least 80 percent of the dust plume mass flux in the downwind direction and to remove the contribution of sources in the upwind direction. If there are obstructions between the upwind sampling location and the downwind location, the accuracy of the measurements is decreased.

For fixed sources (i.e., those requiring a two-dimensional array of samplers):

1. The 2-dimensional array should ideally consist of 9 sampling points on a 3 (height) x 3 (crosswind) grid (see Figure 2). However, as a practical matter, channeling of the plume or limited physical space for positioning sampling equipment may necessitate fewer than 9 samplers being used.

2. The overall width W of the sampling array should be based on field observations of the plume. As a rule of thumb, W should be approximately 75 percent of the observed visible plume width (at the downwind distance D to the measurement plane).

3. The center vertical array of samplers should be positioned as close as possible to the center of the plume. For example, if dusty material is being transferred to a

hopper as illustrated in Figure 2, the center of the sampling grid should be directly downwind from the middle of the hopper.

4. Similarly, the overall height H of the sampling array should also be based on field observation of the plume. It should span approximately 75 percent of the observed plume height.

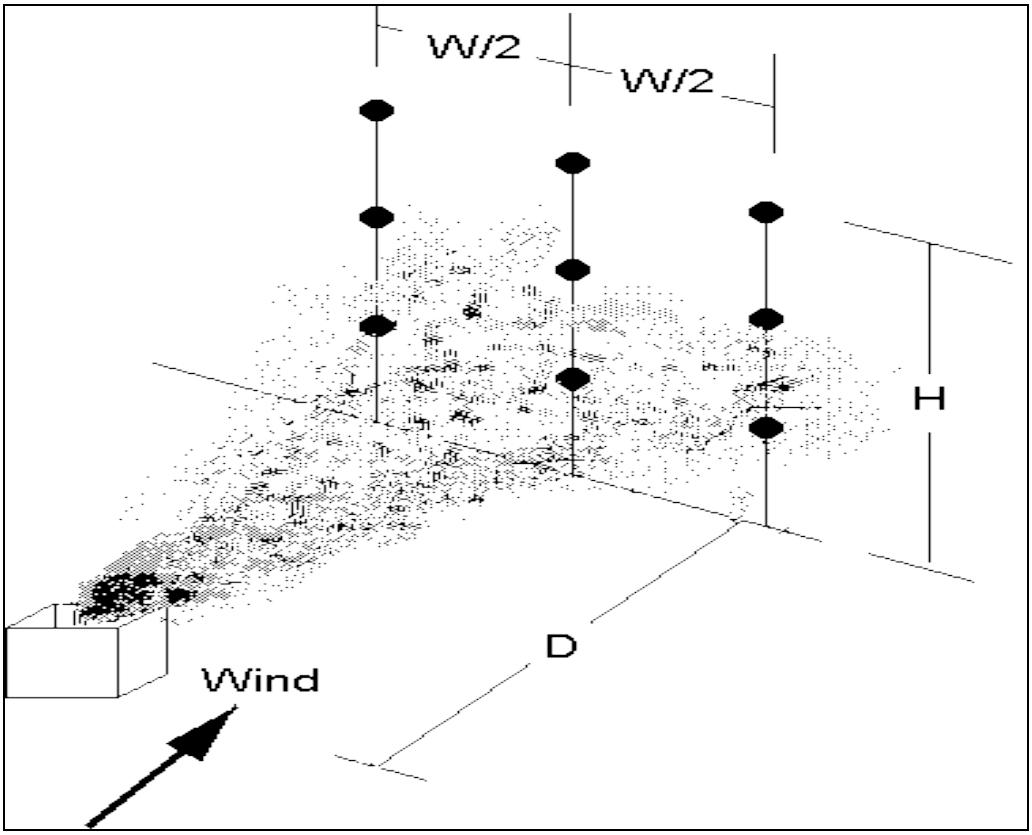

Figure 2. Sampler Array for Fixed Source

For moving point sources:

1. The vertical sampling array should contain a minimum of 3 sampling heights. In general, 4 or 5 heights adequately characterize most plumes.

2. Samplers are typically uniformly spaced throughout the vertical array, although this is not necessary.

3. The array should be positioned at a distance of 2 to 10 meters from the downwind edge of the road (or other travel path). Beyond any practical consideration of

surface grade along a road right-of-way, the goal is to position the array far enough away to avoid traffic-generated turbulence but still allow a ground-based array to characterize the dust plume.

4. The plume dimensions depend on factors such as vehicle travel speed, wind speeds, and the width of the road. Table 2 presents suggested sampler heights for different combinations of these parameters. The values in Table 2 are based on a 5-m downwind distance from the road edge to the measurement plane. The recommended heights could be scaled up or down depending on whether the sampler array is more or less, respectively, than 5 m downwind from the road edge.

Table 2. Recommended Sampler Heights for Roadway Sources

Mean daytime wind speed	Average vehicle speed	Average vehicle weight	Width of road	Recommended sampling heights (m)
< 7 mph	< 35 mph	< 75 tons	< 75 ft	1.5,3,4.5,6
≥ 7 mph				1,2,3.5,5
< 7 mph	≥ 35 mph			2,3.5,5,7
≥ 7 mph				1.5,3,4.5,6
< 7 mph	< 35 mph	≥ 75 tons		2,3.5,5,7
≥ 7 mph				1.5,3,4.5,6
< 7 mph	≥ 35 mph			2,3.5,5,7
≥ 7 mph				2,3.5,5,7
< 7 mph	< 35 mph	< 75 tons	≥ 75 ft	2,3.5,5,7
≥ 7 mph				1.5,3,4.5,6
< 7 mph	≥ 35 mph			2,3.5,5,7
≥ 7 mph				1.5,3,4.5,6
< 7 mph	< 35 mph	≥ 75 tons		2,3.5,5,7
≥ 7 mph				1.5,3,4.5,6
< 7 mph	≥ 35 mph			2,3.5,5,7
≥ 7 mph				2,3.5,5,7

2.5 Test Duration

The duration of an exposure profiling test depends upon several factors, including the following:

1. First, because many open sources consist of discrete events (e.g., dumps of material into/out of trucks, individual vehicle passes over a road) that are cyclic in

nature, the test should be long enough to provide a composite representation of emissions averaged over several cycles.

2. For all open sources, one must collect adequate sample mass at each sampling point in the plume to accurately characterize the plume concentration distribution at the measurement plane.

3. However, because the mass flux varies throughout the plume, one must balance the need for adequate sample mass at the edge of the plume with the risk of overloading samplers near the center of the plume.

An uncontrolled OS will require less source activity to collect adequate mass than would the same source after control application. Furthermore, because many open source controls are highly transient in nature (e.g., roadway watering), tests at the start of the control cycle will require more time to complete than do tests later in the cycle. The following serve as general rules of thumb:

1. For an uncontrolled unpaved road, 25 to 50 vehicle passes are usually sufficient to collect adequate sample mass on a high-volume device. For a highly controlled unpaved road (e.g., within first half hour of watering or within first week after chemical dust suppressant added), 200 to 300 vehicle passes may be necessary.

2. Paved roads with no visible signs of surface loading usually require at least 1000 vehicles passes to collect adequate sample mass on the filter with the lightest loading.

3. For batch operations (such as loading or unloading trucks), testing should span a minimum of 3 cycles. Samplers should be started at least one minute before the first load begins and should run for at least two minutes beyond the end of the last load. For extremely dusty operations, exercise care to not overload samplers.

4. For continuous operations (such as belt-to-belt transfers), tests should be at least 5 minutes in duration.

Determination of whether or not adequate sample mass has been collected can be judged as follows:

1. For samplers with only one collection surface (e.g., a high-volume sample on an 8 in by 10 in filter), the blank-corrected net catch should be at least 3 times the standard deviation of the applicable blank values.

2. For samplers that use multiple collection surfaces (e.g., cascade impactor substrates and backup filter), all blank-corrected net catches should be at least as great as the standard deviation of the applicable blank values.

2.6 Air Sampler Design

The establishment of PM-10 as the basis for a size-specific PM NAAQSs in 1987 had important implications for exposure profiling. In practical terms, this meant that one could restrict attention to only the mass of PM-10 emitted from the source. However, direct application of reference methods for ambient PM-10 monitoring was not necessarily practical because of the very high transient concentrations (such as the plume from an individual vehicle pass over an unpaved road) presented by some open sources. These peak concentrations are often several orders of magnitude higher than the maximum concentrations used in certifying the reference method. To address these concerns, a high-volume cyclone (Figure 3) was adapted to serve as the primary air sampling device in exposure profiling. The cyclone exhibits an effective 50 percent cutoff diameter (D_{50}) of approximately 10 umA 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.

2.7 Isokinetic Sampling

Isokinetic sampling is required for a representative collection of particles larger than about 10 µm in aerodynamic diameter. Biases may result from differences between the sampling intake direction and the direction of the wind. Because of natural fluctuations in wind speed and direction, some anisokinetic sampling effects will always be encountered. In estimating the magnitudes of anisokinetic sampling errors, an aerodynamic particle diameter of about 12 µm is assumed because this approximates the mass median diameter of a high-volume sampler catch near a fugitive dust source.

To hold sampling bias to an acceptable minimum, the angle α between the mean wind direction and the direction of the sampling axis should not exceed 30°. For $\alpha = 30^\circ$, the sampling error is about 10 percent for particles of 12 µm aerodynamic diameter. [7] The restriction on horizontal wind direction fluctuation (i.e., standard deviation σ_α less than 22.5°) excludes sampling under Stability Class A, which is characterized by large horizontal wind meander and low wind speeds. [4]

In the wind speed range of 3 to 20 mph, the sampling rate can be readily adjusted and matched to the corresponding mean wind speed. An isokinetic flow ratio (IFR = ratio of

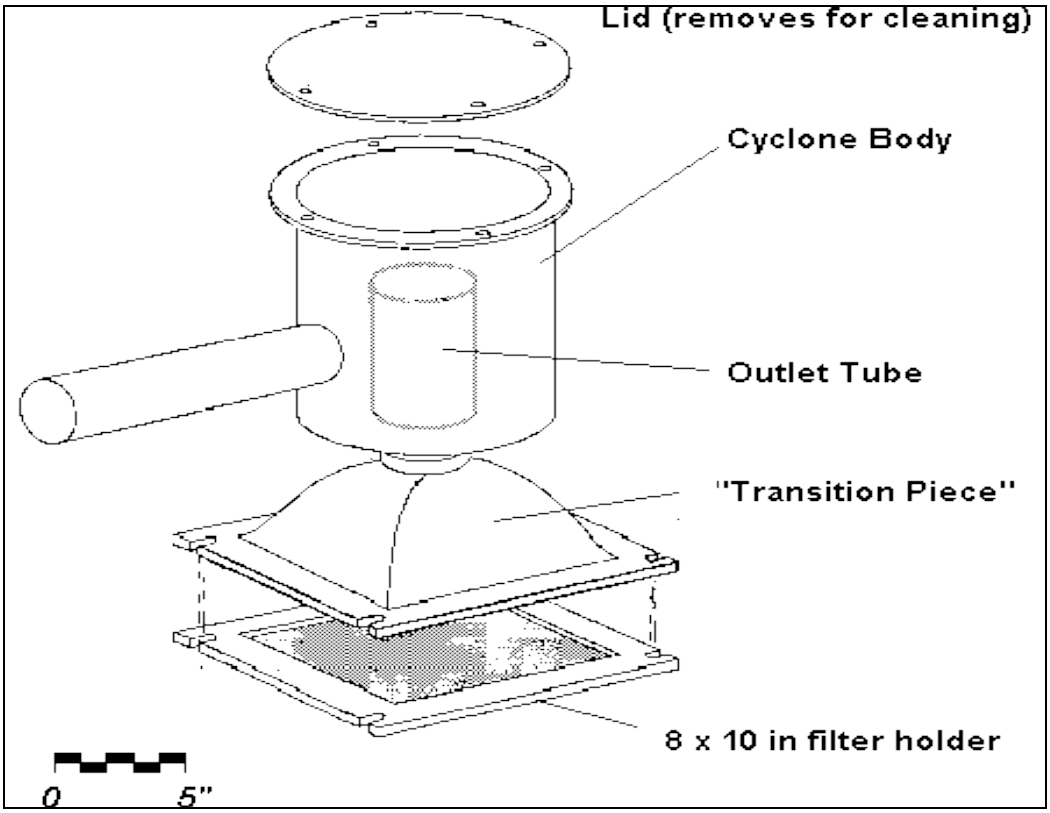

Figure 3. High-Volume Sampler with Cyclone Preseparator

sampling intake speed to approach wind speed) of less than 0.8 or greater than 1.2 may lead to large concentration errors. For particles of 12 µm diameter, it has been shown that the sampling error is less than about 5 percent for an IFR between 0.8 and 1.2.[7] If these wind conditions are met, background concentrations usually amount to less than 5 percent of downwind concentrations (for uncontrolled open dust sources).

The technique for correcting either concentrations or exposures for nonisokinesis is as follows:

Table 3. Exposure vs. Factors

	Multiplicative Factor	
Variable	d < 10 µmA	d > 50 µmA
Exposures	1/(IFR)	1
Concentrations	1	IFR

where d is the particle diameter and IFR is the isokinetic flow ratio. For particulate containing small, intermediate and large particles, exposures were multiplied by (1+r/IFR)/(r+1) and concentrations by (r+IFR)/(r+1), where r = (%<5)/(%>50).

2.8 Particle Size Profiling

Since 1980, particle size profiling has been performed in most exposure profiling field tests. The primary sizing instrument has been a cyclone/cascade impactor. Simultaneous cascade impactor measurements of airborne particle-size distribution with and without a cyclone preseparator indicate that the cyclone preseparator is effective in reducing fine particle measurement bias [8]. A log normal particle mass-size distribution is assumed along with a linear interpolation to obtain the needed mass fractions. However, as noted in the introduction to this section, the 1987 promulgation of PM-10 as the basis for the PM NAAQS reduced the emphasis on characterizing the entire particle size distribution of OS dust emissions.

Additional size-selective particle sizing instruments have been used based on test objectives and newly available devices. Two more recent studies with special particle sizing objectives are of particular interest. A 2-year EPA field study[9] compared PM-10 and PM-2.5 results from dichotomous samplers deployed alongside high-volume cascade impactors. This study confirmed suspicions about interference from large particles and high peak concentrations immediately downwind of an uncontrolled unpaved road. In addition, an ongoing EPA study of mud/dirt carryout from construction sites onto public paved roads [10] is experimenting with use of PM-2.5 cyclones used for ambient air monitoring. To avoid interference by large particles, intakes to the PM-2.5 devices are being positioned below the PM-10 cyclones and sample a small portion of the total flow through the high-volume unit.

Particle size profiling is necessary for the exposure profiling method in cases when the sampler design does not measure the desired particle size fraction directly. Distributed samplers with size-selective inlets or with preseparator and multistage size classifiers may be used for this purpose. Profiles of particle size distribution data can be coupled with TP profiles to develop emission factors based on particle size.

2.9 Exposure Integration

For cases where samplers are equally spaced in the measurement plane, a composite Simpson's rule can be used. Note that the exposure must vanish at ground level and consequently integration is started at the point $(0,E_1)$, where E_1 is the (extrapolated, if necessary) value of exposure at a height of 1 m. This is done to account for the fact that below 1.0 m the TP exposure reaches its maximum and then sharply decays to zero at ground level.

Because Simpson's rule requires an odd number of equally spaced data points, its use placed restrictions on number and spacing for sampler inlets. Nevertheless, selection of the numerical integration scheme is found to have negligible effect on resulting emission factors. At present, the trapezoidal rule is recommended for data reduction, because there are no restrictions on sampler spacing.

Since the promulgation of the PM-10 standards, emission factors have typically been expressed in terms of mass of PM-10 emitted per unit of source activity, such as vehicle

miles traveled (for moving point sources) or mass of material transferred (for fixed point sources). To the extent warranted, emission factors from various operations can be combined to provide greater ease for persons using those factors in emission inventories. For example, the 1998 EMC study of construction-related emissions[11] discusses how scraper loading, travel, and unloading factors can be combined into a single factor based on operating cycles or amount of earth moved.

2.10 Evaluation of Control Measures

Much of the current application of OS emission testing is directed to control performance assessment. Field evaluation of control efficiency requires that the study design include not only adequate emission measurement techniques but also a proven "control application plan." In the past, two major types of plans have been used:

- Type 1: Controlled and uncontrolled emission measurements are obtained simultaneously.
- Type 2: Uncontrolled tests are performed initially, followed by controlled tests.

In order to ensure comparability between the operating characteristics of the controlled and uncontrolled sources, many evaluations are forced to employ Type-2 plans. An example would be a wet suppression system used on a primary crusher. One important exception to this, however, is unpaved-road dust control. In this instance, testing under a Type-1 plan is conducted on two or more contiguous road segments. One segment is left untreated and the others are treated with separate dust suppressants.

Under a Type-2 plan for testing unpaved-road dust controls, uncontrolled testing is initially performed on one or more road segments, generally under worst-case (dry) conditions. Each segment is then treated with a different chemical; no segment is left untreated as a reference. A normalization of emissions may be required to allow for differences in vehicle characteristics during the uncontrolled and controlled tests because they do not occur simultaneously. For example, a change in the mix of vehicle types should not be interpreted mistakenly as part of the efficiency of the control measure being tested.

Section 3 Example Calculations

This section presents example calculations for application of the OS test method to a moving point source and a fixed source.

3.1 Moving Point Source

This example calculation is based on a test of scraper loading emissions. The test duration is 45 minutes. The average temperature is 80°F and the barometric pressure is 28.47 in Hg. During the test there were 33 scraper passes as well as 67 dozer passes. The sampling configuration for the testing consisted of PM-10 samplers located at 3 heights (2 m, 4.5 m, and 7 m) and at a distance of 5 m downwind from the scraper path. Two additional PM-10 samplers were located 15 m upwind of the scraper path at heights of 2 m and 4.5 m.

3.1.1 Calculation of PM-10 Concentrations at Sampling Locations

The equation used to calculate the concentration of particulate matter is:

$$C = m/Qt \quad (2)$$

Where: m = net mass collected on the filter or substrate (mass)
Q = volumetric flow rate of the sampler (volume/time)
t = duration of sampling (time)

Table 4. Sampler Distance vs. Concentration

	m		Q		t	C
Sampler Height and Location	Blank-corrected net filter weight g	mg	Flow Rate acfm	m^3/min	Duration of sampling (min)	PM-10 Concentration (mg/m^3)
2 m downwind	5.86	5860	41.45	1.17	45	111
4.5 m downwind	4.46	4460	41.15	1.17	45	85
7 m downwind	3.36	3360	41.60	1.18	45	63

3.1.2 Correction of Measured PM-10 Concentration for Upwind/Background Concentration

The upwind PM-10 concentration is calculated using Equation 2. As measured in this example, the upwind concentrations at the 2-m and 4.5-m heights are 65 and 50 mg/m^3, respectively. Thus, the average upwind PM-10 concentration is 58 mg/m^3, and the net plume concentration can be determined, as shown below.

Table 5. Sampler Height vs. Concentration

Sampler Height and Location	PM-10 Concentration (mg/m^3)	Average Upwind PM-10 Concentration (mg/m^3)	Net PM-10 Concentration (mg/m^3)
2 m downwind	111	58	53
4.5 m downwind	85	58	27
7 m downwind	63	58	5

3.1.3 Calculation of Net PM-10 Exposure

Exposure is calculated using the equation:

$$E = (C-C_b)Ut \qquad (3)$$

where: C = particulate concentration (mass/volume)

C_b = background concentration (mass/volume)

U = wind speed (length/time)

t = duration of sampling (time)

Wind speed measurements are recorded and averaged. The average is then interpolated using the logarithmic profile to the sampling heights. The wind velocity was measured at a 4.5 m height, and the mean wind speed for the sampling period was 10.0 mph.

Table 6. Sampler Location vs. Concentration

Sampler Height and Location	C-C_b Net PM-10 Concentration mg/m^3	C-C_b Net PM-10 Concentration mg/cm^3	U Mean Wind Speed mph	U Mean Wind Speed cm/sec	t Duration of Sampling min	t Duration of Sampling sec	E Net PM-10 Exposure (mg/cm^2)
2 m downwind	53	5.3×10^{-8}	8.7	389	45	2700	0.0557
4.5 m downwind	27	2.7×10^{-8}	10.0	447	45	2700	0.0326
7 m downwind	5	0.5×10^{-8}	10.7	478	45	2700	0.0065

3.1.4 Integration of Net Exposure over Plume Height

A numerical integration scheme is used to determine the integrated exposure over the effective cross-section of the plume. This represents the total passage of the pollutant mass during the test. The equation used to calculate the integrated exposure for a moving point source is:

$$A = \int_0^H E(h)\ dh \qquad (4)$$

where: H = height (length)

E(h) = particulate exposure (mass/area) at height h

Extrapolation of the 4.5 and 7 m net PM-10 exposures to a value of zero leads to an estimated plume height of H = 7.57 m as seen in the figure below. The exposure values are plotted (Figure 4), and the trapezoidal rule is applied to obtain the integrated exposure value.

The application of the trapezoidal rule produces:

A = 0.0649 + 0.0603 + 0.110 + 0.0489 + 0.0019
A = 0.286 m-mg/cm^2
A = 10.1 lb/mi

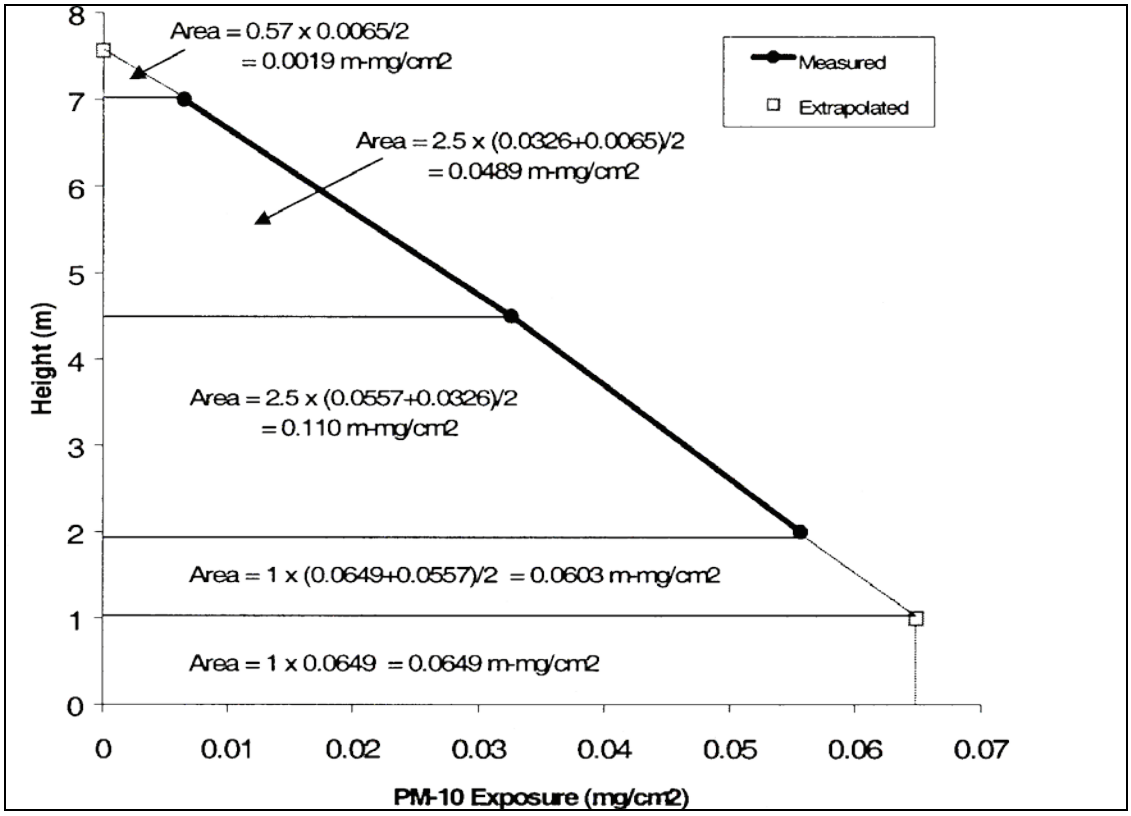

Figure 4. Exposure Profile for Moving Point Source

3.1.5 Determination of an Emission Factor

The emission factor is found by dividing the integrated exposure by the measure of the source activity.

e = (10.1 lb/mi) / 33 vehicles

e = 0.31 lb/veh-mi

3.2 Fixed Source

This example calculation is based on data for the 2-dimensional sampling array shown in Figure 5. Six PM-10 samplers are arranged in 2 horizontal (crosswind) rows at heights of 1.4 and 3.4 m. The vertical arrays are positioned at 2.4-m spacing.

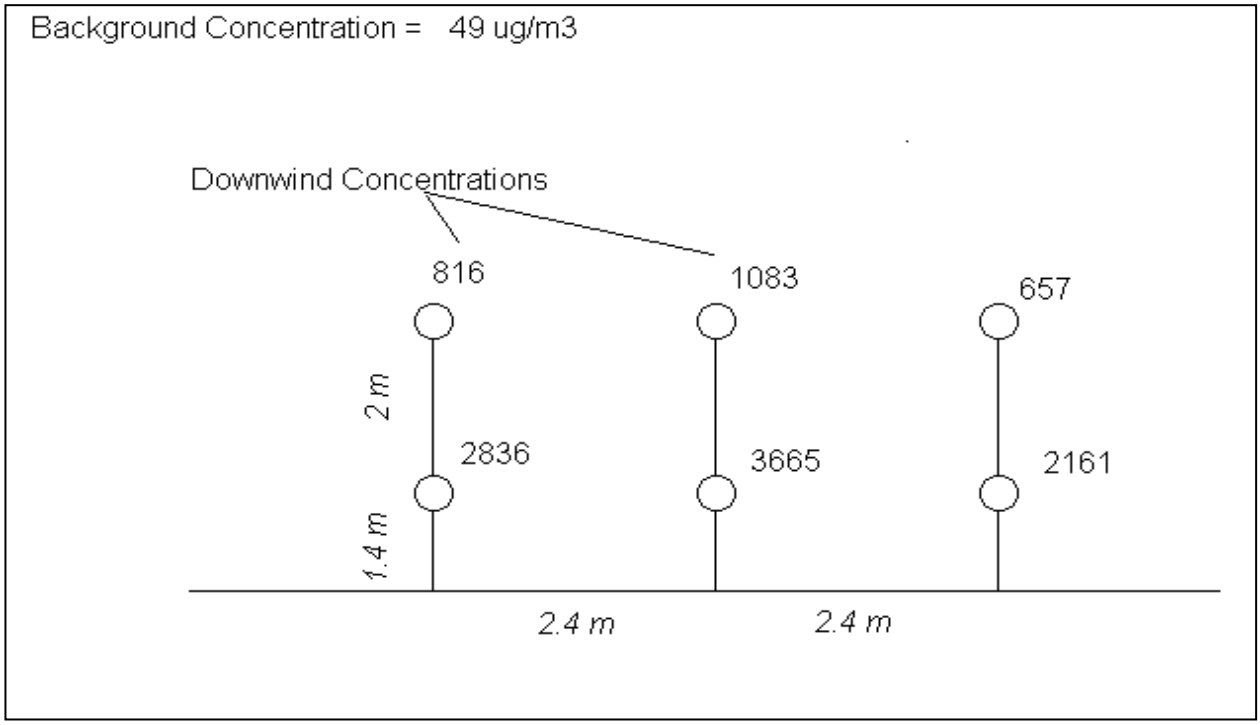

Figure 5. Example 2-Dimensional Sampling Data

3.2.1 Calculation of PM-10 Concentrations at Sampling Locations

Figure 5 shows the downwind concentrations measured at each sampling point, as well as the upwind (background) concentration of 49 :g/m^3. When the background value is subtracted from the downwind values, the net concentrations in Table 3 are obtained.

Table 7. Net PM-10 Concentrations (µg/m^3)

	Crosswind Location		
Height (m)	– 2.4 m	0 m	2.4 m
3.4	767	1034	608
1.4	2787	3616	2112

3.2.2 Calculation of Net PM-10 Exposure

The mean measured wind speed U during the test was determined as 2.73 and 3.35 m/s at the 1.4-m and 3.4-m heights, respectively. Calculation of net particulate flux F (mg/cm^2-s) is given by

$$F = 10^{-7} (C_{net}) U \quad (5)$$

The total exposure is found by multiplying the flux by the duration (time) of the test. Based on a 129 minute test, the exposures (mg/cm^2) in Table 4 are found:

Table 8. Net PM-10 Exposures (mg/cm^2)

	Crosswind Location		
Height (m)	– 2.4 m	0 m	2.4 m
3.4	1.99	2.68	1.58
1.4	5.89	7.64	4.46

For example, the first entry is found by

$$10^{-7} \times 767\ \mu g/m^3 \times 129\ min \times 60\ s/min \times 3.35\ m/s = 1.99\ mg/cm^2$$

3.2.3 Integration of Net Exposure

Figure 6 shows the exposure values at the 1.4- and 3.4-m heights plotted against crosswind direction. The figure also shows how the values are extrapolated to a value of zero to determine the left-hand and right-hand extents of the plume. The exposures are integrated by finding the area under the triangles formed.

Figure 7 plots the crosswind exposures found from Figure 6 against height. The final step of the integration process involves determining the area of the triangle in Figure 7. As shown, the integration of particulate exposure results in a total mass of 4020 g or 4.02 kg.

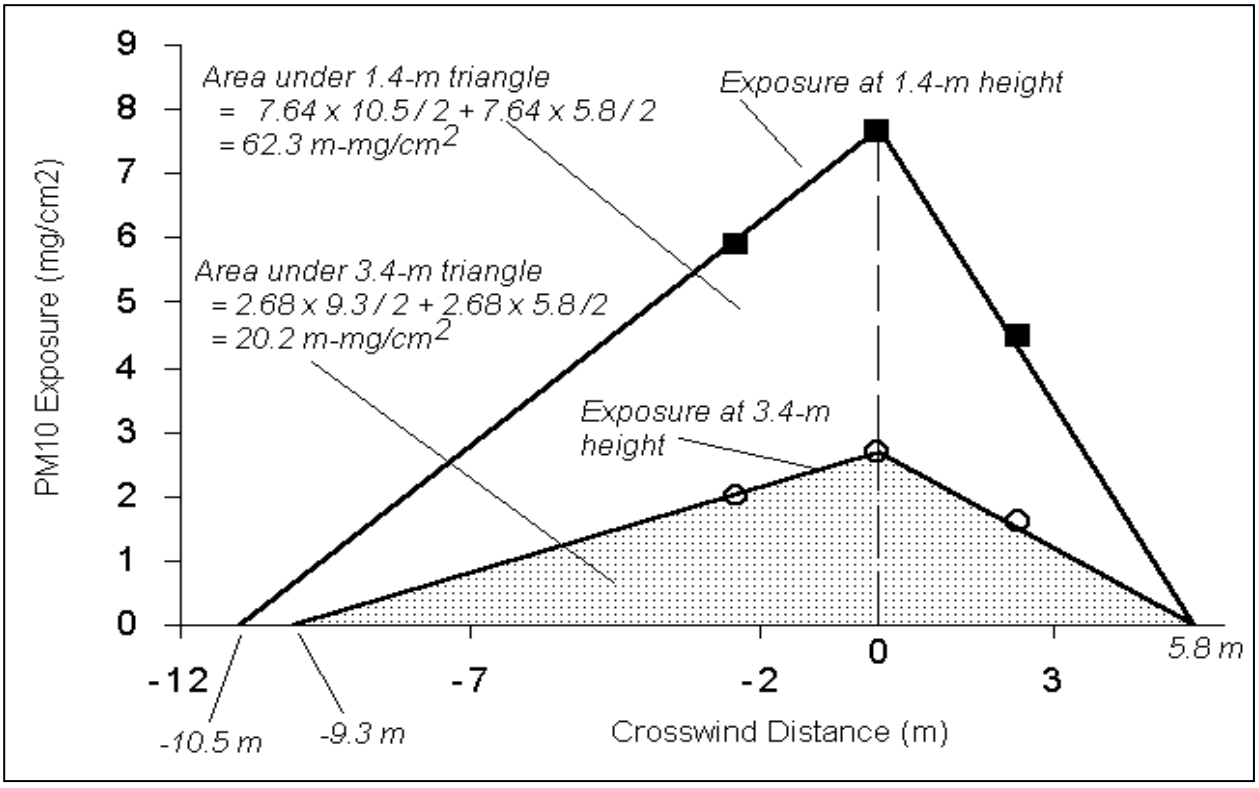

Figure 6. Crosswind Integration of Exposure Values

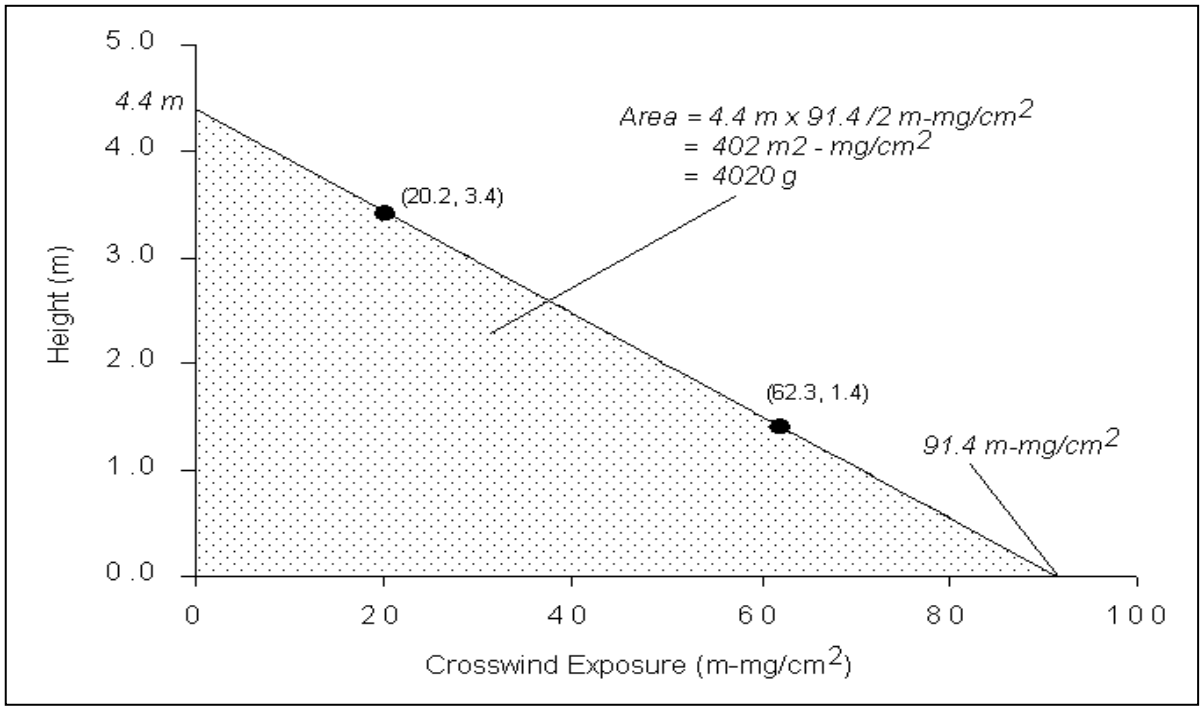

Figure 7. Vertical Integration of the Crosswind Exposure Values

3.2.4 Determination of Emission Factor

The emission factor is found by dividing the total mass calculated in the above steps by the total mass of material transferred during the test. Assuming that a total of 2000 Mg was transferred, the emission factor would be found as

$$4.02 \text{ kg} / 2000 \text{ Mg} = 0.00201 \text{ kg/Mg}$$

Section 4 Reliability of the Method

Many quality control measures and objectives can be instituted into a testing program to increase the accuracy of the results obtained. Since there is usually not a method to directly assess the accuracy of OS emission factors, the approach taken is to set goals for the component measurements that are combined to develop the emission factor.

The inherent reliability of the exposure profiling method is tied to the mass balance calculation scheme that is conceptually identical to the scheme used for Method 5. The challenge in dealing with fluctuating emissions is met by simultaneous sampling at all predetermined locations within the plume. Any uncertainties are associated with potential bias or imprecision in the measurement of the two fundamental variables used in calculating PM mass flux: time-averaged PM concentration and time-averaged wind speed.

If reference method PM-10 ambient sampling equipment is used, it is important to establish whether bias may result at peak plume concentrations. For example, such instantaneous PM-10 concentrations may easily exceed 1,000 $\mu g/m^3$ in the case of uncontrolled sources such as vehicle travel on unpaved roads. Any bias in such measurements would likely be related to poor performance of the size-selective inlet under high concentration conditions. These issues were addressed in a recent field study to determine the PM-10 and PM-2.5 components of fugitive dust emissions from paved and unpaved roads.

Only one collaborative test of exposure profiling has been performed, in June of 1984.[5] Five different organizations implemented the method in side-by-side testing TP emissions and particle size distributions generated by traffic on a paved road with a heavy surface dust load at a steel plant in the Chicago area. Various types of air samplers with directional inlets were used by the participating organizations. In each case, a single tower was used to support the air samplers. Meteorological equipment for measurement of wind speed profiles were also provided and operated by each testing organization.

The results of this collaborative study indicated that “equivalent results” were obtained for TP emissions. However, this was not the case for particle size distributions and emissions by particle size. Of the three particle sizing methods used (cyclone/impactors, stacked filters and scanning electron microscopy, only the inertial sizing (cyclone/impactor) method was believed to produce reliable results.

In recent field studies of traffic related OS emissions using the exposure profiling method, use of collocated samplers has been a standard component of the quality assurance program. Data quality objectives for measurement precision are usually set at $\pm$30 percent for PM-10 concentration and $\pm$40 percent for PM-10 emission factor. These values reflect variations in travel surface conditions over short distances, as well as imprecision in concentration and wind speed measurements. The data quality objectives for measurement

accuracy are typically $\pm$10 percent. Considering the orders of magnitude variations that are typical for OS emissions as a function of surface conditions (e.g., silt and moisture content) and source equipment characteristics (e.g., vehicle weight and vehicle speed) these data quality objectives are considered as very acceptable.

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Appendix Profiling Database

This appendix provides the user with examples of tests performed and data obtained using the exposure profiling test method. Under an earlier study for USEPA (Contract No. 68-D7-0067) a Profiling Database of 156 tests was compiled from MRI specific exposure profiling field studies of fugitive dust emissions. In addition, the database provides profiling data (i.e., horizontal fluxes of PM-10 as a function of height in the plume) for 21 tests that were judged to most appropriately represent the source categories of interest. This information is helpful to the potential user of the method, in anticipating test conditions such as plume dimensions and the duration of sampling required to obtain adequate sample mass, based on the source activity and the level of natural or anthropogenic control.

The field testing studies from which the Profiling Database was extracted are summarized in Table A-1. For convenience, the data sets are denoted by a code:

X.y

where X is a code letter corresponding to the source categories:

U for unpaved roads
P for paved roads
C for construction activities
S for soil tilling

and y is a sequential numeric identifier. References to the original test reports are indicated in Table 2.

In assembling field studies for the Profiling Data Base, the following guidelines were followed:

1. Preference was given to studies that characterized the emission plume in terms of PM-10 rather than total suspended particulate (TSP) or total particulate (TP). As a practical matter, this typically restricted attention to tests conducted since the early 1990s. The major exception applied to soil tilling. For that operation, only earlier (1973-1980) test data referencing TP profiles are available.

Table A-1. Reviewed Data Sets

Location/financing agency	Year	Reference No.	Source Characteristics	Profile specifics		No. of tests*
				Particle size range	No. of points	
Unpaved Roads						
U.1 Tucson–Pennzoil	1997	12	Copper mine road–light/medium duty traffic Rural public road–mostly light-duty traffic	PM-10	4	4
U.2 Reno–USEPA	1996	9	Unimproved spur off public paved road County	PM-10	4	2
U.3 Raleigh–USEPA	1996	9	road–mixed traffic	PM-10	3	4
U.4 Coachella Valley, CA–South Coast AQMD[3]	1995	13	Construction site road–light-duty traffic	PM-10	3	4
U.5 Wyoming–USEPA4	1992	14	Surface coal mine–haul roads	PM-10	3	3
U.6 Arizona–AZ DEQ	1990	15	Rural public roads in Pima, Pinal and Yuma	PM-10	4	20
			Counties	PM-10/TSP	3	27/9
Paved Roads						
P.1 Denver–Colorado DOT	1996/7	16	Arterial roads–baseline and sanded conditions	PM-10	4-5	12
P.2 Pocatello–Bannock Planning Organization	1997	17	Collector, arterial and local roads	PM-10	4	7
P.3 Reno–USEPA	1996	9	Arterial road near edge of town U.S.	PM-10	4	2
P.4 Duluth–USEPA	1992	18	highway–post-sanding tests	PM-10	4	4
P.5a Kansas City–USEPA	1993	19	Arterial road–winter and summer testing	PM-10	4	5
Construction Activities						
C.1 Western and Central Kansas–USEPA	1998	10	Two rural agricultural sites "captive operations"	PM-10	3	15
			• Scraper loading	PM-10	3	15
			• Scraper unloading	PM-10	3	12
			• Scrapers in transit	PM-10	3	2
			• Graders			
C.2 Newport Beach, CA and Las Vegas–South Coast AQMD	1995	13	Two regional test sites–scrapers in transit	PM-10	3	6
C.3 Wyoming–USEPA	1992	14	Surface coal mine–scrapers in transit	PM-10	3	2
Soil Tilling						
S.1 Central California–CARB	1980	20	Two regional sites			
			• discing	TP	4	8
			• land planing	TP	3	3
S.2 Western Kansas–USEPA	1973	2	Two regional sites –discing	TP	4	7

* Uncontrolled tests only.

2. A minimum of three horizontal flux measurement points was considered necessary to characterize the plume profile as a function of height above ground level.

3. Only uncontrolled tests were considered. For example, tests of travel surfaces that had been watered or treated with dust suppressants were not included.

The assembled data set of field studies comprises 156 emission tests (and associated horizontal flux profiles), distributed over the specified source categories as follows:

Source Category	No. of Tests
Unpaved roads	56
Paved roads	30
Construction activities	52
Soil tilling	18
	156

Selection of Profiles

Twenty-one specific exposure profiling tests were selected from the Profiling Data Base. These tests are recommended for further investigation with regard to the use of horizontal flux data to estimate vertical fluxes of PM-10 within the emission plume. The selection process followed these guidelines:

1. At least one test was selected from each category. Thereafter, to the extent practical, the distribution of source categories in the selected data base of 21 tests was roughly comparable to that in the overall Profiling Data Base. Paved and unpaved roads were the most heavily represented source categories in the 21 recommended profiles.

2. The most comprehensive construction data set for construction activities (C.1 in Table A-1) was not selected because, at the time that this database was prepared, test results had not yet been reported or undergone full quality assurance review.

3. In general, one profile was selected for each test site contained in Table 1 (if more than one test was available for that site). Selection of the specific test profile for inclusion in the recommended data set took into account anecdotal information available about the testing program with regard to the suitability of test conditions (e.g., well behaved wind conditions, effective source isolation, etc.). If there was no clearly preferred test to recommend, selection was made randomly.

The result of the selection process is summarized in Table A-2.

Table A-2. Selection of Profiles

Location/funding agency	Total tests	Tests selected	Comments
Unpaved Roads			
U.1 Tucson–Pennzoil	4	1	
	2	1	
U.2 Reno–USEPA	4	–	Access road not considered representative of commonly inventoried sources.
U.3 Raleigh–USEPA	4	1	
U.4 Cacalia Valley, CA–South Coast AQMD	3	1	
U.5 Wyoming–USEPA	20	4	
U.6 Arizona–AZ DEQ	27/9	2	
Paved Roads			
P.1 Denver–CDOT study	12	2	
P.2 Pocatello–Bannock Planning	7	2	
Organization	2	1	
P.3 Reno–PM-2.5 study	4	1	
P.4 Duluth–Snow/ice control study	5	1	
P.5a Kansas City–Continuation of Duluth study			
Construction Activities			
C.1 Kansas–Construction Activities	15	–	Results for C1 are undergoing QA review.
	15	–	
	12	–	
	2	–	
C.2 Newport Beach, CA and Las Vegas–BACM	6	2	
Project No. 1	2	1	
C.3 Wyoming–Section 234 study			
Soil Tilling			
S.1 California–CARB agricultural practices study	8	–	Only TP profiles available.
	3	–	
S.2 Kansas–Original fugitive dust study	7	1	

The site parameters for the selected 21 tests are given in Table A-3. All of the tests entailed dust-generating activities that are best represented as moving point sources. These included vehicle traffic on public roads (paved and unpaved), traffic on unpaved roads at open pit mines, scraper traffic at construction sites and moving of tillage equipment across agricultural fields.

Table A-3. Site Parameters for Selected Tests

Code	Run	Road name/location	Date	Start time	Duration (min)	No. of passes
U.1	BQ-2	Sierrita Mine–plant road (Green Valley, AZ)	5/7/97	13:40	76	71
U.1	BQ-15	Linda Vista –road (Tucson, AZ)	7/21/97	7:24	44	63
U.3	BJ-3	Reedy Creek Road (Raleigh, NC)	4/23/96	10:56	115	247
U.4	BA-11	Construction Access Road (Cathedral City, CA)	4/13/95	14:51	35	29
U.5	BB-11	Cordero Mine Coal Haul Road 1 (Gillette, WY)	9/12/92	12:26	89	57
U.5	BB-16	Cordero Mine Coal Haul Road 1B (Gillette, WY)	9/18/92	15:14	63	51
U.5	BB-33	Cordero Mine Coal Haul Road 2, South Pit (Gillette, WY)	10/10/92	12:32	92	32
U.5	BB-29	Cordero Mine Overburden Haul Road 4 (Gillette, WY)	10/5/92	13:30	37	21
U.6	AZ-11	Warren Road (Rural Pinal County, AZ)	5/24/90	–	96	178
U.6	AZ-23	Reservation Road (Rural Pima County, AZ)	5/27/90	–	47	50
P.1	BL-7	Kipling Avenue (arterial during sand cycle) (Lakewood, CO)	11/2/96	11:24	248	12300
P.1	BH-6	Botanical Gardens (arterial immediately after sanding) (Denver, CO)	3/16/96	9:09	240	3112
P.2	BP-4	Gould Avenue (arterial) (Pocatello, ID)	4/10/97	–	600	6094
P.2	BP-5	Chubbuck Road (collector) (Pocatello, ID)	4/13/97	–	480	3442
P.3	BK-7	Virginia Street (north of Bonanza Casino) (Reno, NV)	6/3/96	12:17	420	7394
P.4	AY-5	U.S. Highway 53 (Duluth, MN)	4/26/92	9:36	220	650

Table A-3 (Continued)

Code	Run	Road name/location	Date	Start time	Duration (min)	No. of passes
P.5	BC-3	47th Street (Kansas City, MO)	2/19/93	10:04	241	3552
C.2	BA-2	Construction Site–Scraper Route (Las Vegas, NV)	6/21/95	14:53	22	12
C.2	BA-3	Construction Site–Scraper Route (Newport Beach, CA)	6/26/95	14:45	40	17
C.3	BB-46	Cordero Mine–Scraper Route (Gillette, WY)	10/24/92	14:40	89	32
S.2	7	Agricultural Field (Morton County, KS)	5/25/73	9:40	24	16

The plume data for the selected 21 tests are given in Table A-4. It should be noted that the net PM-10 exposure is simply the time-integrated value of horizontal net PM-10 flux over the duration of the emission test. In the case of agricultural tilling, profiling test results are expressed as the product of net total particulate matter flux and the ratio of PM-10/TP concentrations. (Note that the data presented in Tables A-3 and A-4 are also available for the remainder of the 156 tests in the Profiling Data Base.)

Table A-4 also presents ambient meteorological conditions at the time of each test, if that information was contained in the test report. The degree to which information was available depends upon the type of sampling equipment employed for the testing. In particular, tests using volumetric flow controllers for the high-volume samplers required that both ambient temperature and barometric pressure be reported. In most cases, information provided in the test reports is not sufficient to determine atmospheric stability class without obtaining supplementary historical meteorological data. Because exposure profiling relies on sampling very close to the source and does not require back-calculation through air quality modeling, stability class is not required for calculation of the vertical profiles of horizontal emission flux.

Table A-4. Plume Data for Selected Tests

Temp (°F)	Barometric pressure (in. Hg)	Height (m)	Net PM-10 concentration ($\mu g/m^3$)	Wind speed (mph)	Net PM-10 exposure (mg/cm^2)
95	26.3	1.3	533	3.1	0.337
		2.7	151	3.8	0.117
		4.1	60	4.2	0.051
		6.0	13	4.6	0.012
78	27.64	1.3	2330	1.2	0.330
		2.7	700	1.7	0.140
		4.1	552	2.0	0.130
		6.0	229	2.3	0.062
84	29.78	1.0	716	12.7	2.80
		3.0	96	15.1	0.449
		5.0	1	16.1	0.005
105	29.86	1.0	8290	3.9	3.03
		3.0	1740	5.3	0.865
		5.0	205	5.9	0.114
80	25.35	1.0	337	14.7	1.18
		3.0	139	16.8	0.557
		5.0	76	17.0	0.307
		7.0	163	17.3	0.260
62	25.60	1.0	936	7.7	1.220
		3.0	607	9.9	1.02
		5.0	507	10.9	0.933
		7.0	263	11.4	0.509
61	25.55	1.0	323	9.3	0.740
		3.0	200	13.1	0.646
		5.0	132	14.6	0.473
		7.0	100	15.4	0.380
65	25.95	1.0	3920	3.7	1.43
		3.0	2280	5.8	1.32
		5.0	1680	6.8	1.14
		7.0	842	7.5	0.626
–	–	1.0	1080	3.0	0.841
		3.0	442	5.3	0.606
		5.0	108	6.4	0.177
–	–	1.0	970	3.9	0.479
		3.0	298	6.9	0.259
		5.0	65	8.3	0.068
58	24.73	2.0	72	1.1	0.053
		3.0	42	1.5	0.042
		5.0	29	2.0	0.039
		7.5	22	2.4	0.035
		10.0	5	2.7	0.009
48	24.62	1.0	252	1.4	0.227
		3.0	301	2.8	0.542
		5.0	32	3.4	0.071
		7.0	19	3.8	0.046

Table A-4
(Continued)

Run	Temp (°F)	Barometric pressure (in. Hg)	Height (m)	Net PM-10 concentration ($\mu g/m^3$)	Wind speed (mph)	Net PM-10 exposure (mg/cm^2)
BP-4	38	25.44	1.3	16	3.6	0.095
			2.7	11	3.8	0.069
			4.1	8	3.9	0.052
			6.0	4	4.0	0.028
BP-5	47	25.48	1.3	6	6.2	0.045
			2.7	2	7.2	0.017
			4.1	1	7.7	0.008
			6.0	1	8.2	0.008
BK-7	89	25.37	1.0	13	5.6	0.084
			3.0	6	6.9	0.043
			5.0	4	7.6	0.031
			7.0	8	8.0	0.073
AY-5	–	–	1.0	20	3.1	0.038
			3.0	8	3.8	0.018
			5.0	4	4.3	0.011
			7.0	3	4.7	0.009
BC-3	–	–	1.0	50	7.6	0.249
			3.0	9	8.5	0.050
			5.0	3	8.7	0.017
			7.0	2	9.2	0.013
BA-2	91	27.50	1.0	3860	5.0	1.14
			3.0	1700	6.1	0.613
			5.0	445	6.6	0.173
BA-3	74	27.20	1.0	362	4.2	0.163
			3.0	200	5.1	0.110
			5.0	93	5.5	0.055
BB-46	80	25.40	1.5	1550[a]	9.3	3.46[a]
			3.0	720[a]	10.1	1.740[a]
			4.5	266[a]	10.6	0.674[a]
7	70	–	0.9	9240[b]	!	5.62[b]
			1.7	2810[b]	!	1.87[b]
			2.4	901[b]	!	0.646[b]
			3.2	181[b]	!	0.133[b]

"–" = not reported.

[a] Because of limitations in readily available data, the PM-10 concentrations reported for the BB runs are downwind rather than net. That is, no background values have been subtracted out. However, in none of the BB runs in the Profiling Data Base did background contribute significantly to the downwind PM-10 flux. The wind speeds reported for the BB runs are based on the net exposure and the downwind concentration. As such, the listed wind speeds are slightly (<5%) lower than the actual values.

[b] Because only TP profiles were reported in Reference 12, the PM-10 concentration and exposure values were calculated from the PM-10/TP ratio of 0.21 given in AP-42, Section 9.1, on agricultural tilling.