Emission Tests of Paved Road Traffic at ADM's Marshall, Minnesota Facility

Test Report

For
McVehil-Monnett Associates

MRI Project No. 310479.1.001

December 5, 2003

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For
McVehil-Monnett Associates
44 Inverness Drive East
Building C
Englewood, Colorado 80112

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Preface

This report presents the results from a field testing program conducted to evaluate emissions from paved roads at the Archer Daniels Midland (ADM) plant in Marshall, Minnesota. The report has been prepared under a contract with McVehil-Monnett Associates (MMA) and will be submitted to the state of Minnesota for review and comment. Dr. George McVehil is MMA's program manager. Dr. Gregory E. Muleski served as MRI's project leader and authored this report. Mr. Ken Muhl's role in coordinating activities at the plant is gratefully acknowledged.

MIDWEST RESEARCH INSTITUTE

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Approved:

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December 5, 2003

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Section 1. Introduction

The U. S. Environmental Protection Agency's (EPA's) *Compilation of Air Pollutant Emission Factors* (commonly referred to as "AP-42")[1] contains factors typically used to estimate particulate matter (PM) emissions from industrial operations. EPA guidance[2] notes that AP-42 emission factors are best viewed as representative of long-term conditions for all facilities within a source category (i.e., a population average). Furthermore, the EPA guidance[2] also notes that test data supporting AP-42 factors are usually insufficient to fully indicate the effect of various source parameters on emission levels.

These points are particularly relevant to the paved road predictive emission factor equation presented in Section 13.2.1 of AP-42[a]:

$$e = k\,(sL/2)^{0.65}\,(W/3)^{1.5} \qquad \textbf{(1-1)}$$

where:

e	=	particulate emission factor in pounds emitted per vehicle mile traveled (lb/vmt)
k	=	base emission factor
	=	0.016 lb/vmt for particulate matter no greater than 10 microns in aerodynamic diameter (PM-10)
	=	0.082 lb/vmt for total suspended particulate (TSP)
sL	=	surface "silt loading" which consists of mass of dried sub-200 mesh material per unit area of road surface (g/m^2)
W	=	average weight (ton) of vehicles traveling the road

Historically, the AP-42 emission factor model has been used to estimate PM emissions at Archer Daniels Midland's (formerly Minnesota Corn Processors' [MCP's]) plant in Marshall, Minnesota. However, in this instance, the AP-42 model has been applied to situations far beyond what is represented in the supporting database. AP-42 states that Equation 1-1 is based on tests of emissions from freely flowing traffic moving at fairly constant speed and that no tests from slow-moving "stop-and-go" traffic are included in the database. At times, traffic into and out of the plant may involve trucks queuing up to unload corn. Furthermore, the plant has a speed limit of 5 mph when vehicles are moving; this is well below any of the vehicle travel speeds in the AP-42 database. Finally, the Marshall facility now has a street sweeping program in place at the plant.

[a] During August 2003, EPA released a draft revision of Section 13.2.1, in which a constant value of 0.00047 lb/vmt is subtracted from Equation 1-1. The purpose of this revision was to avoid "double counting" of brake/tire wear and exhaust.

Recognizing the shortcomings of Equation 1-1 when it was applied to the Marshall plant roads, MCP undertook a series of field tests in April 2001[3]. This report describes a second series of field tests conducted at the ADM plant during September 2003. As in the April 2001 program, tests of both stop-and-go and slowly moving (~ 5 mph) traffic were conducted. The site-specific data developed from the two test programs represent the actual PM emissions from paved roads at the Marshall facility better than the AP-42 factor.

It is important to note that both field programs applied the exposure profiling method, which is **the same fundamental emission measurement methodology** used to develop the AP-42 database. In other words, data generated from the two field programs are directly comparable to the test data supporting AP-42.

The remainder of this report is structured as follows. Section 2 presents a brief description of the test site as well as general test objectives and procedures. Section 3 provides detailed information on the test methodology. Section 4 presents and discusses the test results obtained. Section 5 lists the references cited. Appendix A contains a copy of the test plan memo submitted to Minnesota Air Pollution Control Agency prior to the 2003 field test campaign. Appendix B presents quality assurance and quality control guidelines for the testing, while Appendix C presents detailed test results from the 2003 field program.

Section 2.
General Description of the Test Program

This section describes the test location site and lists the general objectives and procedures that were followed in the 2003 test program.

2.1 Description of the Marshall Facility

Figure 2-1 presents a plan view of the Marshall facility.

The exposure profiling test method (as described in the next section) requires open space for unobstructed wind flow both upwind and downwind of the source. With the exception of roads in the immediate vicinity of the corn receiving area, roadways at the Marshall plant are largely surrounded by buildings. All tests during the 2003 campaign were conducted on the inbound corn haul route.

The main change in operations between the 2001 and 2003 field campaigns was the construction of new building to house corn sampling/grading activities. The location of this building (shown in Figure 2-1) is approximately coincident with the area where field equipment was deployed in 2001 for tests on the inbound corn haul. For that reason, the sampling equipment was moved to the west for the 2003 field program. (The location is shown in Figure 4-1.)

2.2 Test Objectives

The overall purpose of the test program was to develop a site-specific, measurement-based emission factor for paved roads at the Marshall facility. Testing relied on the same exposure profiling test method used to develop the AP-42 data set. Road surface material samples were collected in connection with each test so that test results could be directly compared to the emission factor predicted from the AP-42 model (Equation 1-1).

Both emission sources of interest in this study—stop-and-go queuing and low-speed travel of trucks—can be represented as "line sources." Used in this context, a "line source" is an elongated source whose length is much greater than the distance from the source to the sampling array. All tests in the AP-42 paved road data are based on a line source representation of moving traffic.

Furthermore, trucks queued at Marshall represent a line source in that all emissions (whether travel- or exhaust-related) occur along the path of motion. Natural variability in wind conditions effectively smears the emissions along the length of the queue.

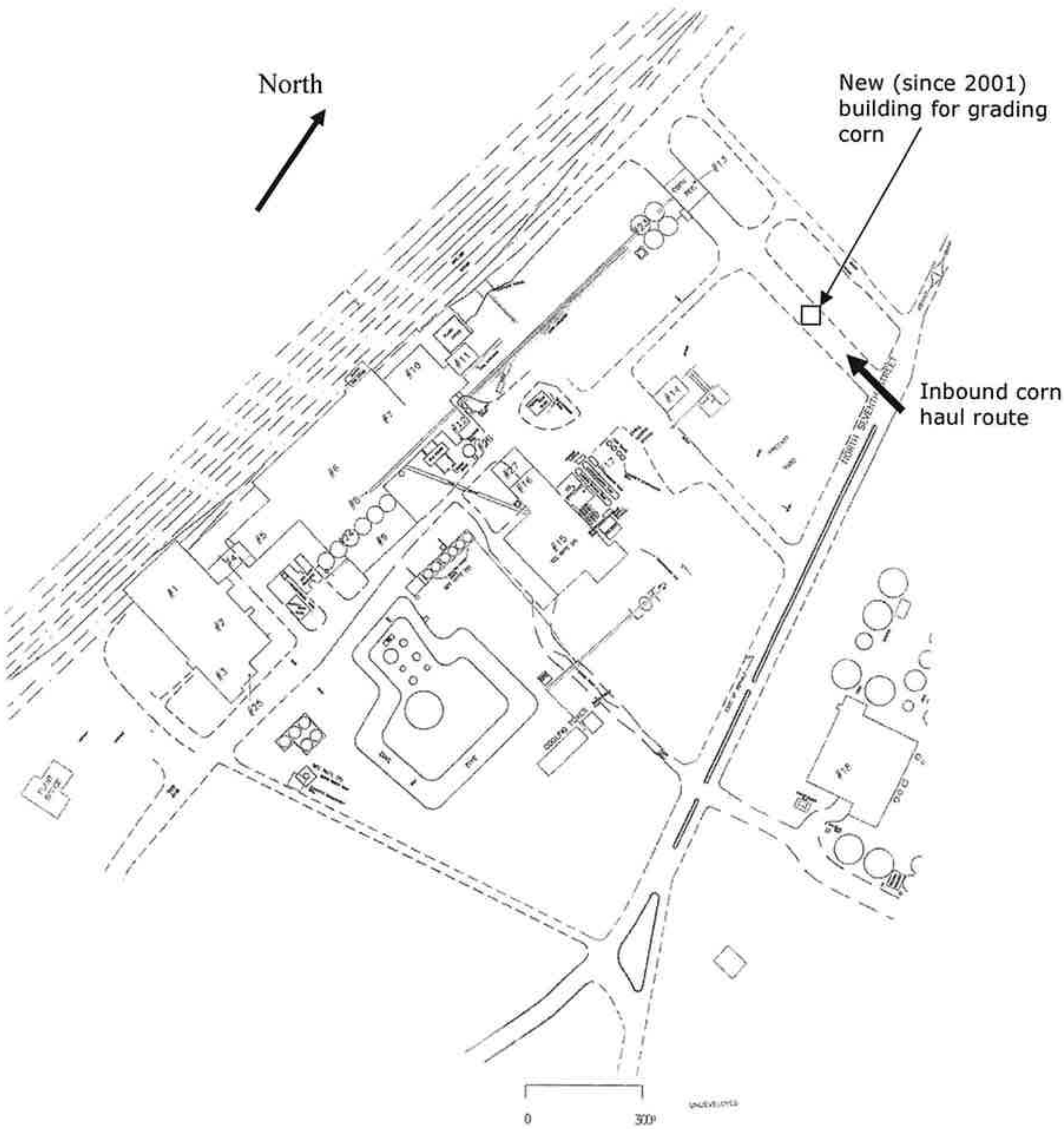

Figure 2-1. Marshall Plant

Section 3. Test Methodology

This section discusses the exposure profiling sampling methodology employed in the program. MRI developed exposure profiling during the early 1970s and has applied the concept to a wide variety of open fugitive emission sources. AP-42 emission factors based on exposure profiling test results first appeared in 1976. Exposure profiling is EPA's preferred method to characterize emissions from fugitive dust sources. Open source emission factors based on the method typically have the highest quality ratings in AP-42.

Appendix A contains a copy of the test plan memo submitted to Minnesota Pollution Control Agency (MPCA) prior to the 2003 field program

3.1 Description of Exposure Profiling Test Method

The exposure profiling test method has been recognized by EPA as the technique most appropriate to characterize the broad class of open anthropogenic PM sources, such as material transfer and moving point sources. Because the method isolates a single emission source while not artificially shielding the source from ambient conditions (e.g., wind), the open source emission factors with the highest quality ratings in EPA's emission factor handbook AP-42[1] are typically based on this approach.

The exposure profiling technique for source testing of open particulate matter sources is based on the same isokinetic profiling concept that is used in stack testing. The passage of airborne pollutant immediately downwind of the source is measured directly by means of simultaneous multipoint sampling over the cross section of the open dust source plume. This technique uses a mass flux measurement scheme similar to EPA Method 5 stack testing rather than requiring indirect emission rate calculation through the application of a generalized atmospheric dispersion model.

The exposure profiling technique relies on simultaneous multipoint measurement of both concentration and airflow (advection) over the effective area of the emission plume. The technique uses a mass flux measurement scheme. Unlike traditional stack sources, both the emission rate and the airflow (i.e., ambient wind) are nonsteady. This requires simultaneous multipoint sampling of mass concentration and airflow over the effective area of the emission plume. As noted above, the two emission sources of interest in this study—stop-and-go queuing and low-speed travel of trucks—can be represented as "line sources." When applied to line sources, the exposure profiling test method requires a vertically oriented array of sampling points.

The sampling deployment described below is fundamentally identical to that used to develop the test database for the AP-42 emission factor equation. As such, the emission test data for slowly moving traffic at Marshall were reduced and analyzed in exactly the same manner as tests in the AP-42 database. That is to say, the measured emission factor has been expressed in terms of mass emitted per unit of vehicle travel (e.g., lb/vmt). On the other hand, tests of trucks moving in a stop-and-go fashion were not associated with the passage of individual vehicles past the sampling array. Instead, because emissions could be viewed as smeared along the length of the source, and the source strength was expressed in terms of the average emission rate (mass/length-time) during the test period.

Two vertical networks of samplers (Figure 3-1) were positioned just downwind and upwind from the edge of the source. The primary air sampling device in the exposure profiling portion of the field program was a standard high-volume air sampler fitted with a cyclone preseparator (Figure 3-2). The cyclone exhibits an effective 50% cutoff diameter (D_{50}) of approximately 10 μmA when operated at a flow rate of 40 cfm (68 m^3/h).[4] Thus, mass collected on the 8- by 10-inch backup filter represents a PM-10 sample.

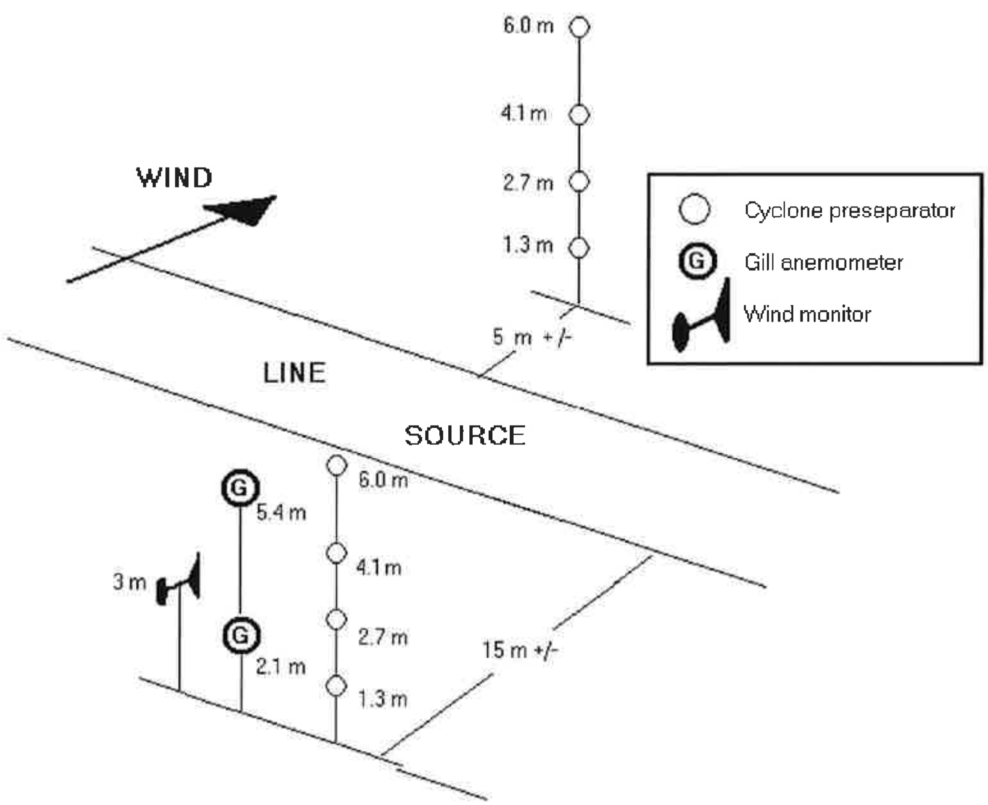

Figure 3-1. Sampler Deployment for Line Sources

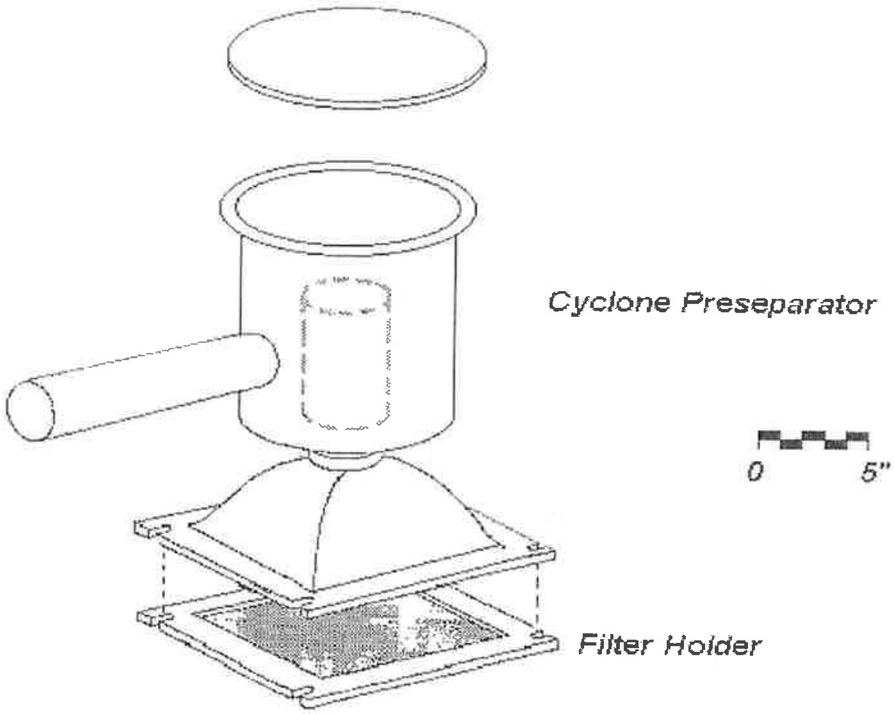

Figure 3-2. Cyclone Preseparator

Besides the air sampling equipment, Figure 3-1 also shows that, throughout each test, wind speed was monitored at two heights using R. M. Young Gill-type (Model 27106) anemometers. Furthermore, an R. M. Young portable wind station (Model 05305) was used to record wind speed and direction at the 3.0 m height. All wind data were accumulated into 5-min averages logged with a 26700 Series R. M. Young "programmable translator."

Sampling activities were subject to the quality assurance/quality control (QA/QC) guidelines discussed in detail in Appendix B. Note that these are the same QA/QC guidelines used to conduct the tests contained in the AP-42 paved road database.

3.2 Data Analysis

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

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

$$C = m/QT \qquad \textbf{(3-1)}$$

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

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

$$IFR = Q/aU \qquad \textbf{(3-2)}$$

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

This ratio is of interest in the sampling of total particulate, since isokinetic sampling ensures that particles of all sizes are sampled without bias. Because the primary interest is directed to PM-10, sampling under moderately nonisokinetic conditions poses little difficulty. It is readily recognized that 10 µm (aerodynamic diameter) and smaller particles have weak inertial characteristics at normal wind speeds and therefore are relatively unaffected by anisokinesis.[5]

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

$$E = (C - C_b)\, U\, T \qquad \textbf{(3-3)}$$

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

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

$$A_1 = \int_0^H E \, dh \tag{3-4}$$

where: A_1 = integrated exposure for a line source (mass/length)
E = net particulate exposure (mass/area)
h = height above ground (length)
H = vertical extent of the plume (length)

Because exposures are measured at discrete points within the plume, a numerical integration is necessary to determine the integrated exposure. For line sources, exposure must equal zero at the vertical extremes of the profile (i.e., at the ground where the wind velocity equals zero and at the effective height of the plume where the net concentration equals zero). However, the maximum exposure usually occurs below a height of 1 m, so that there is a sharp decay in exposure near the ground. To account for this sharp decay, the value of exposure at the ground level is set equal to the value at the lowest sampling height. The integration is performed using the trapezoidal rule.

The measured emission factor for particulate matter is determined from the integrated exposure by normalizing the emissions against some measure of source activity. For the tests of slowly moving traffic, the normalization process is the same as earlier tests supporting the AP-42 paved road emission factor model. In this case, the integrated exposure is divided by the number of vehicle passes during the emission test to express emissions in terms of mass emitted per vehicle distance traveled:

$$e = A_1 / N \tag{3-5}$$

where e = measured emission factor (mass/vehicle-length)
A_1 = integrated exposure for a line source (mass/length)
N = number of vehicle passes during the test

Emission measurements for the queued traffic can follow a different type of normalization. In this instance, emissions are characterized in terms of PM mass emitted per time per unit length of the line source. In addition, the rate can be normalized to a single queue lane:

$$r = A_1 / (T\,L) \tag{3-6}$$

where r = line source emission rate (mass/time-length)
A_1 = integrated exposure for a line source (mass/length)
T = duration of sampling (time)
L = number of lanes used to queue traffic

Section 4.
Test Results and Discussion

This section presents and discusses the results from the field test program carried out at the Marshall plant during September 2003.

4.1 Results

Three PM-10 emission tests were conducted during the week of September 22, 2003. Included in the total were two tests of low-speed traffic and one test of stop-and-go traffic along the inbound corn haul route. Table 4-1 lists the test site parameters associated with each run, and Table 4-2 presents traffic data. Test locations are shown in Figure 4-1. Note that the plant provided "drone" passes by loaded corn semi-trailers to supplement traffic during test periods.

Table 4-1. Test Site Parameters[a]

Run No.	Source	Date	Start time	Duration (min)	Mean wind speed[b] (mph)	Nominal wind direction[b]	Ambient temp. (°F)	Baro. pressure (in. Hg)
CM-1	Low Speed	9/23/03	8:38	183	5.02	S	63	28.53
CM-2	Stop-and-go	9/23/03	12:58	169	7.75	S	75	28.48
CM-4[c]	Low Speed	9/25/03	12:59	180	6.85	S	65	28.74

[a] Refer to Figure 4-1 for test site location.
[b] Wind conditions during test. Mean wind speed refers to speed measured at 5.4 m (17' 9") height during test. Nominal direction refers to cardinal direction most nearly perpendicular to line source.
[c] Run CM-3 was a run with blank filters.

Table 4-2. Traffic During Tests

Run No.	Source	Avg. number of trucks[a] per hr	Average total number trucks in 2 lines	Number of vehicle passes[a] during test
CM-1	Low Speed	153	–	469
CM-2	Stop-and-go	41.9	3.2	118
CM-4	Low Speed	156	–	468

[a] Corn trucks passing the sampling location.

Tests lasted on the order of three hours to collect adequate sample mass on both the upwind and downwind samplers. A minimally detectable (with a confidence level of 95%) PM-10 concentration of approximately 9 $\mu g/m^3$ was derived, based on the following:

- The average (absolute value) blank filter catch (0.86 mg) plus two times the standard deviation (0.52 mg) of the blanks. This produces a value of 0.86 + 2 (0.52) = 1.9 mg.

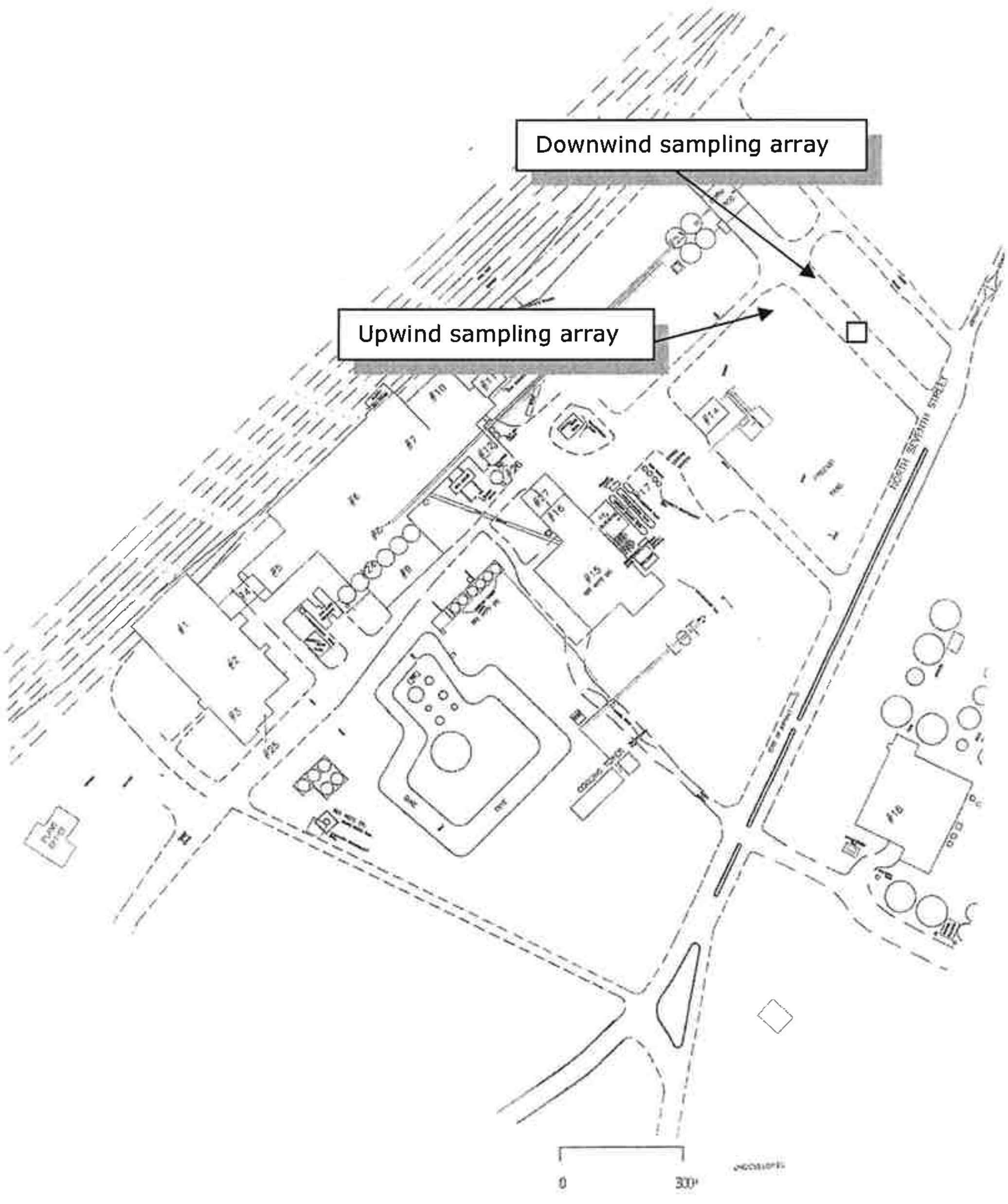

Figure 4-1. Sampling Locations

- A nominal 40 cfm sampling rate
- A nominal sampling duration of three hours

Table 4-3 lists measured concentrations and exposure values for the different sampling locations. The measured concentrations were all greater than the minimally detectable concentration value of 9 $\mu g/m^3$.

Table 4-3. Plume Sampling Data

Run	Sampler height (m) / location[a]	Measured PM-10 concentration ($\mu g/m^3$)	Net PM-10 concentration ($\mu g/m^3$)	Wind speed (mph)	PM-10 exposure (mg/cm^2)
CM-1	1.3 UW	18.7	NA	3.78	0.0355
	2.7 UW	20.5	"	4.42	0.0454
	4.1 UW	20.7	"	4.78	0.0495
	6.0 UW	17.1	"	5.11	0.0437
	1.3 DW	39.1	20.4	3.78	0.0378
	2.7 DW	30.9	10.4	4.42	0.0224
	4.1 DW	35.5	14.8	4.78	0.0348
	6.0 DW	22.1	5.0	5.11	0.0126
CM-2	1.3 UW	18.5	NA	5.79	0.0502
	2.7 UW	17.9	"	6.79	0.0572
	4.1 UW	17.7	"	7.37	0.0611
	6.0 UW	15.4	"	7.89	0.0569
	1.3 DW	54.4	35.9	5.79	0.0942
	2.7 DW	50.8	32.8	6.79	0.1011
	4.1 DW	40.9	23.3	7.37	0.0778
	6.0 DW	19.8	4.5	7.89	0.0160
CM-4	1.3 UW	22.5	NA	5.06	0.0599
	2.7 UW	20.1	"	5.98	0.0634
	4.1 UW	21.2	"	6.51	0.0724
	6.0 UW	18.6	"	6.98	0.0684
	1.3 DW	35.5	13.0	5.06	0.0319
	2.7 DW	33.5	13.4	5.98	0.0386
	4.1 DW	30.1	8.9	6.51	0.0279
	6.0 DW	24.0	5.4	6.98	0.0182

[a] DW = downwind, UW = upwind.

As discussed in preceding sections, the point values of exposure in Table 4-3 were integrated over the height of the plume to develop the emission rates and factors. Those results are shown in Table 4-4, together with the road surface silt loading data collected during the field exercise. Also shown are the AP-42 predicted emission factors calculated from Equation 1-1.

Table 4-4. Measurement-Based PM-10 Emission Rates/Factors

Run	Traffic rate[a] (veh/hr)	Mean vehicle[a] weight (tons)	Silt loading (g/m^2)	Measured line source emission rate (g/mile-s)	Measured per vehicle emission factor (lb/vmt)	AP-42 predicted emission[a] factor (lb/vmt)
CM-1 (low speed)	154	39.8	0.72	0.27[b]	0.014	0.40
CM-2 (stop/go)	41.9	39.6	0.72	0.76[b]	0.14	0.40
CM-4 (low speed)	156	39.5	0.70	0.31[b]	0.016	0.39

[a] Vehicle weights based on the following values (lbs) in MCP's Title V application:

	Empty	Loaded
Straight Truck	10,000	26,000
Tandem	19,000	45,000
Semi	27,000	80,000

All trucks were inbound and full (including "drone" passes). AP-42 factor based on value of 40 tons.

[b] Based on 2 lines of queued traffic.

4.2 Discussion and Recommendation

The PM-10 emission factors developed in the 2003 testing program provide further evidence that Equation 1-1 produces highly overestimated predictions for PM-10 emissions from paved road traffic at the Marshall facility. At least two features of the AP-42 modeling approach fail to describe the emissions observed at Marshall.

First, re-entrained surface road dust is not nearly as dominant in the emissions measured at Marshall as compared to the AP-42 emission factor database. This was first noted in the 2001 test report [3]. The 2003 program provides no evidence that measured emissions exhibit a dependency on silt loading even remotely similar to that found in Equation 1-1.

Just as importantly, the 2003 test results point up a second shortcoming of AP-42 in modeling emissions at the Marshall plant. The predicted emission rate using AP-42 is found by multiplying Equation 1-1 by the traffic volume. In other words, the emission rate varies linearly with traffic rate. For example, if twice as many vehicles pass during one hour compared to the next, then the first hour's emission rate should be twice that of the second.

However, measured emission rates are remarkably constant over the range of traffic rates considered during the two test programs. Figure 4-1 presents the line source emission rate measured in both 2001 and 2003 for the inbound corn haul route. The emission rate is plotted against the traffic rate. Also included for comparison are the predicted values using AP-42. Measured emission rates show no significant relationship with traffic rate.

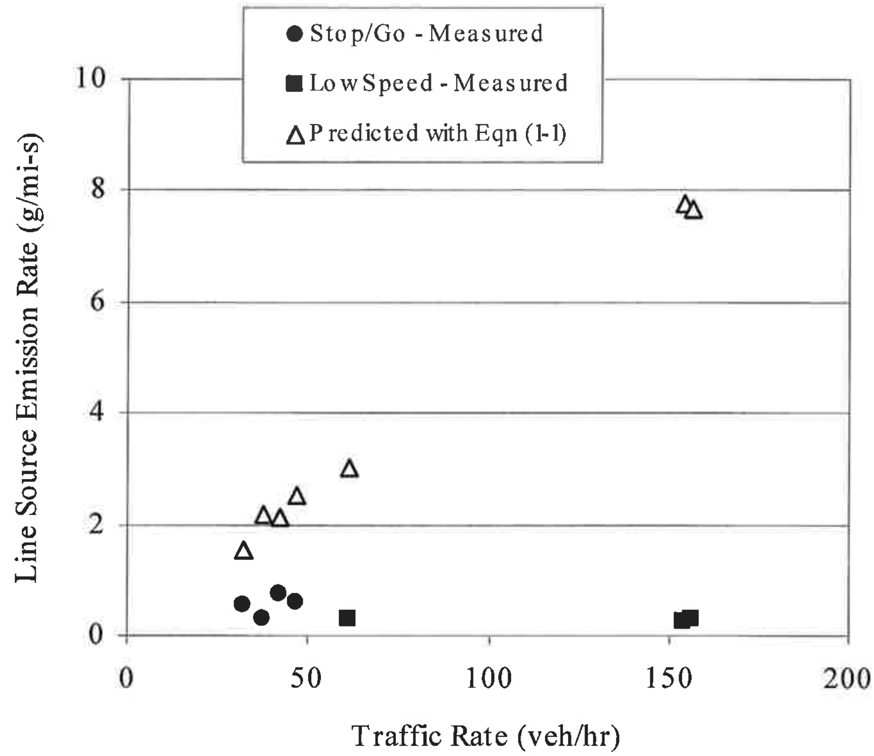

Figure 4-2. Measured and Predicted Emission Rates

In summary, the measurement programs demonstrate two important shortcomings of the AP-42 paved road modeling approach as applied to traffic at the Marshall facility:

- Emissions for either low-speed or stop-and-go traffic show no sign of dependency on silt loading similar to that found in the AP-42 emission factor model.
- Measured emission rates are essentially independent of traffic rate whereas AP-42 suggests linear dependency.

Given these limitations of the AP-42 approach, it is recommended that results from the 2003 test program be used to estimate PM-10 emissions at the facility. (This recommendation is based on the fact that Marshall has instituted a road sweeping program since 2001 and the 2003 test data better reflect the current situation at Marshall.) Specifically, an emission factor of 0.015 lb/vmt (the average of CM-1 and CM-4) should be applied to all roads other than the inbound corn haul road because those roads experience only low-speed traffic. The average of all three 2003 tests (0.057 lb/vmt) should be used to account for occasional stop-and-go traffic on the inbound corn route.

Section 5.
References

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2. USEPA. *Procedures for Preparing Emission Factor Documents.* EPA-454/ R-95-015. Office of Air Quality Planning and Standards. U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1997.

3. Midwest Research Institute. "Emission Tests of Paved Road Traffic at Minnesota Corn Processors Marshall, Minnesota Facility," MRI Project No. 310212.1.001, July 2001.

4. Baxter, T. E., et al. "Calibration of a Cyclone for Monitoring Inhalable Particulates," Journal of Environmental Engineering, 112(3), 468, 1986.

5. Davies, C. N. "The Entry of Aerosols in Sampling Heads and Tubes." British Journal of Applied Physics, 2:921, 1968.

Appendix A

Test Plan Memo of August 27, 2003

Technical Memorandum

MIDWEST RESEARCH INSTITUTE

August 27, 2003

To: File, MRI Project No. 310479

From: Greg Muleski, MRI

Subject: Test Plan for 2003 Field Exercise at Marshall, MN

This memorandum describes the sampling methodology and schedule for a series of paved road tests to be conducted at ADM's corn refining plant in Marshall, MN. This work continues a test program begun in 2001 when the plant was operated by Minnesota Corn Processors (MCP). Because tests have already been conducted at the plant, the 2003 tests will follow the same methodology as described in reports already submitted to and reviewed by the Minnesota Pollution Control Agency (MPCA)

- "Emission Tests of Paved Road Traffic at Minnesota Corn Processors Marshall, Minnesota Facility," Test Plan prepared for McVehil-Monnett Associates, MRI Project No. 310164.1.001, February 2, 2001.

- "Emission Tests of Paved Road Traffic at Minnesota Corn Processors Marshall, Minnesota Facility," Revised Test Report prepared for McVehil-Monnett Associates, MRI Project No. 310212.1.001, July 6, 2001.

This memorandum describes modifications to the original test plan, based on what was learned during the first test program. The following are the main modifications to the original February 2, 2001, test plan; each modification was described in the July 6, 2001, test report:

- During the 2003 tests, the aerometric equipment will be deployed at the upwind location. As noted in the test report, it was determined during the first test (CE-1) that the traffic queue proved to be a more formidable wind break than had been anticipated. During subsequent tests of stop-and-go traffic, the aerometric equipment was deployed at the upwind location.[b]

- The 2003 tests will combine an upwind sampling array together with a downwind array. As noted in the July 6, 2001, test report, because low levels of emissions were encountered, in many cases upwind and downwind concentrations were comparable. On the last test day in 2001, a separate upwind sampling array was operated as Run CE-18 in conjunction with Run CE-19. This arrangement permitted far better definition of the net contribution of roadway emissions throughout the vertical extent of the downwind plume.[c]

- The 2003 tests will focus on corn truck traffic at Test Site 1 (shown in Figure 2-3 of the February 2, 2001 test plan). Figure 1 in this memorandum shows the upwind and downwind sampling locations contemplated for the 2003 test program.[d] Locations are predicated on an assumption of southerly winds. Testing will consider both slowly moving and stop-and-go traffic.

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[b] As explained on page 4-5 of the test report, multiplying upwind wind speeds by downwind concentrations produces conservatively high emission factors for the stop-and-go traffic tests.

[c] Page 4-1 of the test report notes that, because of the better definition of net contribution, greater confidence can be placed on the CE-19 results.

[d] This is the same test location used for runs CE-18 and CE-19.

Testing is planned for the week of September 22, 2003. A preliminary schedule is shown in Table 1. Please note the following points about the schedule:

- Slowly moving traffic and stop-and-go traffic will be tested on alternate days. The program will begin with slowly moving traffic.
- No allowance is made in Table 1 for unfavorable weather conditions (such as antecedent rainfall events or winds parallel to the road)
- Each test is expected to require 3 to 5 hours to complete. If favorable weather conditions exist early in the morning, a second test may be attempted during the afternoon. Emphasis will be placed on ensuring that the roadway contribution is isolated from the background concentration. The decision to attempt a second test will be made day-to-day based on prior experience.

Table 1. Preliminary Test Schedule

Milestone/Activity	Target date
1. Submit test plan to Minnesota Pollution Control Agency (MPCA) for review/comment.	Thursday, 8/28/03
2. Arrive on-site, complete safety training at plant, perform calibrations	Monday, 9/22/03
3. Slowly moving traffic test(s)[a] at Test Site 1	Tuesday, 9/23/03
4. Stop-and-go test(s) at Test Site 1	Wednesday, 9/24/03
5. Slowly moving traffic test(s) at Test Site 1	Thursday, 9/25/03
6. Stop-and-go test(s) at Test Site 1	Friday, 9/26/03
7. Break down equipment, pack truck, return to Kansas City	Saturday, 9/27/03
8. Complete laboratory analyses	Friday, 10/17/03
9. Submit draft test report	Thursday, 11/6/03

[a] Tests are expected to require 3 to 5 hr to complete. If conditions are favorable to begin a test in the early morning, a second test may be attempted during the afternoon. See the discussion in the text.

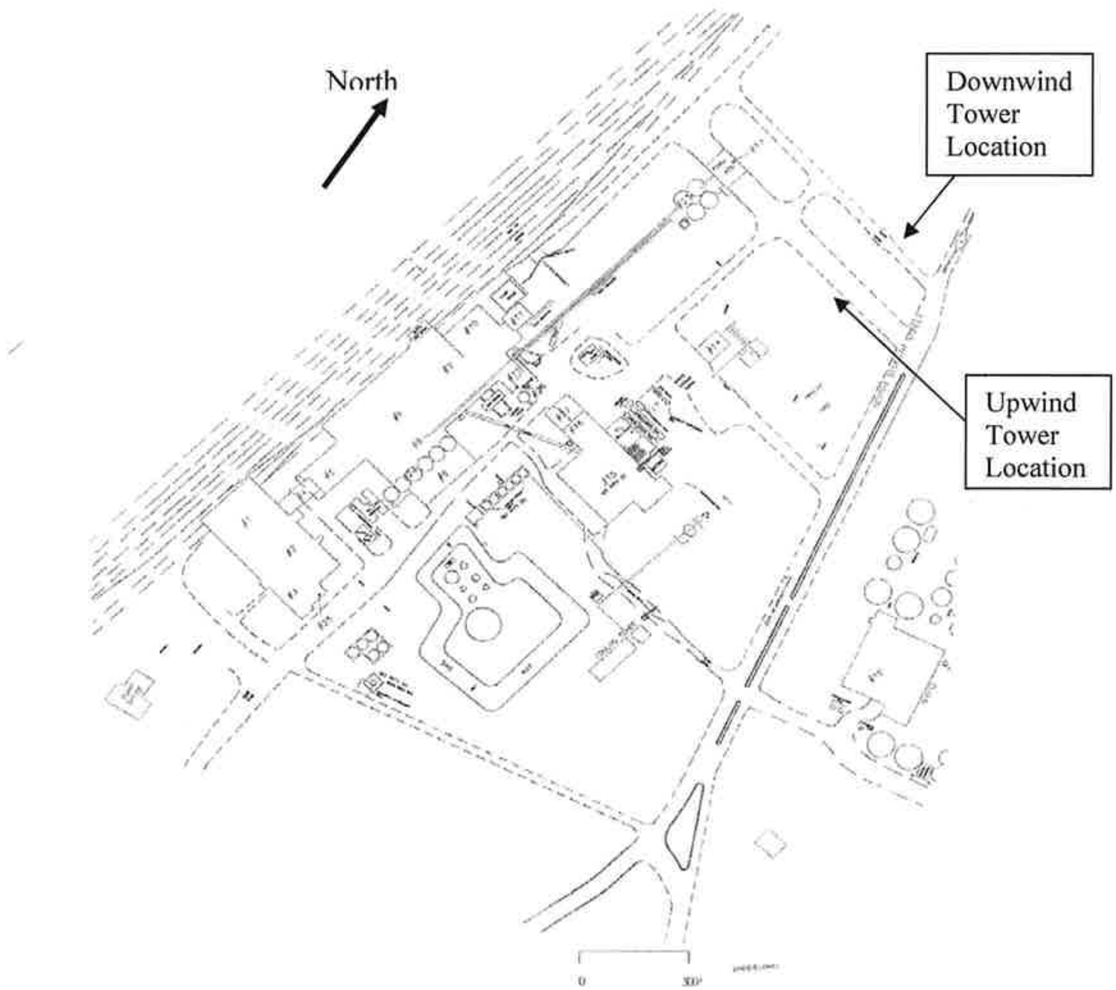

Figure 1. Sampling Locations for the 2003 Program

Appendix B

Quality Assurance/Quality Control Procedures

B.1 Sample Handling and Traceability Requirements

The majority of environmental samples collected during the test program consist of particulate matter captured on a filter medium. Analysis is gravimetric, as described in the following paragraphs.

To maintain sample integrity, the following procedure was used. Each filter was stamped with a unique 7-digit identification number. SOP (standard operating procedure) MRI-8403 describes the numbering system that is employed. A file folder is also stamped with the identification number and the filter is placed in the corresponding folder.

Particulate samples are collected on glass fiber (or quartz) filters (8 in by 10 in) or on glass fiber impaction substrates (4 in by 5 in). Prior to the initial (tare) weighing, the filter media are equilibrated for 24 hr at constant temperature and humidity in a special weighing room. Temperature and humidity levels are given in Table B-1. The room contains a hygrothermograph to provide a permanent record of equilibration conditions. The chart is changed weekly and recalibrated (as necessary) against wet and dry bulb thermometers. Those thermometers are checked annually against traceable units.

During weighing, the balance is checked at frequent intervals with standard (Class S) weights to ensure accuracy. The filters remain in the same controlled environment until a second analyst reweighs them as a precision check. A minimum of ten percent (10%) (with an absolute minimum of three blanks per test site) of the filters used in the field serve as blanks to account for the effects of handling. The QA guidelines pertaining to preparation of sample collection media are presented in Section B.3.

The filters are placed in their like-numbered folders. Groups of approximately 50 are sealed in heavy-duty plastic bags and stored in a heavy corrugated cardboard box equipped with a tight-fitting lid. Unexposed filters are transported to the field in the same truck as the sampling equipment and are then kept in the field laboratory.

Once they have been used, exposed filters are placed in individual glassine envelopes and then into numbered file folders. Groups of up to 50 file folders are sealed within heavy-duty plastic bags and then placed into a heavy-duty cardboard box fitted with a lid. Exposed and unexposed filters are always kept separate to avoid any cross-contamination. When exposed filters and the associated blanks are returned to the main MRI laboratory in Kansas City, they are equilibrated under the same conditions as the initial weighing. After reweighing, a minimum of 10% of each type is audited to check weighing accuracy.

In order to ensure traceability, all filter and material sample transfers are recorded in a notebook or on forms. The following items are recorded: the assigned sample codes, date of transfer, location of storage site, and the names of the persons initiating and accepting the transfer.

B.2 Analytical Method Requirements

All analytical methods required for this testing program are inherently gravimetric in nature. That is to say, 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.

The following procedures are followed whenever a sample-related weighing is performed:

- An accuracy check at the minimum of one level, equal to approximately the tare and actual weight of the sample or standard. Standard weights should be Class S or better.
- The observed mass of the calibration weight (not including the tare weight) must be within 1.0% of the reference mass.
- If the balance calibration does not pass this test at the beginning of the weighing, the balance should be repaired or another balance should be used. If the balance calibration does not pass this test at the end of a weighing, the samples or standards should be reweighed using a balance that can meet these requirements.

B.3 Quality Control Requirements

Routine audits of sampling and analysis procedures are to be performed. The purpose of the audits is to demonstrate that measurements are made within acceptable control conditions for particulate source sampling and to assess the source testing data for precision and accuracy. Examples of items audited include gravimetric analysis, flow rate calibration, data processing, and emission factor calculation. The mandatory use of specially designed reporting forms for sampling and analysis data obtained in the field and laboratory aids in the auditing procedure.

To prepare hi-vol filters for use in the field, filters are weighed under stable temperature and humidity conditions. After they are weighed and have passed audit weighing, the filters are packaged for shipment to the field. Table B-1 outlines the general requirements for conditioning and weighing sampling media. Note that a second, independent analyst performs the audit weights.

Table B-1. Quality Assurance Procedures for Sampling Media

Activity	QA check/requirement
Preparation	Inspect and imprint glass fiber media with identification numbers.
Conditioning	Equilibrate media for 24 hr in clean controlled room with relative humidity of 40% (variation of less than ±5% RH) and with temperature of 23°C (variation of less than ±1°C).
Weighing	Weigh hi-vol filters to nearest 0.05 mg.
Auditing of weights	Independently verify final weights of 10% of filters and substrates (at least four from each batch). Reweigh entire batch if weights of any hi-vol filters deviate by more than ±2.0 mg. For tare weights, conduct a 100% audit. Reweigh any high-volume filter whose weight deviates by more than ±1.0 mg. Follow same procedures for impactor substrates used for sizing tests. Audit limits for impactor substrates are ±1.0 and ±0.5 mg for final and tare weights, respectively.
Collection of blanks	Conduct at least one complete blank test for every 1 to 9 emission tests. A minimum of 3 blank filters is necessary for each test site/source combination.
Calibration of balance	Balance to be calibrated once per year by certified manufacturer's representative. Check prior to each use with laboratory Class S weights.

As indicated in Table B-1, a minimum of 10% field blanks are collected for QC purposes. This is accomplished by conducting one blank test for every 1 to 9 emission tests conducted. A blank test is conducted in exactly the same manner as an emission test except that no air is passed through the filters after they are loaded into the sampling devices. Instead, they are immediately recovered and handled the same as any exposed filter from an actual emission test. Blank runs are labeled in the same manner as other tests, although the run sheets indicate that a blank test was conducted.

Handling blank filters in an identical manner to all sample filters allows one to determine systematic weight changes due to handling steps alone. A field blank filter is loaded into a sampler and then immediately recovered without any air being passed through the media. This technique has been successfully used in many MRI programs to account for systematic weight changes due to handling.

After the particulate matter samples and blank filters are collected and returned from the field, the collection media are placed in the gravimetric laboratory and allowed to come to equilibrium. Each filter is weighed, allowed to return to equilibrium for an additional 24 hr, and then a minimum of 10% of the exposed/blank filters are reweighed. If a filter fails the audit criterion, the entire lot is allowed to condition in the gravimetric laboratory an additional 24 hr and then reweighed. The tare and first weight criteria for filters (Table B-1) are based on an internal MRI study conducted in the early 1980s to evaluate the stability of several hundred 8- x 10-in glass fiber filters used in exposure profiling studies.

B.4 Instrument/Equipment Testing, Inspection, and Maintenance

Inspection and maintenance requirements for sampling equipment are provided in Table B-2. Material presented in italics discusses how these requirements were met during the study.

B.5 Instrument Calibration and Frequency

Calibration and frequency requirements for the balances used in the gravimetric analyses are given in Table A-1.

Requirements for high-volume (hi-vol) sampler flow rates rely on the use of secondary and primary flow standards. The Roots meter is the primary volumetric standard and the BGI orifice is the secondary standard for calibration of hi-vol sampler flow rates. The Roots meter is calibrated and traceable to a NIST standard by the manufacturer. The BGI orifice is calibrated against the primary standard on an annual basis. Before going to the field, the BGI orifice is first checked to assure that it has not been damaged. In the field, the orifice is used to calibrate the flow rate of each hi-vol sampler. (For samplers with volumetric flow controllers, no calibration is possible and the orifice is used to audit the nominal 40 acfm flow rate.) Table B-2 specifies the frequency of calibration and other QA checks regarding air samplers.

Table B-3 outlines the QC checks employed for miscellaneous instrumentation needed. Material presented in italics discusses how these requirements were met during the study.

B.6 Inspection/Acceptance Requirements for Supplies and Consumables

The primary supplies and consumables for this field exercise consist of the air filter and collection media. Prior to stamping and initial weighing (Table B-1), each filter is visually inspected and is discarded for use if any pin-holes, tears, or other damage is found.

B.7 Data Acquisition Requirements

In addition to the field samples, MRI also collected information on the physical size and operational parameters of equipment used in the field exercise. To the extent practical and appropriate, physical characteristics are obtained from the manufacturer or the manufacturer's literature. Physical dimensions are measured and recorded.

Table B-2. Quality Assurance Procedures for Sampling Equipment

Activity	QA check/requirement[a]
Maintenance • All samplers	Check motors, brushes, gaskets, timers, and flow measuring devices at each plant prior to testing. Repair/replace as necessary. *Sampling devices were cleaned and checked prior to loading truck and upon arrival at plant.*
Calibration • Volumetric flow controller (VFC)	Prior to start of testing at each regional site, ensure that flow determined by calibration orifice and the look-up table for each volumetric flow controller agrees within 7%. Alternately, develop a separate calibration curve for each VFC. For 20 acfm devices (particle size profiling), calibrate each sampler against the orifice prior to use for each regional site and every two weeks thereafter during test period. (Orifice calibrated against displaced volume test meter annually.) *VFC calibration records have been included in copy of field data sheets. Calibration curves developed for each VFC are included on diskette with field data and data reduction.*
Operation • Timing	Start and stop all downwind samplers during time span not exceeding 1 min. *All downwind samplers were started / stopped within 1 min.*
• Isokinetic sampling (cyclones)	Adjust sampling intake orientation whenever mean wind direction dictates. *Wind direction relative to line source monitored immediately before and throughout test. Rotation of sampling arrays noted on field run sheets.* Change the cyclone intake nozzle whenever the mean wind speed approaching the sampler falls outside of the suggested bounds for that nozzle. *Wind speed throughout range of sampling heights monitored immediately before and throughout the test. Use of nozzles indicated on field run sheets.*
• Prevention of static deposition	Cover sampler inlets prior to and immediately after sampling. *Samplers were uncovered immediately before start of test and filters recovered immediately after end of test.*

[a] "Mean" denotes a 5-min average.

Table B-3. Quality Assurance for Miscellaneous Instrumentation

Instrumentation	QA check/requirement[a]
Digital manometers	Compare reading against water-in-tube manometers over range of operating pressures, using "Y" or "T" connectors and flexible tubing. Do not use units which differ by more than 7%. *Two units were used during tests. Maximum deviations for unit Y7543 and UEI EM100A were 1.4 and 2.2%, respectively.*
Digital barometer	Compare against mercury-in-tube barometer. Do not use if more than 0.5 in Hg difference in reading. *Deviation of altimeter/barometer Y-1253 was 0.19 in Hg (0.4% deviation).*
Thermometer (mercury or digital)	Compare against NIST-traceable mercury-in-glass. Do not use if more than 3.0 C difference. *Deviation for mg-in-glass unit was 1.0°F (0.6°C) low.*
Gill anemometers and wind station	Conduct a 4-point calibration of each unit over the range of 2 to 20 mph both before the field exercise and upon return to MRI's main laboratories. Use factory-specified devices for calibration of wind speed and direction. *Calibration records have been supplied as part of field run sheets.*
Watches/stopwatches	The field test leader will compare an elapsed time (> 1 hr) recorded by his watch against the US Naval Observatory master clock. Do not use if more than 3% difference. All crew members will synchronize watches (to the nearest minute) at the start of each test day. *Crew chief watch was checked against 6+ hr elapsed time, with deviation of 0.004%. Crew member watches and wind data acquisition device were reset to crew chief watch each day.*

[a] Activities performed prior to going to the field, except as noted.

Table B-4. Criteria for Suspending or Terminating an Exposure Profiling Test

A test may be suspended or terminated if:

1. Rainfall ensues during equipment setup or when sampling is in progress. (Exception made in the case of a source protected by a roof or other enclosure).
2. Mean wind speed during sampling moves outside the 4 to 20 mph acceptable range for more than 20% of the sampling time.[a]
3. The angle between the mean wind direction and the perpendicular to the measurement plane exceeds 45° for more than 20% of the sampling time.
4. Daylight is insufficient for safe equipment operation. (Exception made in case of adequate artificial lighting.)
5. Source conditions deviates from predetermined criteria (e.g., loading equipment malfunction, water splashing, truck spills).

[a] "Mean" denotes a 5-min average.

Appendix C

Detailed Test Data

Run	Date	Location	ID	Start Time	Stop Time	Duration (min)	Avg. Temp. (deg. F)	Avg. B. P. (in. Hg)	Avg. Filter Press. (in. H2O)	Filter Number	Tare (g)	Final (g)	Non-blank Corrected Catch (mg)	Blank Corrected Catch (mg)	Flow rate (acfm)	Measured (Raw) Conc. (ug/m3)	Net Conc. (ug/m3)	Wind Speed (mph)	PM-10 Exposure (mg/cm2)
CM-1	9/23/2003	1.3 UW	78	8:34	11:41	187	63	28.53	18.17	166141	4254.0	4257.1	3.1	3.96	39.99	18.7	NA	3.78	0.03551
		2.7 UW	66	8:34	11:41	187	63	28.53	17.77	166142	4260.6	4264.1	3.5	4.36	40.16	20.5	"	4.42	0.04544
		4.1 UW	75	8:34	11:41	187	63	28.53	18.07	166143	4253.6	4257.2	3.6	4.46	40.79	20.7	"	4.78	0.04951
		6.0 UW	74	8:34	11:41	187	63	28.53	18.27	166144	4265.4	4268.2	2.8	3.66	40.53	17.1	"	5.11	0.04371
		1.3 DW	68	8:38	11:41	183	63	28.53	18.57	166145	4253.4	4260.7	7.3	8.16	40.30	39.1	20.4	3.78	0.03784
		2.7 DW	76	8:38	11:41	183	63	28.53	18.23	166146	4252.6	4258.2	5.6	6.46	40.40	30.9	10.4	4.42	0.02244
		4.1 DW	67	8:38	11:41	183	63	28.53	18.50	166147	4263.1	4269.8	6.7	7.56	41.12	35.5	14.8	4.78	0.03479
		6.0 DW	71	8:38	11:41	183	63	28.53	18.17	166148	4243.0	4246.8	3.8	4.66	40.75	22.1	5.0	5.11	0.01257
CM-2	9/23/2003	1.3 UW	78	12:52	15:47	175	75	28.48	18.27	166149	4257.0	4259.9	2.9	3.76	41.03	18.5	NA	5.79	0.05024
		2.7 UW	66	12:52	15:47	175	75	28.48	17.93	166150	4258.9	4261.7	2.8	3.66	41.20	17.9	"	6.79	0.05720
		4.1 UW	75	12:52	15:47	175	75	28.48	18.20	166151	4249.2	4252.0	2.8	3.66	41.85	17.7	"	7.37	0.06108
		6.0 UW	74	12:52	15:47	175	75	28.48	18.53	166152	4248.8	4251.1	2.3	3.16	41.58	15.4	"	7.89	0.05687
		1.3 DW	68	12:58	15:47	169	75	28.48	18.87	166153	4252.7	4262.6	9.9	10.76	41.34	54.4	35.9	5.79	0.09415
		2.7 DW	76	12:58	15:47	169	75	28.48	18.67	166154	4258.4	4267.6	9.2	10.06	41.43	50.8	32.8	6.79	0.10105
		4.1 DW	67	12:58	15:47	169	75	28.48	18.80	166155	4248.0	4255.4	7.4	8.26	42.17	40.9	23.3	7.37	0.07776
		6.0 DW	71	12:58	15:47	169	75	28.48	18.70	166156	4251.1	4254.2	3.1	3.96	41.79	19.8	4.5	7.89	0.01597
CM-4	9/25/2003	1.3 UW	78	12:44	16:00	196	65	28.74	20.00	166165	4269.2	4273.3	4.1	4.96	39.74	22.5	NA	5.06	0.05990
		2.7 UW	66	12:44	16:00	196	65	28.74	19.53	166166	4272.7	4276.3	3.6	4.46	39.91	20.1	"	5.98	0.06336
		4.1 UW	75	12:44	16:00	196	65	28.74	19.93	166167	4279.6	4283.5	3.9	4.76	40.54	21.2	"	6.51	0.07240
		6.0 UW	74	12:44	16:00	196	65	28.74	20.13	166168	4262.6	4265.9	3.3	4.16	40.28	18.6	"	6.98	0.06836
		1.3 DW	68	12:59	15:59	180	65	28.74	20.07	166169	4255.4	4261.8	6.4	7.26	40.10	35.5	13.0	5.06	0.03188
		2.7 DW	76	12:59	15:59	180	65	28.74	19.90	166170	4260.3	4266.3	6.0	6.86	40.17	33.5	13.4	5.98	0.03861
		4.1 DW	67	12:59	15:59	180	65	28.74	20.43	166171	4264.4	4269.8	5.4	6.26	40.88	30.1	8.9	6.51	0.02792
		6.0 DW	71	12:59	15:59	180	65	28.74	20.13	166172	4280.6	4284.7	4.1	4.96	40.54	24.0	5.4	6.98	0.01819

Blank Filter Data (Runs CM-3)

Filter Number	Tare Wt. (mg)	Final Wt. (mg)	Net Wt. (mg)
166157	4268.3	4268.1	–0.2
166158	4250.3	4249.5	–0.8
166159	4244.7	4244.4	–0.3
166160	4234.7	4233.7	–1.0
166161	4248.2	4246.7	–1.5
166162	4257.4	4255.8	–1.6
166163	4278.8	4277.8	–1.0
166164	4244.5	4244.0	–0.5
		Mean	**–0.8625**
		Std Dev	**0.5181**