Reference # 1

MRI

MIDWEST RESEARCH INSTITUTE
425 Volker Boulevard
Kansas City, Missouri 64110
Telephone (816) 753-7600
Telefax (816) 753-8420

August 30, 1996

Mr. Andrew Goodrich
Air Quality Management Division
Washoe County District Health Department
401 Ryland Street, Suite 331
Reno, NV 89502

Subject: Letter Report of Field Tests, MRI Project No. 4470, "Road Sampling"

Dear Mr. Goodrich:

This letter describes the results of field tests of particulate matter emissions from both a paved road and an unpaved road in the Reno area. The major objective was to provide site-specific emission test data to supplement the yearlong surface sampling program recently completed by the Air Quality Management Division (AQMD). In addition, the program supports an ongoing EPA effort focusing on the PM-2.5 fraction of PM-10 emissions from open dust sources.

Test Sites and Sampling Method

Unpaved road tests (BK-1 through -4) occurred on May 28 and 29, 1996. The unpaved test road was an access road leading to Mira Loma near the Sage Hill Gun Club (see Figure 1). The paved road test site was Virginia Street north of Parr Boulevard (Figure 2). Table 1 presents a summary of site parameters associated with each test. Please note that the unpaved road testing employed only captive traffic supplied by either MRI or AQMD personnel. Runs BK-1 and -2 were conducted with a Ford Contour and Runs BK-3 and -4 were conducted with a Chevrolet Suburban. All passes were at a nominal speed of 15 mph.

Sampling time was long enough to provide sufficient particulate mass and to average over several cycles of the fluctuation in the emission rate (e.g., vehicle passes on the road). Sampling employed the exposure profiling method, which relies on simultaneous measurement of particulate concentrations and wind speed at various points over the effective height of the plume. The technique uses a direct mass-balance calculation scheme similar to stack testing methods rather than relying on an uncalibrated dispersion model to indirectly backcalculate an emission rate.

Figure 3 provides a schematic illustration of equipment deployment. The standard sampling device was a high-volume air sampler fitted with a cyclone preseparator (Figure 4). The cyclone exhibits an effective 50% cutoff diameter of approximately 10 µmA when operated at a flow rate of 40 ACFM (68 m^3/hr) and collects the PM-10 sample on an 8 in by 10 in glass fiber filter. Reference method PM-10 samplers were operated upwind and downwind of the roadway as well. Finally, some additional samplers were operated in conjunction with the EPA PM-2.5 program.

The air sampling and analysis described in this report were subject to various quality assurance/quality control activities as described in Appendix A.

Data Analysis and Results

Appendix B contains a copy of the spreadsheet used to analyze results from the tests. The spreadsheet contains the start/stop times, flow rates, ambient meteorological data and gravimetric results needed to calculate PM-10 concentrations for the various samplers.

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

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

$$C = 10^3 \frac{m}{Qt}$$

where:

where:	C	=	particulate concentration (µg/m^3)
	m	=	particulate sample weight (mg)
	Q	=	sampler flow rate (m^3/min)
	t	=	duration of sampling (min)

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

$$E(h) = 10^{-7} \times CUt$$

where: $E(h)$ = particulate exposure (mg/cm^2) at height h (m)
C = net concentration (μg/m^3)
U = approaching wind speed (m/s)
t = duration of sampling (s)

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 such as a road, a one-dimensional integration is used:

$$A1 = \int_0^H E \, dh$$

where: $A1$ = integrated exposure (m-mg/cm^2)
E = particulate exposure (mg/cm^2)
h = vertical distance coordinate (m)
H = effective extent of plume above ground (m)

The effective height of the plume is found by linear extrapolation of the net concentrations to a value of zero.

Because exposures are measured at discrete heights of the plume, a numerical integration is necessary to determine A1. The exposure must equal zero at the vertical extremes of the profile (i.e., at the ground where the wind velocity equals zero and at the effective height of the plume where the net concentration equals zero). However, the maximum exposure usually occurs below a height of 1 m, so that there is a sharp decay in exposure near the ground. To account for this sharp decay, the value of exposure at the ground level is set equal to the value at a height of 1 m. The integration is then performed using Simpson's rule. Because Simpson's rule requires an odd number of equally spaced points, additional points are obtained (if needed) by linear extrapolation.

The PM-10 emission factor for particulate generated by vehicular traffic on a straight road segment expressed in grams of emissions per vehicle-mile traveled (VMT) is given by:

$$e = 1.609(10^4) \frac{A1}{N}$$

where: e = particulate emission factor (g/VMT)
$A1$ = integrated exposure (m-mg/cm^2)
N = number of vehicle passes (dimensionless)

Table 2 presents the emission factor calculated for each test run.

Also shown in Table 2 are the emission factors estimated for each test on the basis of AP-42 predictive equations. These equations rely on road surface and traffic parameters to estimate the emission factor for a road. MRI collected surface samples from the unpaved road site and AQMD collected surface material samples for the northbound and southbound lanes of the Virginia Street test site. All surface samples underwent sieve analysis at MRI's main laboratories.

The AP-42 paved road emission factor is given by

$$e = 7.3\ (sL/2)^{0.65}\ (W/3)^{1.5} \qquad (1)$$

where:
- e = PM-10 emission factor (g/VMT)
- sL = Silt loading (g/m^2), mass of material less than 200 mesh per unit area of road surface
- W = mean vehicle weight (tons)

The AP-42 unpaved road emission factor is given by

$$e = 960\ (s/12)\ (S/30)\ (W/3)^{0.7}\ (w/4)^{0.5} \qquad (2)$$

where:
- e = PM-10 emission factor (g/VMT)
- s = surface material silt content (%)
- S = mean vehicle speed (mph)
- W = mean vehicle weight (tons)
- w = mean number of wheels per vehicle

In general, there appears to be reasonable agreement between the predicted and measured emissions factors. For the paved road tests, Equation 1 produced a predicted value roughly a factor of two lower than the measured value. For the unpaved road emission factors, Equation 2 results in particularly close estimates for runs BK-1 and -2.

On the other hand, the predicted factors for runs BK-3 and -4 tend to be substantially lower than the measured values. However, by the end of testing, the road had become severely rutted. For testing purposes, the road had been subjected to far more traffic than usual and this may have upset "equilibrium" conditions. Furthermore, once the Suburban was used to generate captive traffic, the rate of road deterioration increased. The emission factor measured for run BK-4 is roughly twice that for run BK-3, even though traffic conditions remained unchanged between the two tests. This suggests that the road surface was badly deteriorating and emissions were not at steady-state conditions. In that case, the failure of Equation 2 to accurately predict measured emission factors would be expected.

Please call me at (816) 753-7600, Extension 1596, with any questions or comments.

Sincerely,

MIDWEST RESEARCH INSTITUTE

Gregory E. Muleski, Ph.D.
Principal Environmental Engineer

Approved:

Thomas J. Grant, Ph.D., P.E.
Director
Applied Engineering

Table 1. Test Site Parameters

					Mean Meteorology [a]			
Run	Paved/ unpaved	Date	Start time	Duration (min)	Air temp°F	Barometric pressure (in Hg)	3m Wind speed (mph)	Number of vehicle passes
BK-1	U	5/28/96	16:19	59	72	25.5	6.0	138
BK-2	U	5/28/96	17:35	29	70	25.5	6.5	150
BK-3	U	5/29/96	15:33	47	70	25.4	6.6	100
BK-4	U	5/29/96	16:40	27	71	25.4	6.6	80
BK-7	P	6/3/96	12:17	420	89	25.4	7.6	3400/4000[b]
BK-8	P	6/4/96	14:47	270	87	25.3	6.4	3100/2600[b]
BK-9[c]	P	6/6/96	14:45	240	90	25.3	2.8	2600/2000[b]

[a] Averages over test duration.
[b] Northbound/southbound counts recorded by pneumatic tube counted.
[c] Winds during run BK-9 were light and variable.

Table 2. Measured and Predicted Emission Factor

					Emission factor (g/VMT)	
Run	Silt content (%)	Silt loading (g/m^2)	Mean vehicle weight (tons)	Mean speed (mph)	Estimated	Measured
BK-1	7.2	—	1.5	15	180	170
BK-2	5.2	—	1.5	15	130	140
BK-3	5.9	—	2	15	180	670
BK-4	6.6	—	2	15	200	1200
BK-7	3.3	0.082[a]	2	45	0.50	1.3
BK-8	3.3	0.082[a]	2	45	0.50	1.0

[a] Average of northbound and southbound samples which had silt loadings of 0.102 and 0.062 g/m^2, respectively.

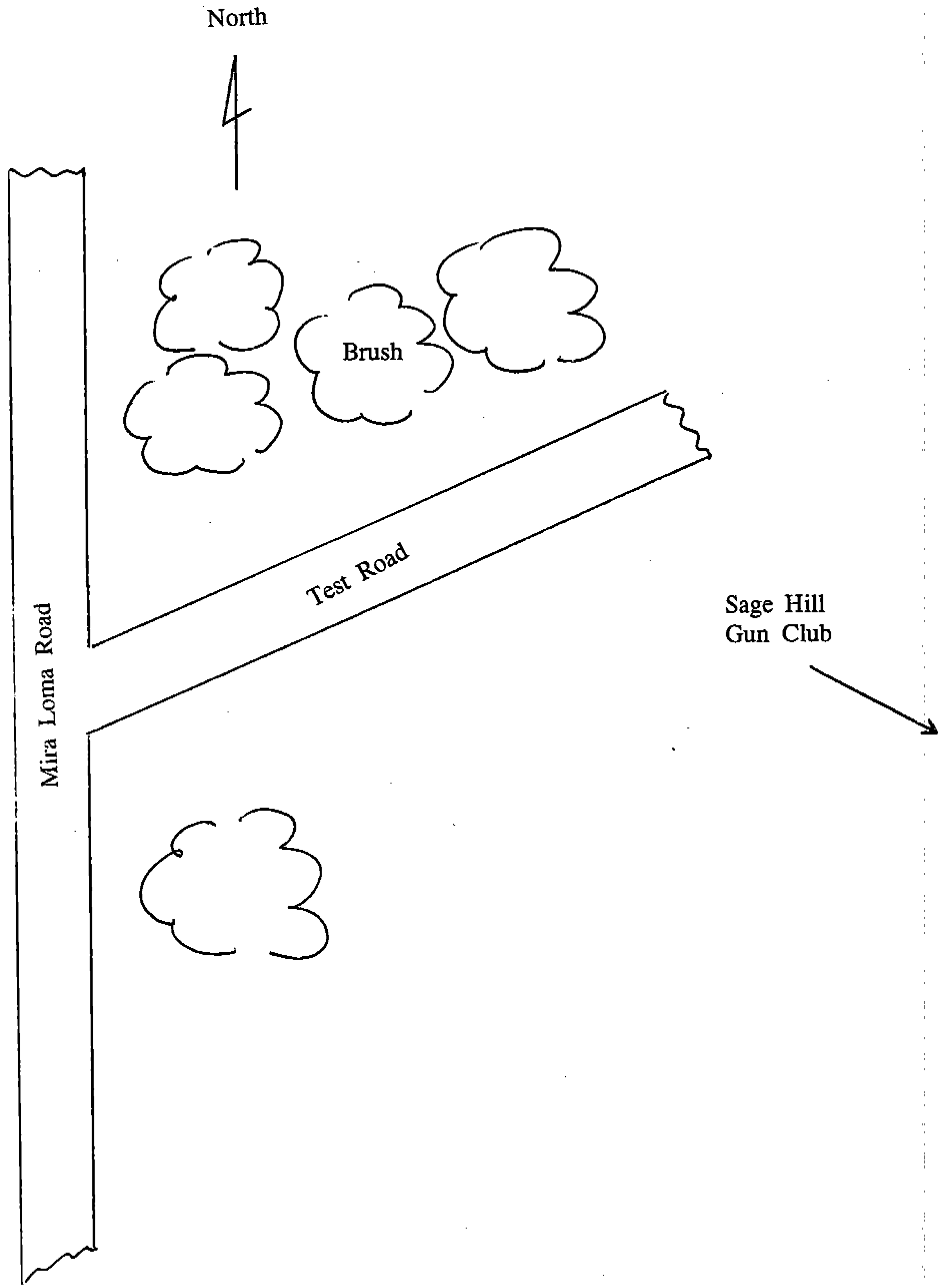

Figure 1. Unpaved Road Test Site

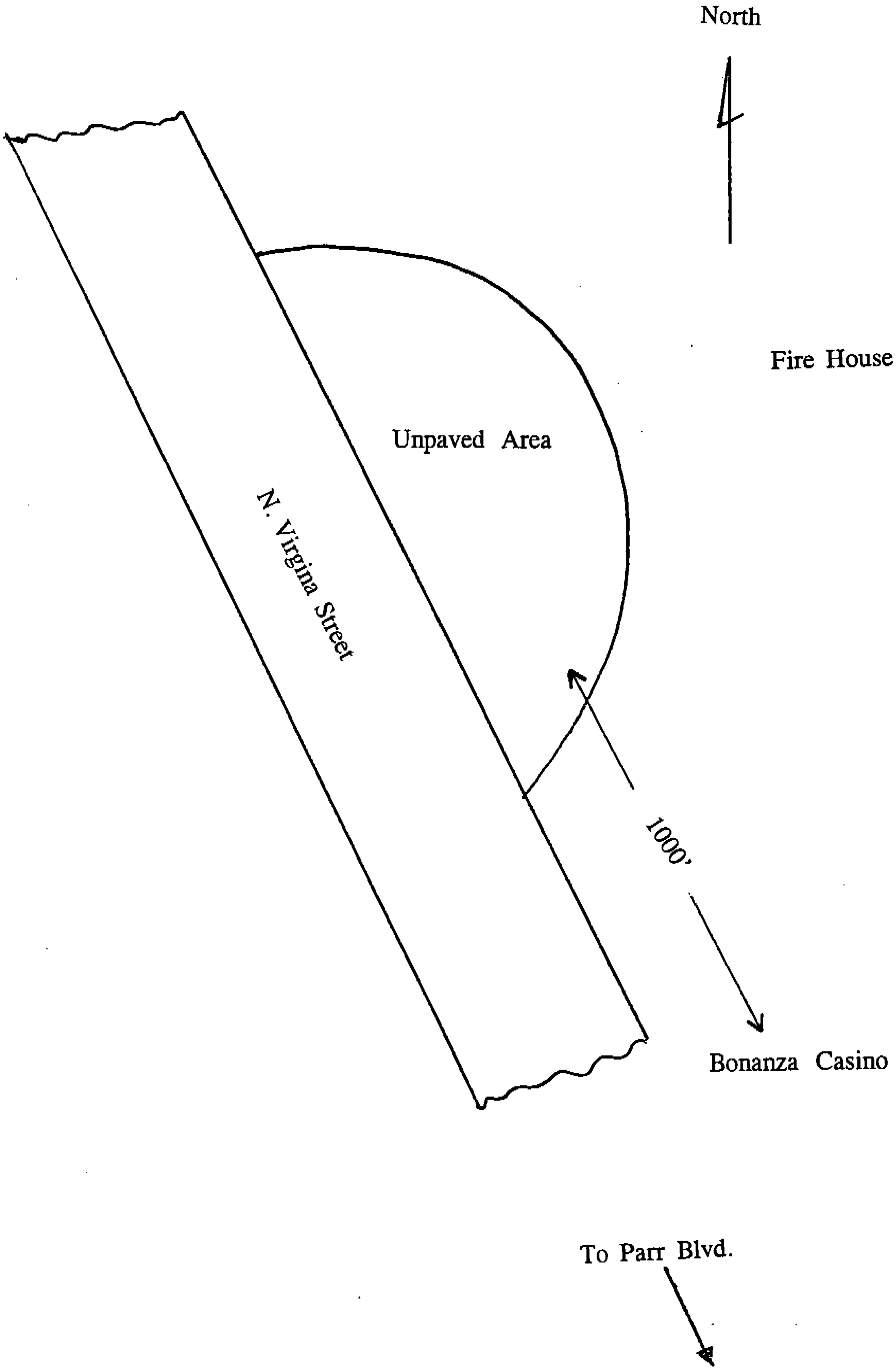

Figure 2. Paved Road Test Site

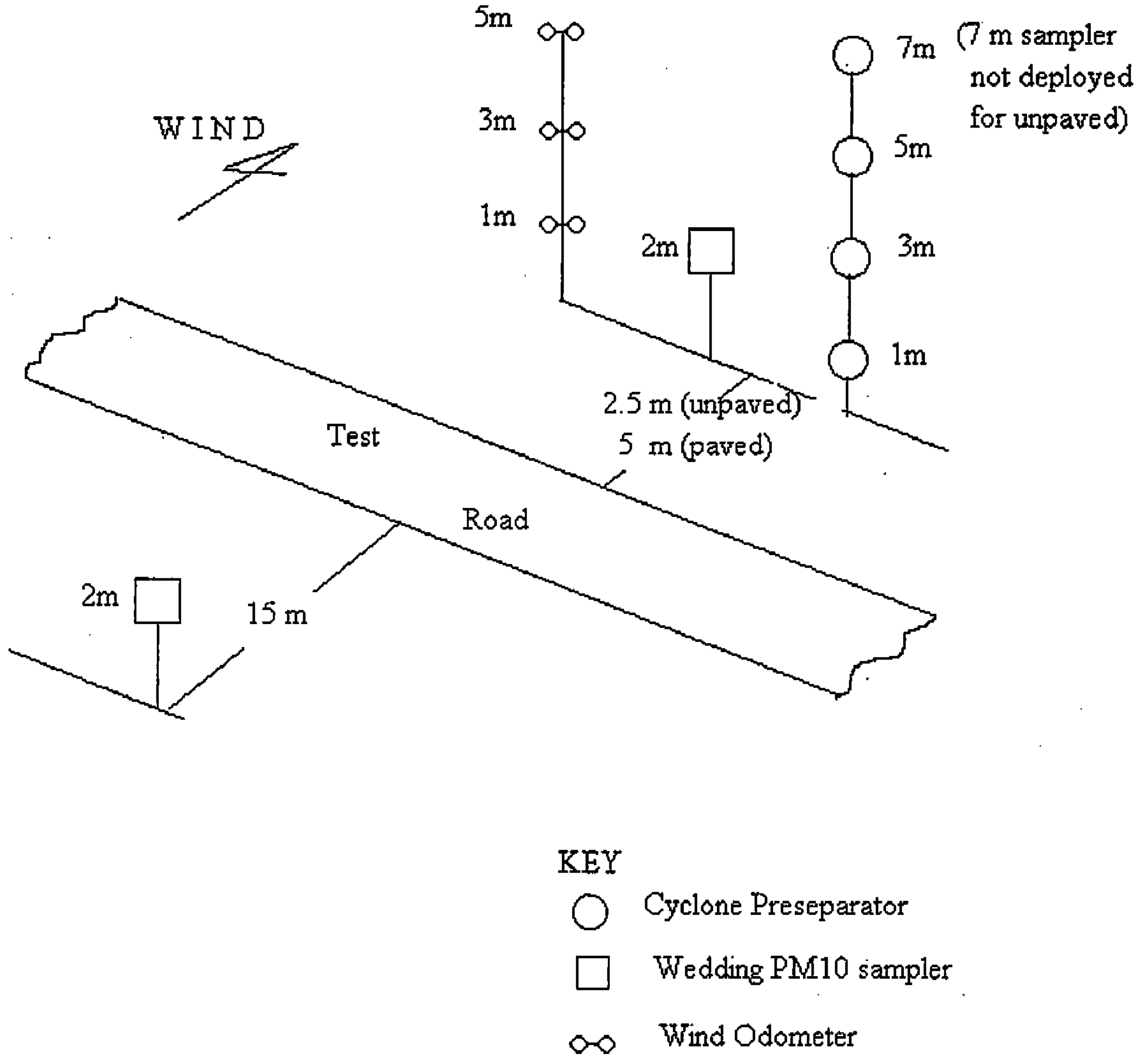

Figure 3. Equipment Deployment

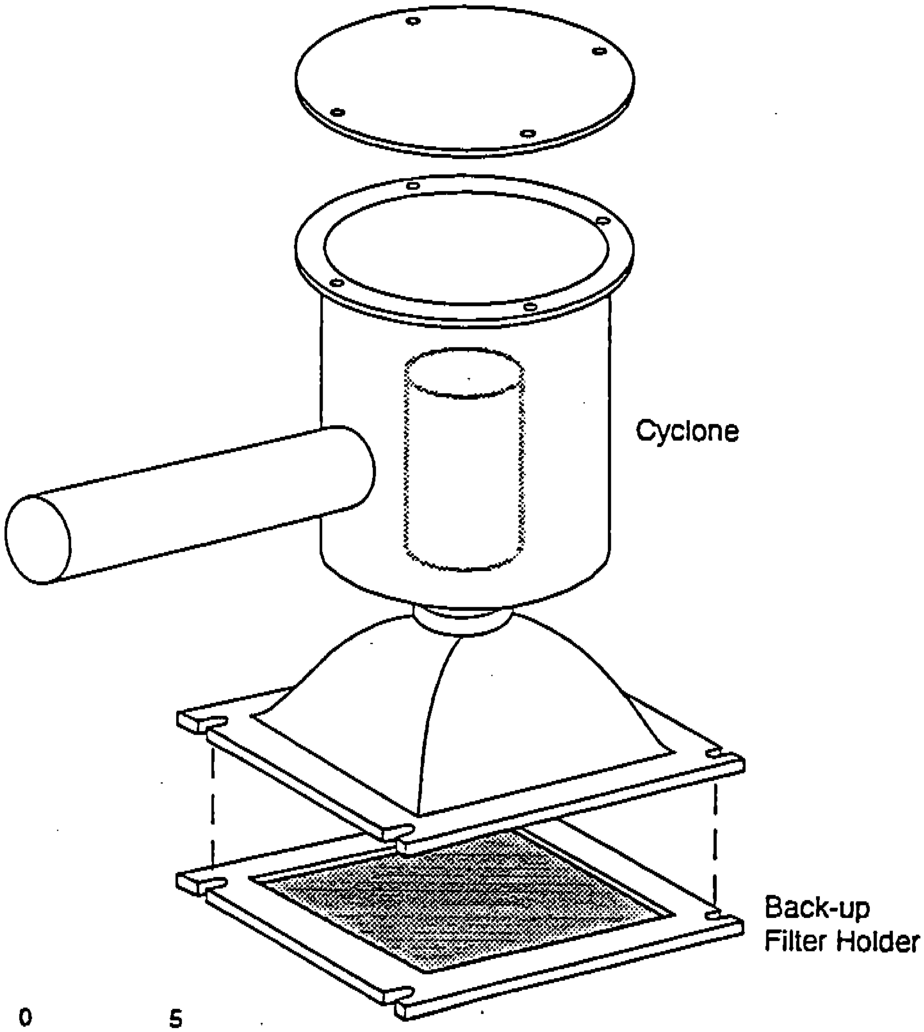

Figure 4. Cyclone Preseparator

Appendix A

General Air Sample Handling, Quality Assurance and Testing Procedures

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

The sampling and analysis procedures followed are subject to certain QA guidelines. These guidelines will be discussed in conjunction with the activities to which they apply. These procedures meet or exceed the requirements specified in the reports entitled "Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II—Ambient Air Specific Methods" (EPA 600/4-77-027a) and "Ambient Monitoring Guidelines for Prevention of Significant Deterioration" (EPA 450/2-78-019).

As part of the QA program, routine audits of sampling and analysis procedures are performed. The purpose of the audits is to demonstrate that measurements were 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 the laboratory aids in the auditing procedure. Further details on specific sampling and analysis procedures are provided in the following sections.

Particulate samples are collected on glass fiber filters. Prior to the initial weighing, the filters are equilibrated for 24 h at constant temperature and humidity in a special weighing room. 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 for another 24 h, after which a second analyst reweighs them as a precision check. Ten percent of the filters used in the field serve as blanks. The QA guidelines pertaining to preparation of sample collection media and equipment operations are presented in Tables A-1 and A-2, respectively.

To prevent particulate losses, the exposed media are carefully transferred at the end of each run to protective containers for transportation. The interior surfaces of cyclone preseparators are washed with distilled water; particulate matter that collected on the interior surfaces of cyclone preseparators during sizing tests is rinsed into separate sample jars which are then capped and taped shut. In the field laboratory, exposed filters are placed in individual glassine envelopes and then into numbered file folders. When exposed filters and the associated blanks are returned to the MRI laboratory, they are equilibrated under the same conditions as the initial weighing. After reweighing, 10% are audited to check weighing accuracy.

To determine the sample weight of particulate collected on the interior surfaces of samplers, the entire wash solution is passed through a Büchner-type funnel holding an 47-cm glass fiber filter under suction. This ensures collection of all suspended material on the filter. (The 11-cm filters can be substituted for standard 47-mm filters because of the large amount of material collected in the cyclone.

All wash filters are weighed with a 100% audit of tared and a 10% audit of exposed filters. Blank values are determined by washing "clean" (unexposed) cyclone preseparators in the field and following the above procedures.

TABLE A-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 h in clean controlled room with relative humidity of 45% (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 0.1 mg.
Auditing of weights	Independently verify final weights of 10% of filters (at least four from each batch). Reweigh batch if weights of any hi-vol filters deviate by more than ±2.0 mg. For tare weights, conduct a 100% audit. Reweigh tare weight of any filters that deviate by more than ±1.0 mg. Follow same procedures for impactor substrates used for sizing tests. Audit limits for impactor substrates are 1.0 and 0.5 mg for final and tare weights, respectively.
Correction for handling effects	Weigh and handle at least one blank for each 1 to 10 filters of each type used to test.
Calibration of balance	Balance to be calibrated once per year by certified manufacturer's representative. Check prior to each use with laboratory Class S weights.

TABLE A-2. QUALITY ASSURANCE PROCEDURES FOR SAMPLING EQUIPMENT

Activity	QA check/requirement[a]
Maintenance • All samplers	Check motors, gaskets, timers, and flow measuring devices at each plant prior to testing.
Operation • Timing	Start and stop all downwind samplers during time span not exceeding 1 min.
• Isokinetic sampling (cyclones)	Adjust sampling intake orientation whenever mean wind direction dictates. Change the cyclone intake nozzle whenever the mean wind speed approaching the sampler falls outside of the suggested bounds for that nozzle. This technique allocates no nozzle for wind speeds ranging from 0 to 10 mph, and unique nozzles for four wind speed ranges above 10 mph.
• Prevention of static mode deposition	Cover sampler inlets prior to and immediately after sampling.

[a] "Mean" denotes a 3- to 15-min average.

Appendix B

Spreadsheet Used to Calculate Concentrations

N	O	P	Q	R	S	T	U	V	W	X
Run	Sampler Location	Filter Number	Tare Wt. (mg)	Final Wt. (mg)	Net Wt. (mg)	Wt. after Blank Correction		PM10 Concentration (ug/m^3)	PM10 Concentration (upwind corrected)	Mean Wind Speed (mph)
BK-1	Wedding 2m UW	9552062	4148.50	4153.20	4.70	5.18		33		
	Cyclone 1m DW	9541201	4243.10	4349.90	106.80	106.95		1551		3.0
	Cyclone 3m DW	9541202	4220.20	4228.80	8.60	8.75		127		6.0
	Cyclone 5m DW	9541203	4225.35	4227.55	2.20	2.35		35		6.0
	Wedding 2m DW	9552063	4145.25	4181.35	36.10	36.58		493		4.6
BK-2	Cyclone 1m DW	9541206	4234.00	4335.25	101.25	101.40		2994		2.8
	Cyclone 3m DW	9541207	4242.00	4249.15	7.15	7.30		216		6.5
	Cyclone 5m DW	9541208	4278.55	4279.45	0.90	1.05		32		7.5
	Wedding 2m DW	9552064	4163.25	4192.50	29.25	29.73		859		5.0
BK-3	Wedding 2m UW	9552065	4160.10	4169.25	9.15	9.63		83		
	Cyclone 1m DW	9541209	4295.35	4530.25	234.90	235.05		4286		3.3
	Cyclone 3m DW	9541210	4259.65	4293.20	33.55	33.70		616		6.6
	Cyclone 5m DW	9541211	4266.45	4274.15	7.70	7.85		146		8.0
	Wedding 2m DW	9552066	4235.35	4302.15	66.80	67.28		1453		5.4
BK-4	Cyclone 1m DW	9541214	4247.50	4580.60	333.10	333.25		10581		3.3
	Cyclone 3m DW	9541215	4265.70	4308.60	42.90	43.05		1373		6.6
	Cyclone 5m DW	9541216	4262.70	4268.55	5.85	6.00		194		8.0
	Wedding 2m DW	9552067	4313.05	4403.80	90.75	91.23		2858		5.4
BK-7	Wedding 2m UW	9552075	4206.89	4217.75	10.86	10.51		20		
	Cyclone 1m DW	9541235	4288.75	4305.20	16.45	16.26		33		5.6
	Cyclone 3m DW	9541236	4271.10	4283.55	12.45	12.26		25		6.9
	Cyclone 5m DW	9541237	4300.90	4312.55	11.65	11.46		23		7.6
	Cyclone 7m DW	9541238	4301.95	4315.90	13.95	13.76		28		8.0
	Wedding 2m DW	9552073	4233.30	4248.40	15.10	14.75		29		6.4
BK-8	Wedding 2m UW	9552076	4211.30	4217.65	6.35	6.00		17		
	Cyclone 1m DW	9541250	4329.25	4339.80	10.55	10.36		33		4.5
	Cyclone 3m DW	9541249	4313.70	4320.45	6.75	6.56		21		5.8
	Cyclone 5m DW	9541248	4296.60	4303.95	7.35	7.16		23		6.4
	Cyclone 7m DW	9541247	4305.35	4313.75	8.40	8.21		26		6.8
	Wedding 2m DW	9552077	4210.35	4219.00	8.65	8.30		26		5.3
BK-9	Wedding 2m UW	9552078	4214.00	4221.40	7.40	7.05		23		
	Cyclone 1m DW	9541253	4302.65	4311.35	8.70	8.51		30		1.6
	Cyclone 3m DW	9541254	4306.30	4313.25	6.95	6.76		24		2.4
	Cyclone 5m DW	9541255	4298.45	4303.45	5.00	4.81		17		2.8
	Cyclone 7m DW	9541256	4314.55	4320.30	5.75	5.56		20		3.0
	Wedding 2m DW	9552079	4209.40	4216.70	7.30	6.95		24		2.1

FIELD BLANKS

Run	Sampler Location	Filter Number	Tare Wt. (mg)	Final Wt. (mg)	Net Wt. (mg)
BK-5	Wedding 2m UW	9552068	4317.75	4317.45	-0.30
	Cyclone 1m DW	9541219	4286.90	4286.90	0.00
	Cyclone 3m DW	9541220	4271.90	4271.95	0.05
	Cyclone 5m DW	9541221	4298.80	4298.30	-0.50
	Wedding 2m DW	9552069	4241.00	4240.35	-0.65

Unpaved glass fiber blank average = -0.15, Sx = 0.30
Unpaved quartz blank average = -0.48, Sx = 0.25

Run	Sampler Location	Filter Number	Tare Wt. (mg)	Final Wt. (mg)	Net Wt. (mg)
BK-6	Wedding 2m UW	9552072	4243.20	4243.55	0.35
	Cyclone 1m DW	9541227	4296.30	4297.10	0.80
	Cyclone 3m DW	9541228	4286.25	4286.35	0.10
	Cyclone 5m DW	9541229	4281.75	4282.05	0.30
	Cyclone 7m DW	9541230	4338.45	4338.00	-0.45
	Wedding 2m DW	9552071	4236.25	4236.60	0.35

Paved glass fiber blank average = 0.19, Sx = 0.52
Paved quartz blank average = 0.35, Sx = 0.00

S8=R8-Q8
T8=S8+0.48 for BK-1-4 Weddings, =S8+0.15 for BK-1-4 cyclones, =S8-0.35 for BK-6-9 Weddings, =S8-0.19 for BK-6-9 cyclones
V8=(T8*1000)/(L8*H8*0.02832)
Y8=L8/(nozzle area*X8*88)
Z8=W8*0.0000001*X8*H8*0.44704*60

Run	Date	Sampler Location	Sampler ID	Sampler Start Time	Sampler Stop Time	Sampler Run Time (min)	Avg. Temp. (deg. F)	Avg. B.P. (in. Hg)	Avg. Filter Pressure (in. H2O)	Flowrate (ft^3/min)
BK-1	05/28/96	Wedding 2m UW	1598	16:10	18:22	132	71	25.48	16.98	41.54
		Cyclone 1m DW	76	16:19	17:18	59	72	25.48	16.17	41.27
		Cyclone 3m DW	66	16:19	17:18	59	72	25.48	15.48	41.14
		Cyclone 5m DW	78	16:19	17:18	59	72	25.48	15.55	40.53
		Wedding 2m DW	1424	16:20	17:22	62	72	25.48	16.97	42.28
BK-2 (a)	05/28/96	Cyclone 1m DW	76	17:35	18:04	29	70	25.48	15.96	41.24
		Cyclone 3m DW	66	17:35	18:04	29	70	25.48	15.66	41.07
		Cyclone 5m DW	78	17:35	18:04	29	70	25.48	15.59	40.46
		Wedding 2m DW	1424	17:35	18:04	29	70	25.48	17.43	42.12
BK-3	05/29/96	Wedding 2m UW	1598	15:32	17:11	99	70	25.45	17.07	41.50
		Cyclone 1m DW	76	15:33	16:20	47	70	25.45	16.38	41.20
		Cyclone 3m DW	66	15:33	16:20	47	70	25.45	15.75	41.07
		Cyclone 5m DW	78	15:33	16:20	47	70	25.45	15.60	40.46
		Wedding 2m DW	1424	15:41	16:20	39	70	25.45	18.32	41.91
BK-4 (b)	05/29/96	Cyclone 1m DW	76	16:40	17:07	27	71	25.45	16.62	41.19
		Cyclone 3m DW	66	16:40	17:07	27	71	25.45	16.11	41.01
		Cyclone 5m DW	78	16:40	17:07	27	71	25.45	15.57	40.49
		Wedding 2m DW	1424	16:40	17:07	27	71	25.45	19.43	41.75
BK-7	06/03/96	Wedding 2m UW	1598	11:53	19:37	464	89	25.37	18.54	40.91
		Cyclone 1m DW	66	12:17	19:17	420	89	25.37	16.18	41.63
		Cyclone 3m DW	78	12:17	19:17	420	89	25.37	16.02	41.06
		Cyclone 5m DW	68	12:17	19:17	420	89	25.37	16.02	41.50
		Cyclone 7m DW	76	12:17	19:17	420	89	25.37	16.35	41.85
		Wedding 2m DW	1424	12:17	19:17	420	89	25.37	18.41	42.66
BK-8	06/04/96	Wedding 2m UW	1598	14:42	19:43	301	87	25.28	18.68	41.82
		Cyclone 1m DW	66	14:47	19:17	270	87	25.28	16.54	41.52
		Cyclone 3m DW	78	14:47	19:17	270	87	25.28	15.80	40.99
		Cyclone 5m DW	68	14:47	19:17	270	87	25.28	15.83	41.43
		Cyclone 7m DW	76	14:47	19:17	270	87	25.28	16.50	41.73
		Wedding 2m DW	1424	14:47	19:17	270	87	25.28	18.78	42.43
BK-9	06/06/96	Wedding 2m UW	1598	14:37	18:56	259	90	25.28	18.84	41.89
		Cyclone 1m DW	66	14:45	18:45	240	90	25.28	16.40	41.62
		Cyclone 3m DW	78	14:45	18:45	240	90	25.28	16.26	41.05
		Cyclone 5m DW	68	14:45	18:45	240	90	25.28	16.36	41.44
		Cyclone 7m DW	76	14:45	18:45	240	90	25.28	16.31	41.89
		Wedding 2m DW	1424	14:45	18:45	240	90	25.28	18.47	42.63

(a) Upwind is the same as BK-1
(b) Upwind is the same as BK-3