Reference # 9

MIDWEST RESEARCH INSTITUTE

MRI REPORT

FUGITIVE EMISSION MEASUREMENT OF COAL YARD TRAFFIC AT POWER PLANT

FINAL REPORT

MRI Project No. 8162-L

December 31, 1985

Prepared for

For a confidential client

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FUGITIVE EMISSION MEASUREMENT OF COAL YARD TRAFFIC AT POWER PLANT

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SECTION 1.0

INTRODUCTION

This report presents the results of a field testing program performed by Midwest Research Institute (MRI) at power plant. Seven tests of particulate emissions generated by vehicle traffic on a watered, unpaved surface were conducted on Friday, August 9, 1985. Four uncontrolled tests were performed at the same location the next day.

The airborne particle size fractions of interest in this report are:

- TP Total airborne particulate matter.
- SP Suspended particulate matter consisting of particles equal to or smaller than 30 μm in aerodynamic diameter.
- IP Inhalable particlate matter consisting of particles equal to or smaller than 15 μm in aerodynamic diameter.
- PM_{10} Thoracic particulate matter consisting of particles equal to or smaller than 10 μm in aerodynamic diameter.
- FP Fine particulate matter consisting of particles equal to or smaller than 2.5 μm in aerodynamic diamter.

The SP size fraction in this study reflects potential air quality impact as measured by the standard high-volume sampler. The 50% cutpoint for this sampler can range between 25 and 50 μm in aerodynamic diameter (μmA) depending on wind speed and direction. An effective cutpoint of 30 μmA is usually assigned to the standard high-volume sampler (USEPA, 1982; 1983).

The following sections of this report present (a) the test methodology used, (b) the test results obtained, and (c) the conclusions derived from this testing program.

SECTION 2.0

TEST METHODOLOGY

2.1 DESCRIPTION OF SOURCE OPERATION

A map showing the [redacted] coal yard (as of the week of August 5, 1985) is shown as Figure 2-1. In both stockpiling and reclaiming operations, scrapers traveled up (i.e., west) Road No. 2 onto the main reserve pile and exited by going down the pile to Road No. 1.

As shown in the figure, the northern quarter of the main pile had been removed and surveyed for drainage improvements prior to the arrival of MRI personnel. However, no activities other than reclaiming fuel from the main pile occurred during the week of testing.

Plans were originally made to test particulate emissions from scraper traffic on Road No. 1. However, rainfall during August 5 through 7 and subsequent drainage from the pile onto this road precluded air sampling at this site. As a result, all 11 tests were conducted using Road No. 2 which, because of its slight slope, had dried completely.

2.2 AIR SAMPLING EQUIPMENT AND TECHNIQUE

The exposure profiling technique used for the tests in this study was based on the isokinetic profiling concept that is used in conventional source testing. The passage of airborne pollutant immediately downwind of the source was measured directly by means of simultaneous multipoint sampling over the effective cross section of the open dust source plume. This technique used 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 equipment deployment for these tests is shown in Table 2-1. As shown in Figure 2-2, three downwind sampling locations (U, X, and Y) were equipped with identical air sampling devices. The common upwind station is also shown in the figure.

Each profiler head (Figure 2-3) was operated as an isokinetic exposure sampler directing passage of the flow stream through a settling chamber and then upward through a standard 8-in. by 10-in. glass fiber filter positioned horizontally. Sampling intakes were pointed into the bay, and the sampling velocity of each intake was adjusted to match the local mean wind speed, as electronically determined by 1- to 10-min averages prior to and during the test.

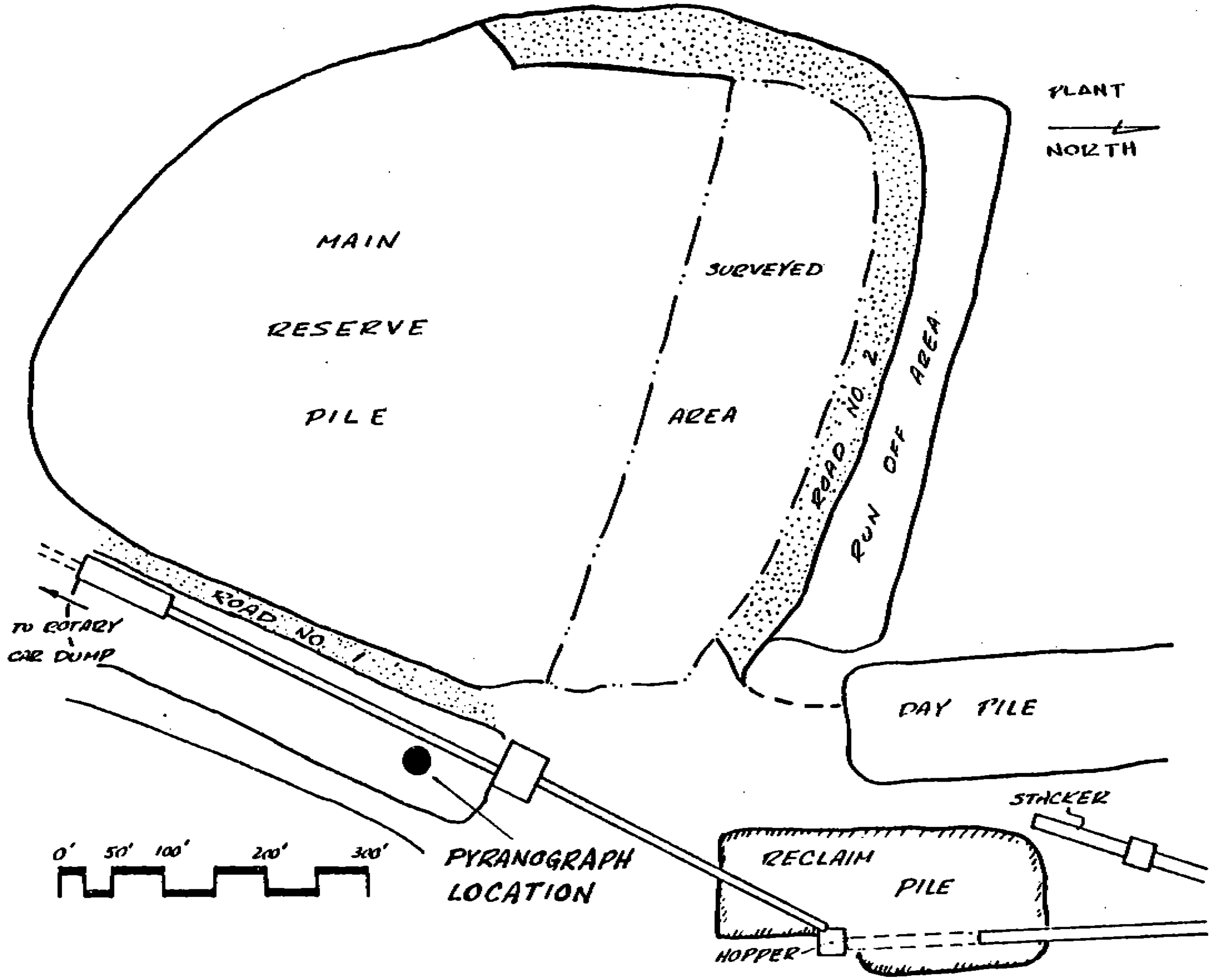

Figure 2-1. Plan view of main reserve pile at during the week of testing.

TABLE 2-1. AIR SAMPLING AND METEOROLOGICAL EQUIPMENT

Sampler	Location(s)	Intake height(s) (m)
Profiling head	X, Y, U	1.5, 3.0, 4.5, 6.0
Cyclone/impactor and 37 mm cassette	X, Y, U, upwind	2.2
Warm-wire anemometers	Y	3.0, 6.0
Wind vane	Y	4.5

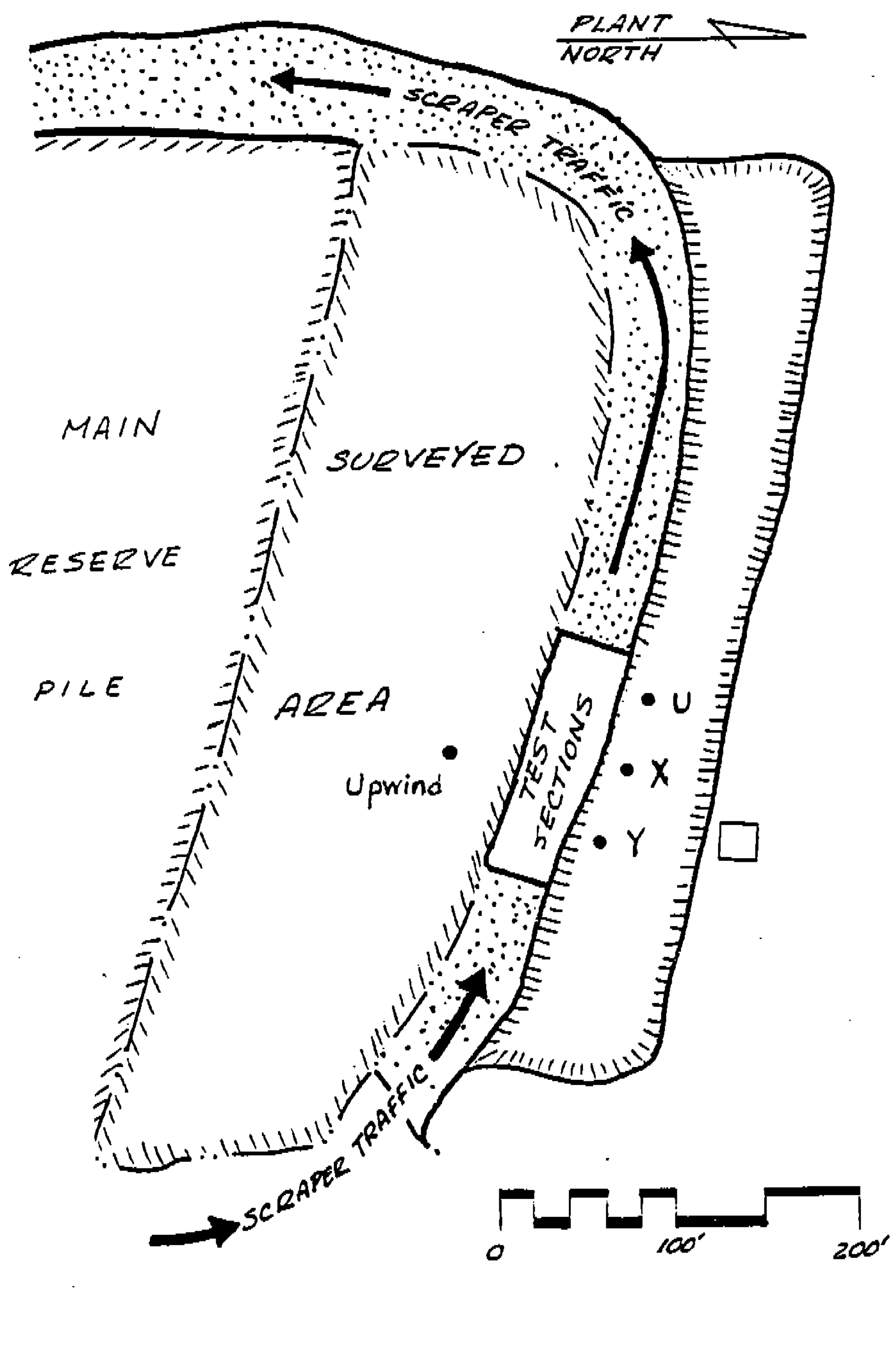

Figure 2-2. Plan view of test site, showing air sampling stations.

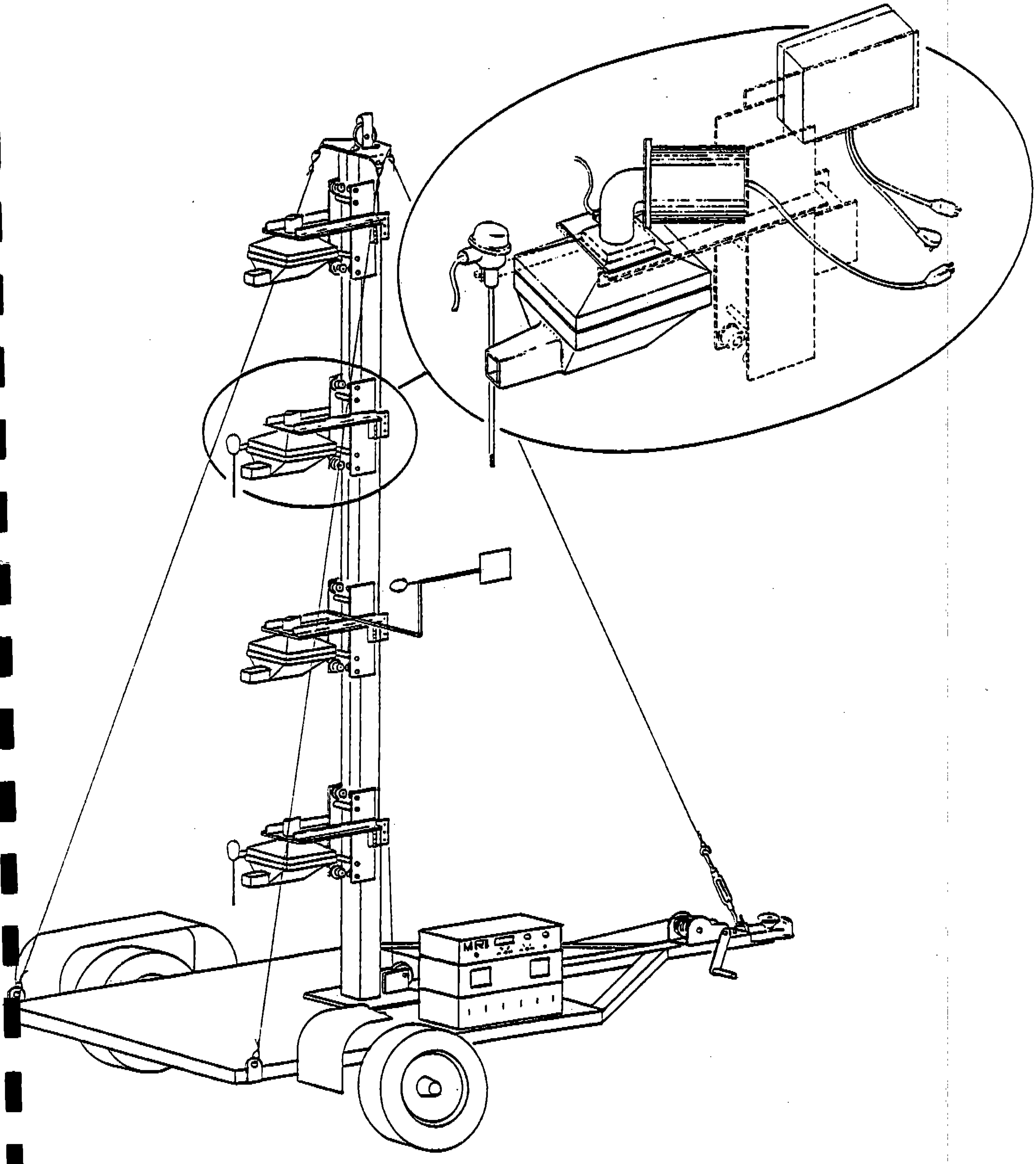

Figure 2-3. MRI exposure profiler.

Throughout each test, wind speed was monitored by warm-wire anemometers at two heights. Horizontal wind direction was monitored by a wind vane at a single height and averages (over the same period as wind speed) were determined electronically prior to and during the test.

High-volume, parallel-slot cascade impactors, (Sierra Instruments, Model No. 230) with 20 cfm flow controllers were used to measure the downwind particle size distribution. As shown in Figure 2-4, the impactor units were equipped with Sierra Model No. 230CP cyclone preseparators to remove coarse particles which otherwise would tend to bounce off the glass fiber impaction substrates, causing fine particle measurement bias. To further reduce particle bounce problems, each stage of the impactor substrates was sprayed with a stopcock grease solution to provide a sticky impaction surface. The impactors contained three impaction stages (cutoffs for 50% collection are 10.2, 4.2, and 2.1 µmA at 20 ACFM). Provision was also made to measure the upwind particle size distribution and total particulate concentration using a cyclone/impactor combination.

Because of the importance of incoming solar radiation on the control performance of watering of unpaved roads, a mechanical pyranograph (Weathertronics Model 3010) was deployed approximately 400 ft to the southwest of the test sections (see Figure 2-1). This device provided a continuous record of the intensity of direct and scattered solar radiation during the test days.

2.3 PARTICULATE SAMPLE HANDLING AND ANALYSIS

The sampling and analysis procedures followed in this field testing program were subject to certain quality assurance (QA) guidelines. These guidelines will be discussed in conjunction with the activities to which they apply. These procedures met or exceeded 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 for this study, routine audits of sampling and analysis procedures were performed. The purpose of the audits was 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 laboratory aided in the auditing procedure. Further detail on specific sampling and analysis procedures are provided in the following sections.

2.3.1 Preparation of Sample Collection Media

Particulate samples were collected on Type A slotted glass fiber impactor substrates and Type AE glass fiber filters. To minimize the problem of particle bounce, all glass fiber cascade impactor substrates were greased.

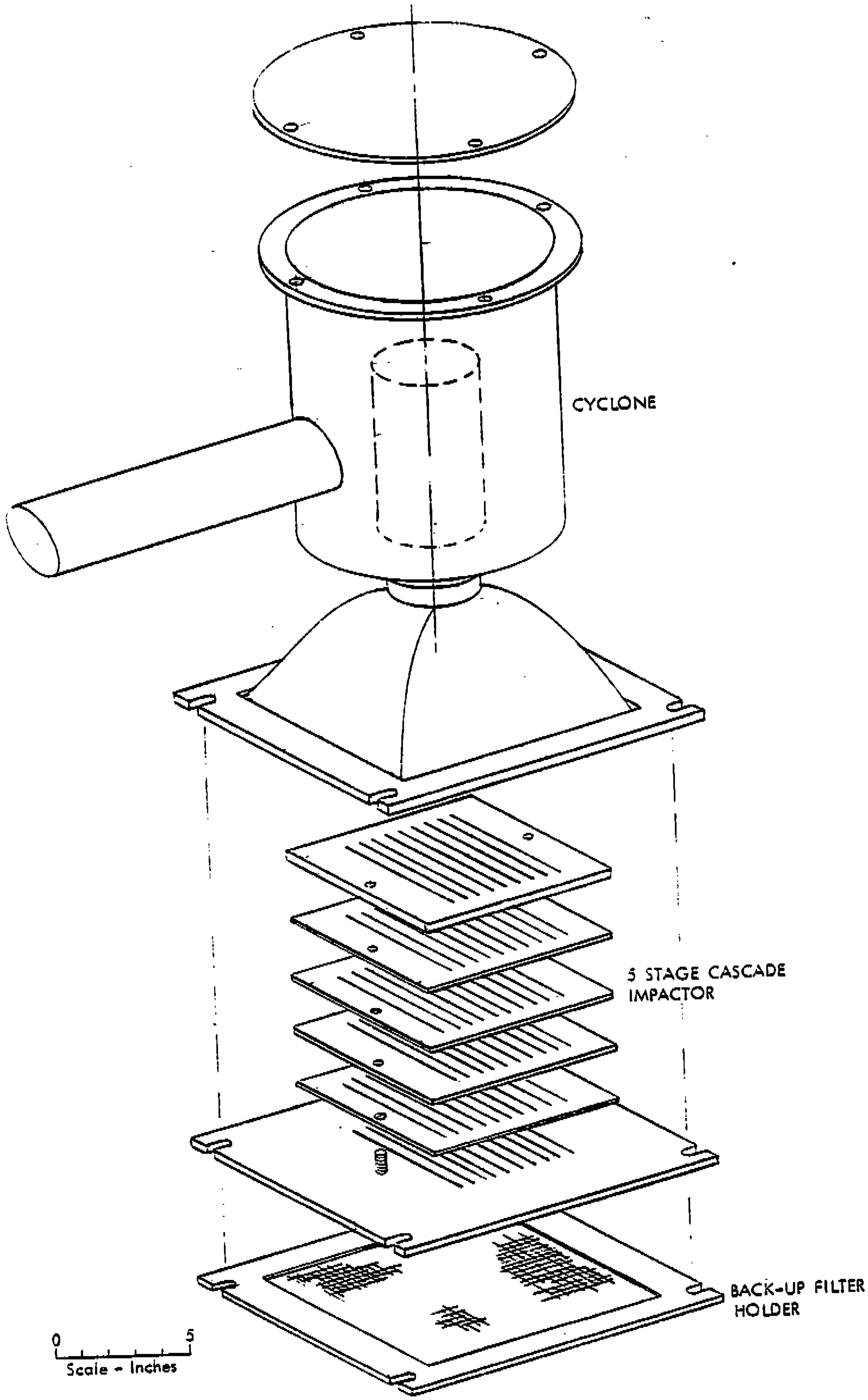

Figure 2-4. Cyclone/cascade impactor combination.

The substrates were handled, transported, and stored in specially designed frames which protect the greased surfaces.

Prior to the initial weighing, the greased substrates and filters were equilibrated for 24 hr at constant temperature and humidity in a special weighing room. During weighing, the balance was checked at frequent intervals with standard weights to assure accuracy. The substrates and filters remained in the same controlled environment for another 24 hr, after which a second analyst reweighed all as a precision check. Ten percent of the substrates and filters taken to the field were used as blanks. The quality assurance guidelines pertaining to preparation of sample collection media are presented in Table 2-2.

2.3.2 Pre-test Procedures/Evaluation of Sampling Conditions

If conditions were considered acceptable for testing on a given day, sampler deployment was initiated. During this time, the sampling flow rates were set for the various air sampling instruments. The quality control guidelines governing this activity are found in Table 2-3.

Once the source testing equipment was set up and the filters inserted, air sampling commenced. Information recorded on specially designed reporting forms for quality assurance included:

a. Exposure profiler - Start/stop times, wind speed profiles and sampler flow rates (1- to 10-min average), and wind direction.

b. Other samplers - Start/stop times and flow rates.

c. Record of loading activity.

d. General meterology - Wind speed, wind direction, and temperature.

From the information in (a), adjustments were made to ensure isokinetic sampling both of profiler heads (by changing the intake velocity) and cyclone preseparators (by changing intake nozzles). Table 2-4 outlines the pertinent QC procedures.

The duration of sampling was long enough to provide sufficient particulate mass and to average several periods of the cyclic fluctuation in the emission rate. Table 2-5 outlines the criteria used for suspending or terminating an exposure profiling test.

2.3.3 Sample Handling and Analysis

To prevent particulate losses, the exposed media were carefully transferred at the end of each run to protective containers within the MRI instrument van. In the field laboratory, exposed filters were placed in individual glassine enveloped and numbered file folders. Substrates were replaced in the protective frames. Particulate that collected on the interior surface of the cyclone preseparator was rinsed with distilled water into sample jars which were then capped and taped shut.

TABLE 2-2. QUALITY ASSURANCE PROCEDURES FOR SAMPLING MEDIA

Activity	QA check/requirement
Preparation	Inspect and imprint glass fiber media with identification numbers.
Conditioning	Equilibrate media for 24 hr in clean controlled room with relative humidity of less than 50% (variation of less than ± 5%) and with temperature between 20 C and 25 C (variation of less than ± 3%).
Weighing	Weigh hi-vol filters and impactor substrates to nearest 0.1 mg.
Auditing of weights	Independently verify final weights of 10% of hi-vol filters and impactor substrates (at least four from each batch). Reweigh batch if weights of any hi-vol filters or impactor substrates deviate by more than ± 2.0 mg and ± 1.0 mg, respectively. For tare weights, conduct a 100% audit. Reweigh tare weight of any hi-vol filters or impactor substrates that deviate by more than ± 1.0 mg, and ± 0.5 mg, respectively.
Correction for handling effects	Weigh and handle at least one blank for each 1 to 10 hi-vol filters or impactor substrates of each type for each 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 2-3. QUALITY ASSURANCE PROCEDURES FOR SAMPLING FLOW RATES

Activity	QA check/requirement
Calibration	
• Profilers, hi-vols, and impactors	Calibrate flows in operating ranges using calibration orifice upon arrival and every 2 weeks thereafter at each regional site prior to testing.
Single-point checks	
• Profiler, hi-vols, and impactors	Check 25% of units with a calibration orifice, or electronic calibrator once at each site prior to testing (different units each time). If any flows deviate by more than 7%, check all other units of same type and recalibrate noncomplying units. (See alternative below.)
• Alternative	If flows cannot be checked at test site, check all units every 2 weeks and recalibrate units which deviate by more than 7%.
Orifice calibration	Calibrate against displaced volume test meter annually.

TABLE 2-4. QUALITY ASSURANCE PROCEDURES FOR SAMPLING EQUIPMENT

Activity	QA check/requirement
Maintenance	
• All samplers	Check motors, gaskets, timers, and flow measuring devices at each plant prior to testing.
Operation	
• Timing	Start and stop all samplers during time span not exceeding 1 min.
• Isokinetic sampling (profilers only)	Adjust sampling intake orientation whenever mean[a] wind direction changes by more than 30 degrees.
	Adjust intake velocity whenever mean wind speed approaching sampler changes by more than 20%.
• Prevention of static mode deposition	Cap sampler inlets prior to and immediately after sampling.

[a] "Mean" denotes time average.

TABLE 2-5. CRITERIA FOR SUSPENDING OR TERMINATING AN EXPOSURE PROFILING TEST

A test may be suspended or terminated if:[a]

1. Rainfall ensues during equipment setup or when sampling is in progress.

2. Mean wind speed during sampling moves outside the 1.8 to 8.9 m/s (4 to 20 mph) acceptable range for more than 20% of the sampling time.

3. The angle between mean wind direction and the stationary point source or the perpendicular to the path of the moving point source during sampling exceeds 45° for more than 20% of the sampling time.

4. Mean wind direction during sampling shifts by more than 30° from profiler intake direction.

5. Mean wind speed approaching profiler sampling intake is less than 80% or greater than 120% of intake speed.

6. Daylight is insufficient for safe equipment operation.

7. Source condition deviates from predetermined criteria (e.g., occurrence of spill).

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[a] "Mean" denotes a time average.

When exposed impactor substrates and hi-vol filters (and the associated blanks) were returned to the MRI laboratory, they were equilibrated under the same conditions as the initial weighing. After reweighing, 10% were audited to check weighing accuracy (if any cannot pass audit limits, the entire lot is reweighed.) To determine the sample weight of particulate collected on the interior surface of a sampler, the entire wash solution was passed through a 47-mm Buchner type funnel holding a glass fiber filter under suction. The sample jar was then rinsed twice with 10 to 20 mL of deionized water. This water was passed through the Buchner funnel ensuring collection of all suspended material on the 47 mm filter which was then dried in an oven at 100°C for 24 hr. After drying, the filters were conditioned at constant temperature and humidity for 24 hr.

All wash filters were weighed with a 100% audit of tared and a 10% audit of exposed filters. Blank values were determined by washing "clean" (unexposed) settling chambers in the field and following the above procedures. The quality assurance guidelines governing sample handling and analysis are the same as those presented in Table 2-2.

2.3.4 Calculation Procedures

To calculate emission rates using the exposure profiling technique, a conservation of mass approach was used. The passage of airborne particulate, i.e., the quantity of emissions per unit of source activity, was obtained by spatial integration of distributed measurements of exposure (mass/area) over the effective cross section of the plume. Exposure is defined as the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement. The steps in the calculation procedure are described below.

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

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

where:

- C = particulate concentration ($\mu g/m^3$)
- m = particulate sample weight (mg)
- Q = sampler flow rate (m^3/min)
- t = duration of sampling (min)

To be consistent with the National Ambient Air Quality Standard for TSP, all concentrations and flow rates were expressed in standard conditions (77°F and 29.92 in. Hg).

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:

$$IFR = \frac{Q}{aU}$$

where: Q = sampler flow rate (m^3/min)
a = intake area of sampler (m^2)
U = mean wind speed at height of sampler (m/min)

This ratio is of interest in the sampling of TP, since isokinetic sampling assures that particles of all sizes are sampled without bias. In this study, profilers and cyclone preseparators were the directional samplers used.

If it was necessary to sample at a superisokinetic flow rate (IFR > 1.0), to obtain sufficient sample under light wind conditions, the following multiplicative factors may be used to correct measured exposures and concentrations to corresponding isokinetic values:

	Small Particles (d < 5 μmA)	Large Particles (d > 50 μmA)
Exposure Multiplier	1/IFR	1
Concentration Multiplier	1	IFR

A separate IFR was calculated for each profiler head based on the measured values of Q and U.

For a particle-size distribution containing a mixture of small, intermediate, and large particles, the isokinetic correction factor was an average of the above factors weighted by the relative proportion of large and small particles. For example, if the mass of small particles in the distribution equals twice the mass of the large particles, the weighted isokinetic correction for exposure would be:

$$(1 + 2/IFR)/3$$

Particle-size distributions were determined from a cascade impactor using the proper 50% cutoff diameters for the cyclone precollector and each impaction stage. These data were fitted to a log-normal mass size distribution after correcting for any residual particle bounce (Muleski et al., 1984). The size distribution was assumed to be constant with respect to height, with the sampling height based on examination of previous test results.

For directional samplers operated isokinetically, particulate exposures are calculated by:

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

where:
- E = particulate exposure (mg/cm^2)
- C = net concentration ($\mu g/m^3$)
- U = approaching wind speed (m/sec)
- t = duration of sampling (sec)

The exposure values vary over the height of the plume. If exposure is integrated over the height of the plume, then the quantity obtained represents the total passage of airborne particulate matter due to the source per unit length of the line source. This quantity is called the integrated exposure A and is found by:

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

where:
- A = integrated exposure ($m\text{-}mg/cm^2$)
- 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 uppermost net TP concentrations to a value of zero.

Because exposures are measured at discrete heights of the plume, a numerical integration is necessary to determine A. 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 TP exposure usually occurs below a height of 1 m, so that there is a sharp decay in TP 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 integrated exposure A is directly proportional to the emission factor which characterizes the emissions attributed to the source tested. All that remains to be done is divide A by a suitable measure of source activity. The emission factor for total airborne particulate generated by vehicular traffic on a straight road segment expressed in pounds of emissions per vehicle-mile-traveled (VMT) is given by:

$$e = 35.5 \, A/N$$

where:
- e = emission factor (lb/VMT)
- A = integrated exposure ($m \cdot mg/cm^2$)
- N = number of vehicle passes

Although controlled and uncontrolled tests were conducted at the same site, it is necessary to obtain normalized values of emission factors in order to make meaningful comparisons. This is true simply because the vehicle mix on the test road may vary not only from day to day but also during different tests on one day. Thus, measurement-based emission factors require normalization in order that a change in vehicle mix is not mistakenly interpreted as the effect of the control measure being tested (Muleski et al., 1984).

The method used to normalize emission factors is based on MRI's experimentally determined predictive emission factor equation for uncontrolled open dust sources (USEPA, 1983). For unpaved roads, the emission factors are scaled by:

$$e_n = e_i \left(\frac{S_n}{S_i}\right)\left(\frac{W_n}{W_i}\right)^{0.7}\left(\frac{w_n}{w_i}\right)^{0.5}$$

where:
- e_n = normalized value of the emission factor corresponding to run i
- e_i = measured emission factor from run i
- S_n = normalizing value for average vehicle speed
- S_i = average vehicle speed during run i
- W_n = normalizing value for average vehicle weight
- W_i = average vehicle weight during run i
- w_n = normalizing value for average number of wheels per vehicle pass
- w_i = average number of wheels per vehicle pass during run i

The normalizing value for a parameter is generally the average value observed during the tests. The instantaneous control efficiency for a controlled test in percent (c) is then found as:

$$c = \left(1 - \frac{e_c}{\bar{e}_u}\right) \times 100\%$$

where:
- e_c = normalized emission factor for the controlled test
- $\bar{e}_u$ = geometric mean of normalized emission factors for the uncontrolled tests

Instantaneous efficiency is a measure of the control effectiveness over the span of the test.

2.4 AGGREGATE MATERIALS SAMPLING AND ANALYSIS

Samples of the road surface material were taken in the course of this study, with special emphasis placed on determining moisture content before and after watering.

Each bulk field sample was split with a riffle to a sample size amenable to laboratory analysis. The basic procedure for moisture analysis was determination of weight loss on oven drying. Table 2-6 presents a step-by-step procedure for determining moisture content. Moisture analysis was performed in the field laboratory on the same day as sample collection. In this fashion, the measured value was a more reliable estimate of the field conditions at the time of the test.

The basic procedure for silt analysis was mechanical, dry sieving. A step-by-step procedure, based on the ASTM-C-136 method discussed in AP-42 Supplement 14 (USEPA, 1983), is given in Table 2-7. The silt analysis was performed upon return to the main MRI laboratories.

TABLE 2-6. MOISTURE ANALYSIS PROCEDURES

1. Preheat the oven to approximately 80°C (180°F) for coal. Record oven temperature.

2. Tare the laboratory sample containers which will be placed in the oven. Tare the containers with the lids on if they have lids. Record the tare weight(s). Check zero before weighing.

3. Record the make, capacity, smallest division, and accuracy of the scale.

4. Weigh the laboratory sample in the container(s). Record the combined weight(s). Check zero before weighing.

5. Place sample in oven and dry coal samples 1-1/2 hr.

6. Remove sample container from oven and (a) weigh immediately if uncovered, being careful of the hot container; or (b) place tight-fitting lid on the container and let cool before weighing. Record the combined sample and container weight(s). Check zero before weighing.

7. Calculate the moisture as the initial weight of the sample and container minus the oven-dried weight of the sample and container divided by the initial weight of the sample alone. Record the value.

8. Calculate the sample weight to be used in the silt analysis as the oven-dried weight of the sample and container minus the weight of the container. Record the value.

TABLE 2-7. SILT ANALYSIS PROCEDURES

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

2. Obtain a mechanical sieving device such as a vibratory shaker or a Roto-Tap (without the tapping function).

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

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

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

6. After nesting the sieves in decreasing order with the pan at the bottom, dump dried laboratory sample (probably immediately after moisture analysis) into the top sieve. The sample should weigh between 800 and 1600 g (1.8 and 3.5 lb).[a] Brush fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.

7. Place nested sieves into the mechanical device and sieve for 10 min. Remove pan containing minus No. 200 and weigh. Repeat the sieving in 10 min intervals until the difference between two successive pan sample weighings (where the tare of the pan has been subtracted) is less than 3.0%. Do not sieve longer than 40 min.

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

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

10. Calculate the percent of mass less than the 200 mesh screen (75 µm). This is the silt content.

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[a] This amount will vary for finer textured materials; 100 to 300 grams may be sufficient when 90 percent of the sample passes a No. 8 (2.36 mm) sieve.

SECTION 3.0

RESULTS AND DISCUSSION

3.1 RESULTS FROM THE EXPOSURE PROFILING TESTS

As noted in Section 1.0 of this report, seven exposure profiling tests were conducted on August 9 after the road dust control application using the plant's water truck (a converted scraper fitted with a 10,000-gal. tank). Application intensity was measured using tared sampling pans; results are presented below:

Station	Application Intensity (gal/yd^2) Mean	Standard Deviation
U	0.41	0.11
X	0.44	0.14
Y	0.53	0.11
Overall	0.46	0.12

No difference between any two sections was found to be significant at the 10% level.

Although the original test plan called for sampling to begin at the start of the day shift, meteorological conditions and the subsequent need to relocate equipment to Road No. 2 forced a delay to the mid-afternoon. Water was applied on two passes with first at 14:59 and the second at 15:04. Air sampling began approximately 30 min later. In addition, to reduce background levels, areas upwind and surrounding the test sections were re-watered at 18:19. Figure 3-1 presents a chronology of events during the seven controlled tests.

Table 3-1 presents the test site parameters for the 11 tests of vehicle travel. Because of equipment malfunctions, test section X was abandoned after the first test. Testing at stations U and Y were staggered to provide a more complete description of control decay over time.

Table 3-2 lists, for each run, the individual point values of TP concentration and exposure at each sampling location. The latter are the values that were integrated over the plume area in order to determine emission factors.

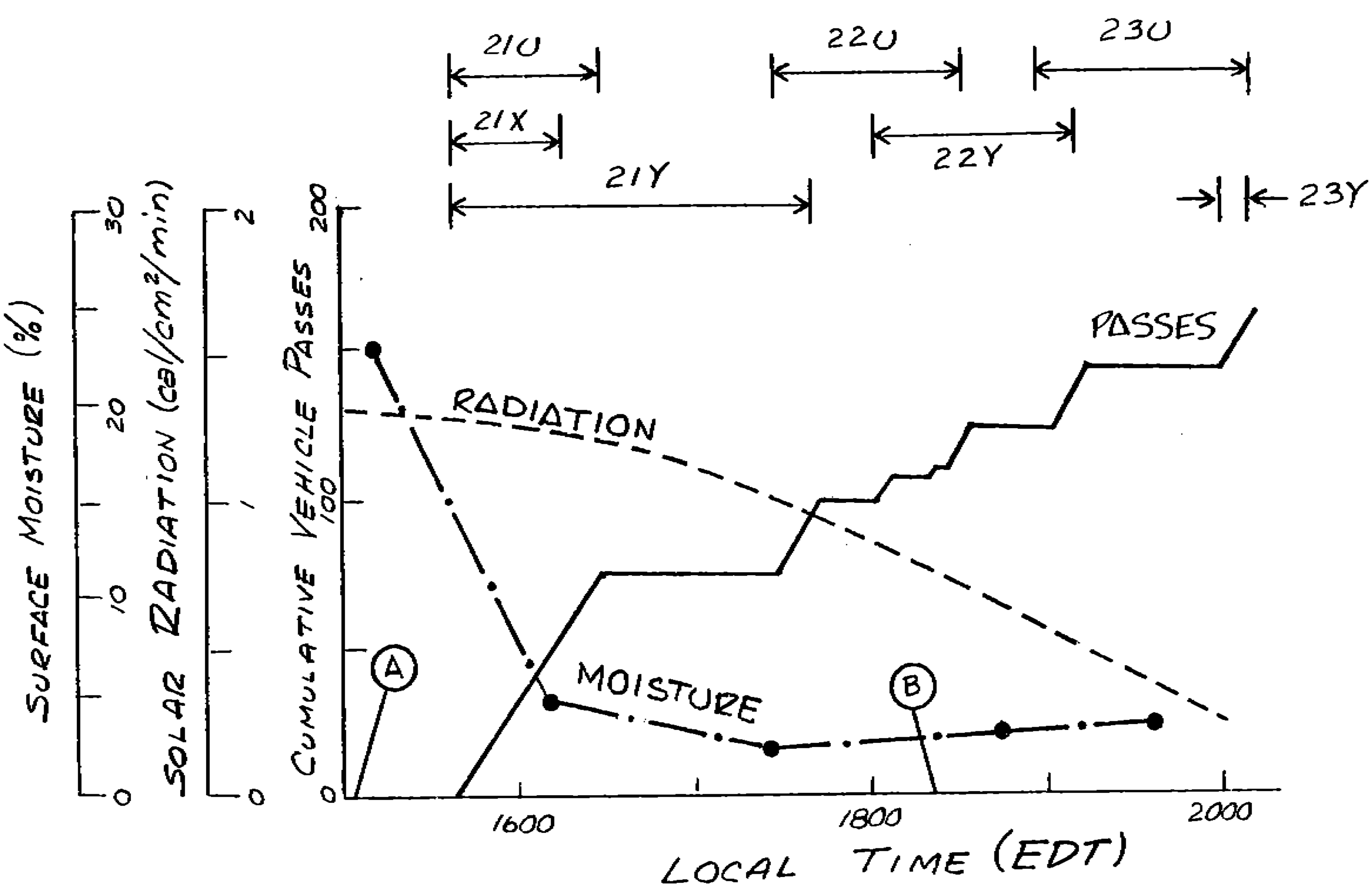

Figure 3-1. Chronology of testing on August 9, 1985. "A" indicates final water application on test road (15:04) and "B" indicates rewatering of surrounding areas (18:19).

TABLE 3-1. EXPOSURE PROFILING TEST PARAMETERS

Run	Date	Start time	Sampling duration[a] (min)	Average time after watering[b] (hr)	Vehicle passes during test	Cumulative passes prior to start	Ambient air temperature[c] (°C)	Ambient air temperature[c] (°F)	Average wind speed[d] (mph)	Cloud cover (10ths)
AN21U	8-9-85	15:32	46	0.93	75	0	29	84	3.8	0
AN21X	8-9-85	15:32	57	0.85	59	0	29	84	3.7	0
AN21Y	8-9-85	15:32	81	1.6	99	0	29	84	3.9	0
AN22U	8-9-85	17:20	56	2.9	49	75	27	81	4.1	0
AN22Y	8-9-85	17:59	61	3.6	45	99	26	79	3.7	0
AN23U	8-9-85	18:53	35	4.5	40	124	25	77	3.1	0
AN23Y	8-9-85	20:00	15	5.1	20	144	22	72	2.1	0
AN24U	8-10-85	10:57	23	NA	20	NA	28	82	7.1	10
AN24Y	8-10-85	10:57	23	NA	20	NA	28	82	7.1	10
AN25U	8-10-85	12:37	12	NA	10	NA	28	83	6.8	10
AN25Y	8-10-85	12:37	12	NA	10	NA	28	83	6.8	10

a Only includes time samplers operated.

b Watering completed at 15:04.

c Taken from data collected at

d Average of on-site measurements during periods of vehicle traffic.

TABLE 3-2. PLUME SAMPLING DATA

Run	Height (m)	Sampling rate (cfm)	IFR	TP concentration (μg/m³)	Net TP exposure (mg/cm²)
AN21U	1.5	21	1.21	8,380	4.59
	3	23	1.32	2,050	0.981
	4.5	21	1.21	1,960	0.929
	6	21	1.21	827	0.283
AN21X	1.5	-	-	-	2.70[a]
	3	20	1.15	3,880	1.64
	4.5	20	1.17	1,600	0.588
	6	20	1.17	524	0.0894
AN21Y	1.5	19	1.07	21,700	18.0
	3	19	1.07	4,860	3.80
	4.5	19	1.08	4,520	3.52
	6	19	1.06	872	0.454
AN22U	1.5	19	1.01	44,700	27.1
	3	21	1.12	18,400	11.0
	4.5	19	1.01	6,750	3.92
	6	19	1.01	2,590	1.38
AN22Y	1.5	21	1.21	22,400	13.4
	3	21	1.21	7,100	4.11
	4.5	21	1.21	4,260	2.38
	6	21	1.21	723	0.238
AN23U	1.5	19	1.32	34,900	10.1
	3	23	1.58	19,000	5.43
	4.5	19	1.32	7,550	2.10
	6	19	1.32	4,250	1.14
AN23Y	1.5	12	1.21	30,200	2.74
	3	12	1.21	9,120	0.806
	4.5	13	1.28	7,670	0.673
	6	20	2.02	1,220	0.0816
AN24U	1.5	30	0.91	51,800	22.7
	3	30	0.91	21,700	9.45
	4.5	31	0.94	7,600	3.25
	6	33	1.00	1,250	0.452
AN24Y	1.5	30	0.91	35,600	15.6
	3	30	0.91	3,650	1.51
	4.5	18[b]	1.03	2,120	0.836
	6	30	0.91	231	0.00352
AN25U	1.5	30	0.95	56,100	12.3
	3	30	0.95	25,500	5.58
	4.5	30	0.95	8,650	1.86
	6	30	0.95	3,030	0.618
AN25Y	1.5	30	0.95	39,400	8.64
	3	30	0.95	15,100	3.27
	4.5	30	0.95	6,330	1.34
	6	30	0.95	418	0.0425

[a] Sampler malfunction; exposure value extrapolated.

[b] Smaller inlet used.

GH

It should be noted that the wind speeds measured by the anemometers at the 3 and 6 m heights routinely differed by approximately 10 - 20%, with the speed at the lower height generally being larger. As a result, an average wind speed was applied to the entire tower. Table 3-3 summarizes the particle sizing data in terms of aerodynamic diameter.

Table 3-4 gives emission factors for each run for the various particle size fractions. From this table, normalized, uncontrolled emission factors are found for runs AN24 and AN25. These values (presented in Table 3-5) were normalized using the average vehicle speed of 17 mph, the average weight of 49 tons, and the average of four wheels.

Normalization of the results from the seven controlled tests yields the control efficiency values presented in Table 3-6.

3.2 EFFECTIVENESS OF WATERING AS A CONTROL MEASURE

Table 3-6 shows a rapid decline in control efficiency over the first four tests, but a rather constant level of control over the final three tests. Furthermore, as can be seen from Figure 3-1, the surface moisture content initially decreased rapidly during the testing period and thereafter rose slightly to a fairly constant value during the latter part of the day. Although it is possible that some leakage onto the test road may have occurred from the water truck when the surrounding areas were re-watered, the moisture stabilization probably resulted from the reduced levels of vehicle travel and solar radiation later in the test day (Figure 3-1) and lower ambient temperatures (Table 3-1). The average radiation value between 15:00 and 18:30 was at least twice that for the period 18:30 to 20:00. Similarly, the traffic volume during the first 3-1/2 hr was 35 passes per hour compared to 24 passes per hour during the final 1-1/2 hr. As a result, the total set of control efficiency values did not correlate well with either time or cumulative vehicle passes after application.

3.2.1 Worst-Case Decay

The traffic and weather conditions associated with the first four tests (i.e., those concluded by 18:30) approximate those for worst-case efficiency decay. The following compares ambient meteorological conditions observed on August 9 with their climatological averages for [redacted]

	August Average[a]	Test Day[b] (8/9/85)
Max. temperature (°F)	82	84
Sky cover (tenths)	5.7	0
Mean wind speed (mph)	8.2	10.5[c]

[a] Taken from LCD Annual Summaries (1982) for [redacted]

[b] During testing.

[c] Determined from data taken at

TABLE 3-3. AERODYNAMIC PARTICLE SIZE DATA

Run	% < 30 μm	% < 15 μm	% < 10 μm	% < 2.5 μm
AN21U	46	33	26	9
AN21X	36	25	20	8
AN21Y	62	44	32	6
AN22U	56	41	32	11
AN22Y	68	46	32	6
AN23U	41	30	23	9
AN23Y	52	36	29	9
AN24U	43	27	20	5
AN24Y	52	36	28	8
AN25U	43	29	22	7
AN25Y	53	38	30	10

TABLE 3-4. EXPOSURE PROFILING TEST RESULTS

Run	Mean vehicle speed[a] (mph)	Silt (%)	Moisture[b] (%)	Emission factor (lb/VMT) TP	SP	IP	PM_{10}	FP
AN21U	13	8.9	7.3	7.2	3.3	2.4	1.9	0.65
AN21X	15	8.9	8.7	5.9	2.1	1.5	1.2	0.47
AN21Y	16	8.9	3.5	21	13	9.2	6.7	1.4
AN22U	17[c]	5.9[d]	2.3	66	37	27	21	7.2
AN22Y	17[c]	5.9[d]	3.1	35	24	16	11	2.1
AN23U	16	8.4	3.6	32	13	9.5	7.3	2.8
AN23Y	16	8.4	3.4[e]	17	8.7	6.0	4.8	1.5
AN24U	18	7.7[e]	1.7[f]	130	58	36	27	6.7
AN24Y	18	7.7[e]	1.7[f]	79	41	28	22	6.3
AN25U	20	7.7[e]	1.7[f]	150	64	43	33	10
AN25Y	20	7.7[e]	1.7[f]	100	54	38	30	10

[a] All passes by four-wheel, 49-ton scrapers except as noted.

[b] Interpolated from values in Figure 3-1 using midpoint of test, unless otherwise noted.

[c] Two passes by water truck and one by pickup. Average number of wheels is four and average weight for test is 49 tons.

[d] Average of two samples.

[e] Estimated value.

[f] Measured.

TABLE 3-5. UNCONTROLLED EMISSION FACTORS[a]

Size range	Geometric mean (lb/VMT)	Standard geometric deviation
TP	110	1.31
SP	51	1.17
IP	34	1.11
PM_{10}	26	1.11
FP	7.7	1.13

[a] Normalized to 17 mph, 49 tons and 4 wheels.

TABLE 3-6. CONTROL EFFICIENCIES

Run	Vehicle passes after application	Time after application (hr)	Control efficiency[a] (%)				
			TP	SP	IP	PM_{10}	FP
AN21U	38	0.93	91	92	91	90	89
AN21X	30	0.85	94	95	95	95	93
AN21Y	50	1.6	80	73	71	73	81
AN22U	100	2.9	40	27	21	19	6
AN22Y	122	3.6	68	53	53	58	73
AN23U	144	4.5	69	73	71	70	61
AN23Y	154	5.1	84	82	81	80	79

[a] Based on emission factors normalized to 17 mph, 49 tons, and four wheels.

In addition, no rain had fallen at the site for approximately 60 hr and the slight slope of the test road insured that the surface was dry prior to the watering.

Worst-case decay functions were constructed by using the results of the first four tests (together with a value of 100% control at zero time) and fitting a parabola of the form:

$$c(t) = a - bt^2$$

where: $c(t)$ = instantaneous control efficiency (%)
a,b = constants
t = time after application (hr)

The regression parameters for each size range are given below:

	TP	SP	IP	PM_{10}	FP
a	99	100	100	100	100
b	7.0	8.7	9.4	9.6	11
Correlation coefficient	-0.999	-0.997	-0.997	-0.999	-0.993

The curves for SP and PM_{10} are shown in Figure 3-2 as illustrations.

It is important to note that the average efficiency is of more importance in terms of assessing control performance and determining how often to reapply. Average control efficiency C is found by:

$$C(T) = \frac{1}{T} \int_0^T c(t)\, dt$$

where: $C(T)$ = average control efficiency during period ending T hours after application (%)
$c(t)$ = instantaneous control efficiency at t hours after application (%)
T = time period over which average control efficiency is desired

For the worst-case decay curves discussed earlier:

$$C(T) = a - \frac{b}{3} T^2$$

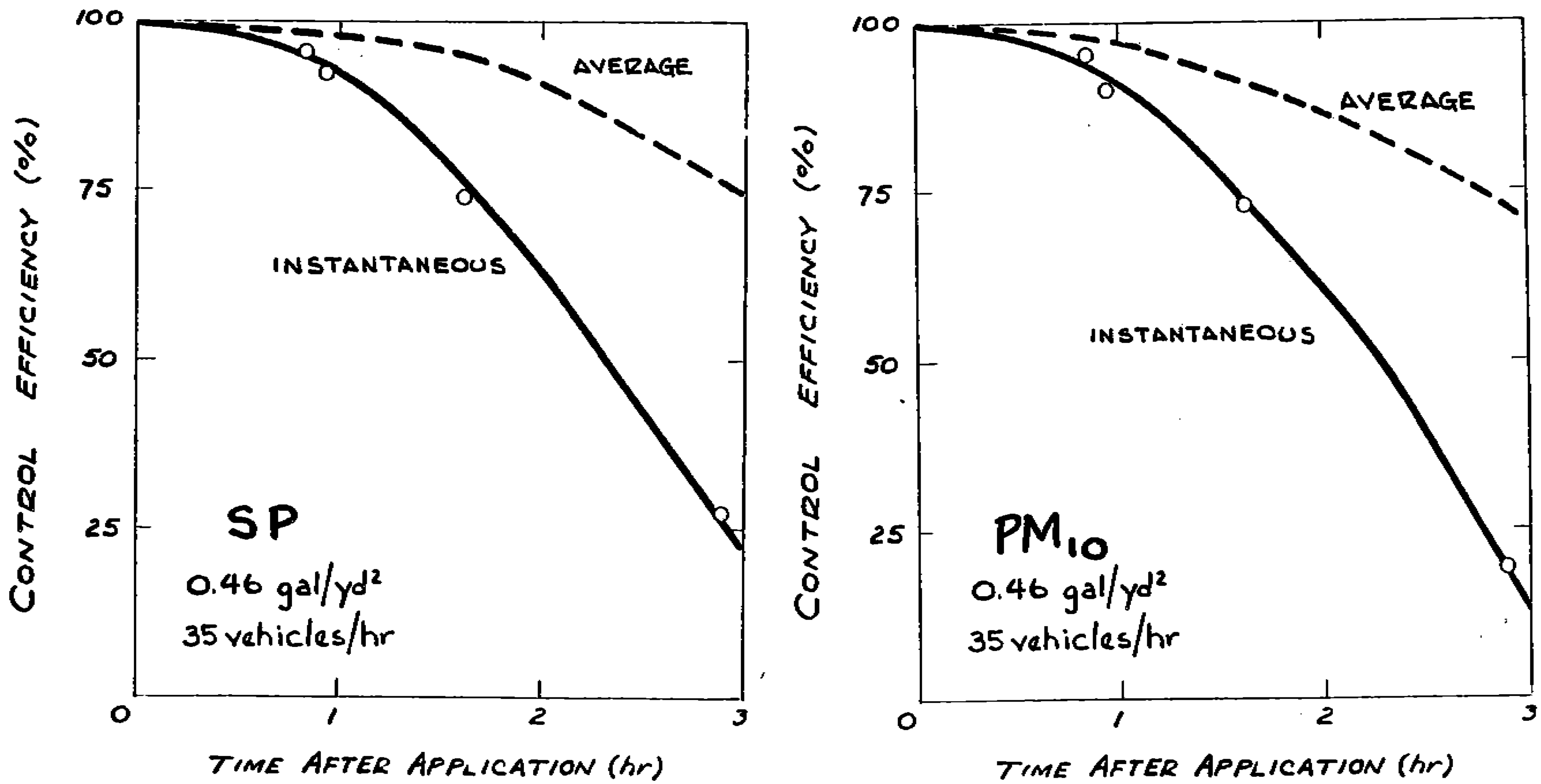

Figure 3-2. Worst-case SP and PM_{10} instantaneous and average control efficiency as functions of time after watering.

The average control curves for SP and PM_{10} are also shown in Figure 3-2. As can be seen, SP control averaged 97% over the first hour, 88% over the first 2 hr, and 74% over the first 3 hr. Average PM_{10} control values were slightly lower.

3.2.2 Relationship Between Control Efficiency and Moisture Content

For the reasons noted earlier in this section, the control efficiency values over all seven tests did not correlate well with time or vehicle passes after application. Not surprisingly, however, these values do show a strong correlation with surface moisture content.

Figure 3-3 shows the relationships for SP and PM_{10}. As can be seen, between the average uncontrolled moisture content (1.8%) and a value of approximately 3.5%, a small increase in moisture content results in a large increase in control efficiency. Beyond this point, control efficiency grows slowly with increased moisture content. Although it is possible to fit hyperbolas to the data, the relatively simple bilinear relationship shown in the figure provides an adequate description. Furthermore, this relationship is applicable to all size ranges considered in this report:

$$c = \begin{cases} -79 + 44\,M & 1.8 \leq M \leq 3.5 \\ 62 + 3.6\,M & 3.5 \leq M \leq 9 \end{cases}$$

where: c = instantaneous control efficiency (%)
M = surface moisture content (%)

3.3 ESTIMATION OF ANNUAL EMISSIONS

Finally, it is also possible to estimate the annual emission rate from scraper traffic in the coal yard at [redacted]. Based on the 1981 emissions inventory submitted by [redacted], scrapers annually transport 1,145,130 tons of coal at the plant, with an average load of 40 tons and an average round-trip distance of 0.5 mile. Thus, there are 28,600 round-trips during the year, resulting in 14,300 vehicle miles traveled (VMT).

The AP-42 (USEPA 1983) empirical expression used to estimate particulate emissions from unpaved surfaces is:

$$E = k(5.9)\left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right)$$

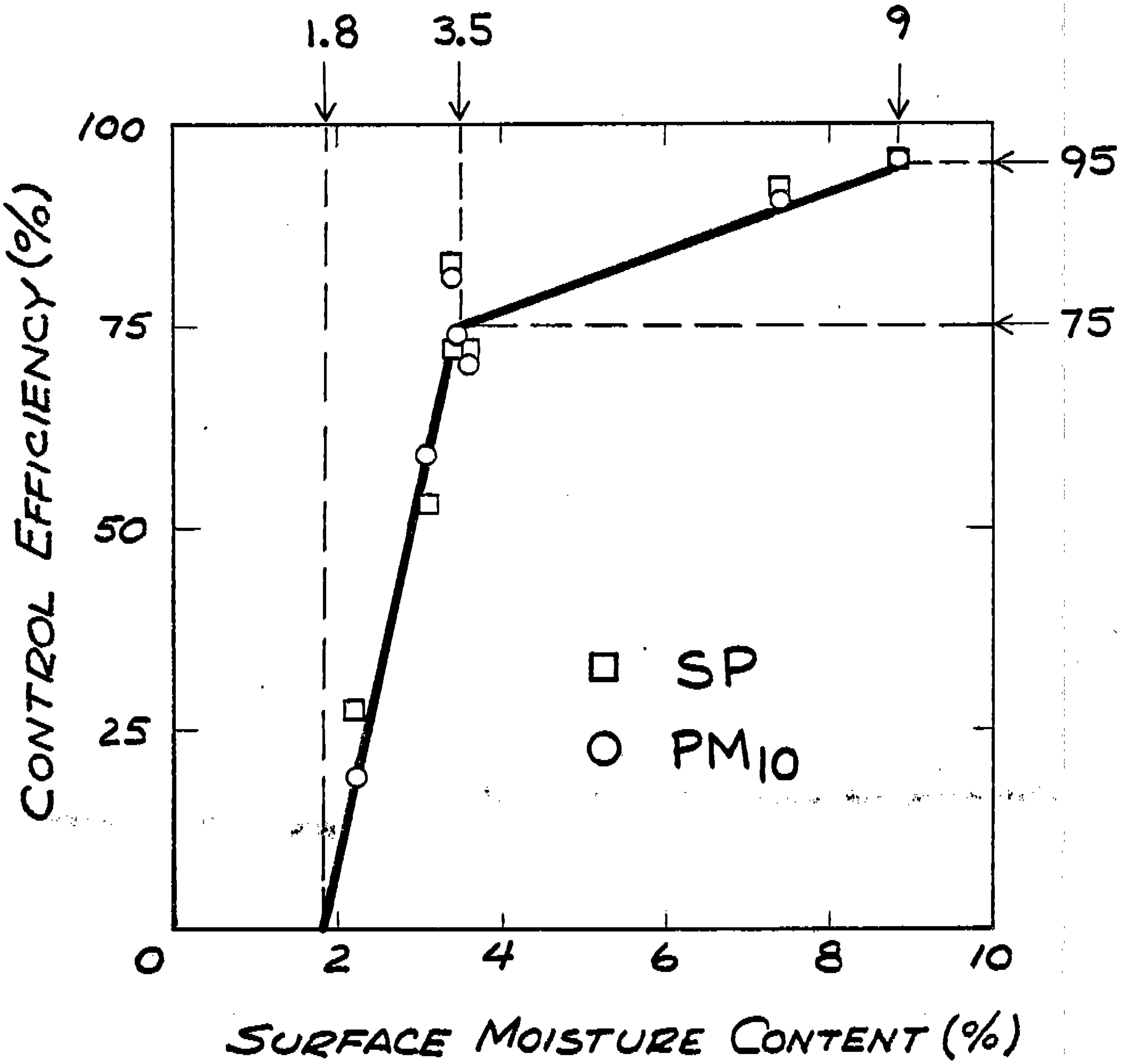

Figure 3-3. Dependence of control efficiency on surface moisture content.

where: E = emission factor (lb/VMT)
k = particle size multiplier (dimensionless)
s = silt content of road surface material (%)
S = mean vehicle speed (mph)
W = mean vehicle weight (tons)
w = mean number of wheels
p = number of days with at least 0.01 in. of precipitation per year.

The particle size multiplier (k) varies with aerodynamic particle size range as follows:

<u>Aerodynamic Particle Size Multipler</u>

SP	TP	PM_{10}	FP
0.80	0.57	0.45	0.16

Assuming an average silt content (s) of 8%, speed (S) of 15 mph, weight (W) of 69 tons (i.e., tare of 49 tons plus a half load), 4 wheels (w) per vehicle and 140 days (p) per year with precipitation (USEPA 1983), the following emission estimates are obtained:

Size Range	Emission Factor (lb/VMT) Dry[a]	Emission Factor (lb/VMT) Annual	Rate Emission Rate (tpy)
SP	14	8.7	62
IP	10	6.2	44
PM_{10}	7.9	4.9	35
FP	2.8	1.7	12

a Last term in AP-42 equation neglected.

Comparison of the above estimates (for dry conditions) with the mean, uncontrolled emission factors in Table 3-5 indicates that the AP-42 equation underpredicts the field measurements by a factor of approximately 3.2.

Several items should be noted relative to this comparison. First, although the field measurements were normalized to a speed of 17 mph and a weight of 49 tons, these differences tend to cancel one another in the comparison with the AP-42 estimates. Second, the field measurements reflect the conditions of the test road, which because of its slope and compacted nature, had substantially better drainage than other travel areas in the coal yard. Finally, the tests were conducted in the summer when fugitive emissions tend to be highest. Thus, it is not particularly surprising that the measured emissions are greater than the AP-42 estimates because the field measurements in Table 3-5 reflect worst-case rather than annual conditions.

In light of the above discussion, the field results may be used to place upper bounds on annual uncontrolled as well as controlled emissions, as shown in Table 3-7. Two sets of controlled emission estimates are presented. The first set assumes that water is applied every 3 hr (during periods of traffic) and that the worst-case decay functions of Section 3.2.1 are applicable. Because of the heavy traffic volume and the meteorological conditions associated with these functions, however, this set can only provide very conservative upper limits on controlled emissions.

The second set represents more realistic estimates of annual controlled emissions achievable at the plant. This set assumes a watering program designed to maintain a moisture content of at least 3.5% during periods of traffic. As shown in Figure 3-2, this moisture value corresponds to an instantaneous control efficiency of 75%. If it is assumed that control decays linearly from an initial control of 95%, then an average control value of 85% may be expected.

SECTION 4.0

CONCLUSIONS

Following the plant's standard procedure of applying water in two passes, a total application of 0.46 gal/yd^2 was found to provide at least 3 to 4 hr of effective control under worst-case conditions. Furthermore, over this lifetime of 3 to 4 hr, an average control efficiency of approximately 70% may be expected.

Additionally, it was found that the control efficiency associated with watering may be estimated quite successfully by examining the moisture content of the travel surface. Thus, the results of this testing program can be applied to other ambient meteorological conditions if the time history of surface moisture can be determined. This would be especially valuable in designing an effective watering program that takes into account both daily and annual variation in evaporation rates.

Finally, upper bounds on the annual emission rates for scraper traffic in the coal yard were found. The annual uncontrolled TP, SP and PM_{10} emission rates were estimated at 480, 220, and 110 tpy, respectively. This would indicate that 46% of the total mass emissions would potentially impact a standard high-volume air sampler, with one-half of this potential impact in the form of 10 µmA and smaller particles. Two estimates of controlled emissions indicate that average effectiveness values of 70 to 85% are achievable using water as a control measure at the plant.

TABLE 3-7. ANNUAL EMISSION ESTIMATES FOR SCRAPER TRAFFIC

Size range	Annual emission rate[a] (tpy) Uncontrolled[b]	Controlled (set 1)[c]	Controlled (set 2)[d]
TP	480	110	73
SP	220	59	34
IP	150	42	22
PM_{10}	110	33	17
FP	34	11	5.1

[a] These estimates may be viewed as upper bounds. See discussion in text.

[b] Taken from values in Table 3-5. Effect of natural precipitation included using the AP-42 scaling term with p = 140.

[c] Based on worst-case decay functions in Section 3.2.1. Water applied at 0.46 gal/yd^2 every 3 hr during periods with traffic.

[d] Assumes a watering program designed to maintain a surface moisture content of at least 3.5% during periods with traffic. See discussion in text.

SECTION 5.0

REFERENCES

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