United States
Environmental Protection
Agency

EPA-600/2-87-102
November 1987

EPA

Research and Development

EVALUATION OF THE EFFECTIVENESS OF CHEMICAL DUST SUPPRESSANTS ON UNPAVED ROADS

Prepared for

EPA Region 5

Prepared by

Air and Energy Engineering Research Laboratory
Research Triangle Park NC 27711

EPA

Robert C. McCrillis, P.E.
MECHANICAL ENGINEER

U.S. Environmental Protection Agency
Air and Energy Engineering
Research Laboratory
Research Triangle Park, N.C. 27711

(919) 541-2733
FTS: 629-2733

EPA-600/2-87-102
November 1987

EVALUATION OF THE EFFECTIVENESS OF CHEMICAL DUST SUPPRESSANTS ON UNPAVED ROADS

By

G. E. Muleski and C. Cowherd, Jr.
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

Funded By:

LTV Steel Company, Inc.
Penalty Credit Project 5200-868236

EPA Project Officer:

Robert C. McCrillis
Air and Energy Engineering Research Laboratory
Research Triangle Park, North Carolina 27711

Prepared For:

U. S. Environmental Protection Agency
Office of Research and Development
Washington, DC 20460

PREFACE

This report was prepared by Midwest Research Institute (MRI) under LTV Steel Company, Inc. (formerly, Jones and Laughlin Steel Corporation) Purchase Order No. 5200-868236. The penalty credit project described herein was directed by the U.S. Environmental Protection Agency, Air and Energy Engineering Research Laboratory (Robert C. McCrillis, Project Officer). All work was performed in MRI's Air Quality Assessment Section (John Kinsey, Head).

The authors of this report are Gregory E. Muleski, Project Leader, and Chatten Cowherd, Jr. Field sampling was conducted under the direction of Frank Pendleton and Muleski with assistance from David Griffin, Julia Hoffmeister, Phillip Englehart, and Scott Smith. Additional laboratory analysis was performed by Stephen Cummins.

CONTENTS

FIGURES

TABLES

SUMMARY AND CONCLUSIONS

The purpose of this study was to obtain data characterizing the average control performance of dust suppressants commonly used by the iron and steel industry to mitigate particulate emissions from unpaved roads. Vehicular traffic on unpaved roads has been estimated to contribute more than half of the suspended particulate emissions from open sources in the industry.

Control efficiency values were determined not only for total particulate (TP), but also for particles less than 15 µm in aerodynamic diameter (inhalable particulate, IP), less than 10 µm in aerodynamic diameter (PM_{10}), and less than 2.5 µm in aerodynamic diameter (fine particulate, FP). The study focused on PM_{10} control performance of dust suppressants in particular, because this size fraction is anticipated to form the basis of any revised National Ambient Air Quality Standard for particulate matter.

In order to make the control performance test results as useful as possible to the industry, unpaved road vehicular traffic characteristics and dust control techniques used in the industry were surveyed early in the study. Subsequently these results formed the basis for the design of the field testing program so that commonly used suppressants could be evaluated under service conditions representative of typical iron and steel industry unpaved roads.

The exposure profiling method developed by MRI was the technique utilized to measure uncontrolled and controlled emission factors for vehicular traffic on unpaved roads. Exposure profiling of roadway emissions involves direct isokinetic measurement of the total passage of open dust emissions approximately 5 m downwind of the edge of the road by means of simultaneous sampling at four points distributed vertically over the effective height of the dust plume. Downwind particle size distributions were measured using cyclone precollectors followed by parallel slot cascade impactors. Upwind particle size distributions were also determined using impaction. A total of 64 tests of controlled and uncontrolled particulate emissions from vehicular traffic on unpaved roads were conducted at two iron and steel plants.

Five chemical dust suppressants were evaluated during the study:

- Petro Tac, an emulsified asphalt
- Coherex®, a petroleum resin
- Soil-Sement, an acrylic cement

- Generic 2 (QS), a generic petroleum resin product developed at the Mellon Institute

- Liquidow , a salt (calcium chloride)

All products, with the exception of Generic, have been used in iron and steel plants. In addition, industry personnel have expressed considerable interest in the use of Generic.

These suppressants were applied under the direction of MRI personnel in quantities that generally span the range of common practice in the industry, manufacturers' recommendations, and previous field evaluations. Control efficiency measurements were made over periods up to 70 days after application, although the main averaging period of interest was approximately 1 month. The latter is representative of time periods between control applications in the industry.

Average control efficiencies over the first 30 days for specific particle size ranges are presented in Figure SC-1. Note that code letters (explained in the text) have been assigned to the various dust suppressants in order to discourage selective citation of test results. It is recommended that the report taken as a whole be used as a basis for decisions regarding dust control programs rather than any one data set taken independently.

All chemicals tested exhibited average control efficiencies of approximately 50% or more over the first 30 days after application. These tests were conducted using application and traffic parameters that may be considered typical in the iron and steel industry. Note that while the control provided by some suppressants showed significant temporal decay, others exhibited a relatively constant level of control over the time period.

Statistical analyses of the data indicate that reapplication results in a significantly higher level of control and that only one suppressant exhibited significant differences in control between the various particle size fractions. Comparisons between the control efficiencies for different chemicals indicate that there were relatively few suppressant/size fraction combinations which could be considered significant at the 5% level.

Comparison of the relative cost-effectiveness reveals only a slight variation between the suppressants other than calcium chloride. In terms of cost-effectiveness, the salt did not compare favorably with the other products; however, this is at least a partial result of the abnormally high precipitation during the field exercise.

Several road surface material properties were discussed as possible indicators of control performance. While reasonably strong relationships between silt loading and control were found for some of the suppressants, the clustered nature of the entire data set precluded development of a reliable performance indicator. However, the data suggest that the industrial paved road emission factor equation may be used to conservatively overestimate emissions from controlled unpaved roads.

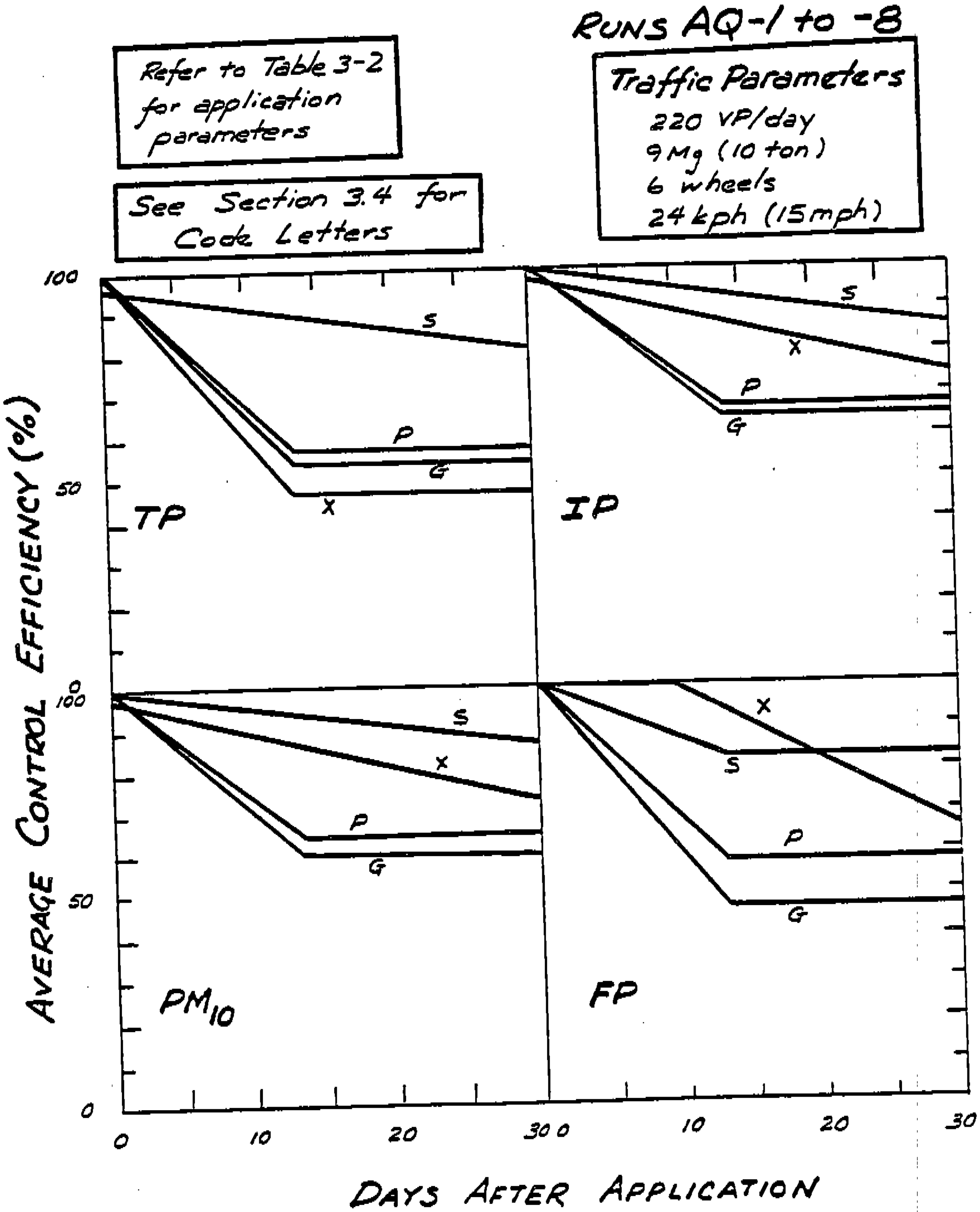

Figure SC-1. Average control efficiency as a function of time over 30 days.

Finally, results of previous tests were combined with data from the present study to develop an average control performance model for petroleum resins. The model was designed to meet typical needs in the iron and steel industry in terms of averaging periods and service environments.

SECTION 1.0

INTRODUCTION

Numerous prior studies of the iron and steel industry[1-4] have shown that open dust sources (such as vehicular traffic on paved and unpaved roads, material handling and wind erosion) merit prime consideration in the development of particulate emission control strategies. This conclusion has been based on (a) industry-wide comparisons between uncontrolled emissions from open dust sources, and (b) typically controlled fugitive emissions from major process sources such as steel-making furnaces, blast furnaces, coke ovens, and sinter machines. In addition, preliminary cost-effectiveness (dollars expended per unit mass of reduced particulate emissions) analysis of promising control options for open dust sources has indicated that control of these sources might result in significantly improved air quality at a lower cost compared to the control of process sources.

Of open dust sources, vehicular traffic on paved and unpaved roads generally account for the vast majority of particulate emissions in the iron and steel industry. For the 1970's, unpaved surfaces were estimated to account for roughly 70% of open source particulate emissions in the industry.[2] By the early 1980's the contribution was considerably smaller. This reduction was due to implementation of dust control programs which, in addition to chemical treatment of unpaved roads, included paving numerous roads and using shuttle buses to reduce emissions from employees commuting to their work stations.

Some unpaved roads in the iron and steel industry are, by their nature, not suitable for paving. These roads are normally used by very heavy vehicles or may be subjected to considerable spillage. Because of the additional maintenance costs associated with a paved road under this type of service environment, emissions from these roads generally are controlled with regular reapplications of chemical treatments.

Besides water, petroleum resins (such as Coherex®) have historically been the products most widely used in the industry; however, considerable interest has been shown at both the plant and corporate level in alternative chemical dust suppressants. As a result of this continued interest, several new dust suppressants have been introduced recently. These have included asphalt emulsions, acrylics, salts, and adhesives. In addition, the generic petroleum resin formulations developed at the Mellon Institute with funding from the American Iron and Steel Institute (AISI) have gained considerable attention. These generic suppressants were designed to be produced on-site at iron and steel plants.[5]

1.1 PROGRAM OBJECTIVES

The overall objective of this study was to provide data that document the reduction of particulate emissions (in several particle size ranges) generated by vehicular traffic on representative unpaved roads in the iron and steel industry following control application. The data were used to provide average control efficiencies for common road dust suppressants, over ranges of averaging periods and application parameters that span typical values used in the iron and steel industry. Information on this type is valuable to both industry and regulatory personnel in developing and monitoring dust control programs.

In addition, there were several secondary objectives which largely supported the primary objective stated above. These included: (a) a survey of current and projected industry practices in unpaved road dust control; (b) characterization of traffic on unpaved roads in the industry; (c) collection of cost data to develop relative cost-effectiveness values for the suppressants evaluated; (d) examination of less expensive measures to monitor control performance; and (e) analysis of the current previous studies in order to develop a model to estimate control performance.

1.2 REPORT STRUCTURE

The report is structured as follows: (a) Section 2.0 focuses on the methodology used to quantify road dust controls used in the iron and steel industry; (b) Section 3.0 presents and discusses the results of source testing by exposure profiling; (c) Section 4.0 discusses control efficiency and cost-effectiveness values for the dust suppressants evaluated; and (d) Section 5.0 discusses a model developed to estimate average control performance as a function of application parameters. Sections 6.0 and 7.0 presents the references and a glossary, respectively.

This report contains both metric and English units. In the text, most numbers are generally reported in metric units with English units in parentheses. For numbers commonly expressed in metric units in the air pollution field (e.g., particle size in μm, density in g/cm³, and concentration in μg/m³), no English equivalent is given. A conversion table is given as Section 8.0.

Finally, the particle size ranges used in this report are:

TP — Total airborne particulate matter.

IP — Inhalable particulate matter consisting of particles smaller than 15 μm in aerodynamic diameter.

PM_{10} — Particulate matter consisting of particles smaller than 10 μm in aerodynamic diameter.

FP — Fine particulate matter consisting of particles smaller than 2.5 μm in aerodynamic diameter.

Particular attention is paid to the PM_{10} size fraction, in anticipation of possible revision of National Ambient Air Quality Standards for particulate matter.

SECTION 2.0

SELECTION OF CONTROL MEASURES, TEST SITES, STUDY DESIGN, AND DESCRIPTION OF TEST METHODOLOGY

This section describes how specific unpaved road dust suppressants were selected for testing and how the test conditions were determined. Also, the selection criteria for test sites and the study design are reviewed. Finally the detailed test methodology, including air and surface material sampling and analysis, is described.

2.1 CHARACTERIZATION OF UNPAVED ROAD TRAFFIC

During recent years, the iron and steel industry has paved many previously unpaved roads used primarily by light-duty vehicles (e.g., automobiles, pickup trucks), while roads used by heavy-duty trucks have largely remained unpaved. In addition, a good deal of light duty traffic has been eliminated by employee bussing programs. In order to design the testing program so that the test results would be as useful as possible, a study was conducted to determine the relative importance of light-duty vehicles on unpaved roads in the industry.

IN-TECH of Pittsburgh, Pennsylvania was retained to provide summary data collected during traffic studies of paved and unpaved roads at nine different steel plants east of the Mississippi River. These data are presented in Figures 2-1, 2-2, and 2-3.

These data show that, while autos generally account for a large fraction of the total number of vehicle miles on unpaved roads, the average vehicle weight mile is substantially larger than that for a car. For the nine plants, an average weight of approximately 10 tons was found, and over half of the daily mileage was due to vehicles weighing between 10 and 30 tons.

Although paved roads generally experience a greater volume (approximately six times, on the average) of traffic than do unpaved roads, it is important to note that unpaved roads are usually responsible for more SP emissions. This statement is based on the fact that the leading term for the AP-42 unpaved road emission factor equation is about 60 times greater than that for industrial paved roads.[6] Because unpaved roads generally are used by much heavier vehicles, it is apparent that unpaved roads are the more important source. Furthermore, comparison of the leading terms for the PM_{10} equations shows that unpaved roads contribute emissions in this size range at a level comparable to paved roads.

SUMMARY TABLE 1

TOTAL MILES OF PAVED ROADWAY
AND DAILY VEHICLE MILES OF TRAVEL (V.M.T.)
BY PLANT I.D. AND TYPE OF ROADWAY

PLANT I.D.	MILES OF ROADWAY		DAILY V.M.T.	
	UNPAVED	PAVED	UNPAVED	PAVED
1	3.62	1.02	262.00	299.08
2	4.59	0.82	115.20	4462.40
3	1.40	3.35	938.50	839.50
4	9.50	0.37	3675.00	124.00
5	1.57	0.18	154.30	131.70
6	1.4	8.2	384.02	7750.98
7	1.8	8.4	438.60	5213.00
8	10.717	14.815	436.00	9800.00
9	11.51	1.97	1877.30	1105.70

Figure 2-1. Copy of IN-TECH summary data of vehicle miles traveled in iron and steel industry.

SUMMARY TABLE 2

TOTAL DAILY VEHICLE MILES OF TRAVEL FOR UNPAVED ROADWAYS

BY PLANT I.D. AND VEHICLE CLASSIFICATION

PLANT I.D.	AUTOS	TRUCKS (AXLES) 2	3	4	5	6	7	8	9	10	11	EUCLID	PLANT EQUIPMENT	TOTAL
1	118.6	18.9	0.24	0.24	4.5							84.0	35.52	262.0
2	43.5		18.1	30.2	22.2								1.2	115.20
3	641.2	39.66			132.96							7.0	55.78 61.9 *	938.50
4	2514.33	182.96	79.3	47.3	171.84	110.56						121.0	443.71	3675.00
5	19.10	27.5	20.3	10.2	48.9								28.3	154.30
6	191.6	87.5	27.6	8.0	9.5								60.0	384.02
7	148.70	5.0	128.0	85.0	19.2								52.7	438.60
8	105.2	2.9	1.2	5.8	243.5	2.7		0.2		3.8	2.6		68.10	436.00
9	815.7	29.60	83.80		541.0	5.0						306.4	85.4 10.4 **	1877.3

* K-MAG

** SLAG POT

Figure 2-2. Copy of IN-TECH summary data of iron and steel unpaved road traffic by vehicle type.

SUMMARY TABLE 3

AVERAGE VEHICLE WEIGHTS IN THOUSANDS OF POUNDS
FOR VEHICLES USING UNPAVED ROADS
BY PLANT I.D. AND VEHICLE CLASSIFICATION

PLANT I.D.	AUTOS	TRUCKS (AXLES) 2	3	4	5	6	7	8	9	10	11	EUCLID	PLANT EQUIPMENT
1	3.5	36.0	23.0	47.0	49.2							80.0	36.5
2	3.5	37.5	23.0	48.5	52.5							81.5	36.0
3	3.5	31.5			48.9							80.0	28.0 190.00 *
4	3.5	34.5	23.0	47.5	46.5	51.5						80.0	34.3
5	3.5	32.5	23.0	47.0	51.5								33.5
6	3.5	27.0	23.0	53.5	52.5								35.0
7	3.5	30.6	23.0	49.7	50.6								32.8
8	3.5	33.0	38.0°	44.0°	48.0	52.0		62.0		72.0	73.0		38.0
9	3.5	33.0	37.5°		53.0	56.0						76.0	37.5 145.00 **

* K-MAG
** SLAG POT
° Average of loaded and unloaded weight

Figure 2-3. Copy of IN-TECH summary data of average weights for vehicle types on iron and steel unpaved roads.

In summary, most vehicle-generated road dust in the iron and steel industry appears to be due to unpaved roads, and most of this contribution arises from medium- to heavy-duty vehicles. As more roads become paved in the industry, the relative importance of unpaved road dust emissions may decline, but the importance of reducing emissions from medium to heavy vehicles on unpaved roads will remain. This is the type of traffic considered in the field testing program.

2.2 CONTROL MEASURE SELECTION

Historically, the most widely used control measure for unpaved roads, besides watering, has been Coherex® (a petroleum resin). However, because of the sharp rise in prices of petroleum-based products over the past decade, the iron and steel industry has expressed interest in less expensive, alternative chemical controls. These control measures may be either petroleum resin products similar to Coherex® (such as Resinex 60™) but with potentially lower delivery costs, or products of another nature (such as asphalt emulsions, salts, or adhesives).

In order to assess interest in chemical control of road dust within the industry, a survey of corporate officials was conducted. Additional information was obtained during site surveys. The results (based largely on data from 1984 control programs) are shown in Table 2-1. As can be seen, petroleum resins represented the most widely used dust suppressants in the industry at the end of 1984. In fact, only one of the five surveyed corporations did not use this type of product during 1984. Asphalt emulsions (e.g., Petro Tac) were the next most widely used suppressant type in the industry.

To further characterize the changing nature of dust suppressant use in the iron and steel industry, the survey also contained questions about past control programs and any plans to evaluate chemicals in the future. The replies are presented as Table 2-2. In addition to the interest shown in Dustaside® and Soil Sement, considerable interest in generic petroleum resin was expressed. These generic formulations were developed at the Mellon Institute with funding from the American Iron and Steel Institute (AISI).

Upon completion of the survey, five products were selected for field testing -- Coherex®, Petro Tac, Soil Sement, Dustaside®, and Generic 2 (QS). Based on the results of the survey, these products largely characterized current and projected practice in the iron and steel industry.

2.3 TEST SITE SELECTION

Because the scope of work for this study required that test sites be chosen from LTV's Aliquippa, Cleveland and Indiana Harbor works, each of these plants was surveyed by MRI personnel. Candidate sites were examined using criteria of: (a) road length and orientation with respect to prevailing winds; (b) traffic mix and rate; (c) upwind/downwind flow obstructions; (d) general meteorology such as mean wind speed, prevailing direction and frequency of precipitation; (e) availability of chemical dust suppressants and application equipment; and (f) proximity to MRI.

TABLE 2-1. UNPAVED ROAD DUST CONTROL SURVEY RESULTS

Company	Plant	Dust suppressants used[a]	Application intensity (gal/yd^2)[b]	Application frequency	Areas in which water is used
Armco	Middletown	Coherex® (200,000)[c]	0.08/0.08 (20%/12%)	Once a week to every 6 months	Coal storage, recycle plant, slag processing
Inland	Indiana Harbor	Dustaside® (26,500)	0.3/0.1 (17%/9%)	Approximately every 3 weeks	-
Inland	Indiana Harbor	Resinex 60™ (29,500)	0.5/0.1 (17%/7 to 9%)	Approximately twice per week	-
Inland	Indiana Harbor	Flambinder (120,000)[d]	0.5/0.1 (18%/10%)	As needed, based on visual inspection	-
LTV[e]	Aliquippa	Petro Tac (6,000)[c,f]	N/A	N/A	-
LTV[e]	Aliquippa	Soil-Sement (18,000)[c,f]	N/A	N/A	-
LTV[e]	Cleveland	Water and waste oil	N/A	N/A	General dust mitigation
LTV	Indiana Harbor	Petro Tac (110,000)	0.5/0.5 (10%/10%)	As needed, based on visual observation	
National	Granite City	Coherex®	0.28/0.28 (17%/11%)	Once per week to once per month	-

(continued)

TABLE 2-1 (continued)

Company	Plant	Dust suppressants used[a]	Application intensity (gal/yd^2)[b]	Application frequency	Areas in which water is used
National	Great Lakes	Coherex®	0.09 (15%)	Once per month	-
USS	Fairfield	Dustaside® (6,000)[g]	N/A	Quarterly during the entire year	Used as a supplement on roads as needed (usually once a day)
USS	Gary	Resinex 60™ (500,000)[g]	N/A	Daily rotation through plant	-
USS	Geneva	Magnesium chloride	N/A	Every 6 months	Open unpaved areas on a weekly rotation schedule
USS	Mono Valley	Coherex® (50,000)[g]	N/A	N/A	-

a Value in parentheses is gallons delivered in 1984, except as noted.

b Initial/follow-up applications. Value in parentheses represents dilution ratio.

c 1983 value.

d Used primarily on storage piles and infrequently for light-duty roads

e LTV data obtained during site surveys.

f Waste oil used in 1984. See also Table 2-2.

g Estimated value.

TABLE 2-2. DUST SUPPRESSANTS RECENTLY USED OR CONSIDERED FOR EVALUATION

Plant	Dust suppressant	Comments
Middletown	Resinex	Full scale program during 1983
Indiana Harbor	Generic	Corporate personnel have expressed interest, but have no plans to evaluate
Aliquippa	Dustaside®	Plant had hoped to purchase 10,000 gal. in 1984, but business conditions prevented expenditure. Dustaside is preferred for 1985
Indiana Harbor	Dustaside®	Considering future evaluation
	Soil Sement	Considering future evaluation
	Coherex®	Evaluated in 1982
	Resinex™	Evaluated in 1982
Corporate	Generic	Corporate personnel have expressed interest
Gary	Dustaside®	Currently evaluating
Geneva	Coherex®	Evaluated during 1982-1983; considered too expensive

On the basis of the above criteria, no site at the Cleveland Works was suitable for testing. However, one suitable site was identified at both Aliquippa and Indiana Harbor. At the Aliquippa Works, the candidate road was approximately 1,600 ft long and was oriented southeast to northwest. This road was used to haul both slag to processing and refuse to a landfill.

The site at Indiana Harbor was the same road that was tested during an earlier study.[1] However, the BOF slag haul road had been substantially changed, with the southern half of the road isolated and devoted to BOF slag hauling (approximately two round trips per hour). This road was maintained by the slag processor at the plant, and Coherex® and calcium chloride were used to control emissions during 1984 and 1985, respectively. The remaining part of the road carried a variety of vehicles, ranging from cars and pick-ups to scrap trucks and Euclids. This road was maintained by ..., and Petro Tac has been applied since 1982.

In addition, the dust suppressants to be tested were assigned to each site:

Aliquippa	Coherex® Generic 2 (QS) Soil Sement
Indiana Harbor	Coherex® Petro Tac Dustaside®

In the decision process, attention was paid to locating a nearby source of the dust suppressant and contractors familiar with its application. Note that the petroleum resin Coherex® was selected for both sites to make inter-plant comparisons.

2.4 SELECTION OF STUDY DESIGN

In developing a study design to characterize the control performance of unpaved road dust suppressants, both a sampling methodology and a control application plan must be chosen. The sampling method must be able to accurately characterize the dust emissions, and the control application plan must be developed with attention to possible interference effects which could impact control efficiency determination.

Unpaved road dust emissions are especially difficult to characterize for the following reasons:

1. Both uncontrolled and controlled emission rates have a high degree of temporal variability.

2. Emissions are comprised of a wide range of particle size (including coarse particles which deposit immediately adjacent to the source) and the control efficiency for different size ranges can vary substantially.

The scheme for quantification of emission factors must effectively deal with these complications to yield source-specific emission data needed to evaluate the priorities for emission control and the effectiveness of control measures.

Two basic techniques have been used in quantifying particulate emissions from vehicular traffic on unpaved roads.

1. The <u>upwind/downwind</u>[7] method involves measurement of concentrations upwind and downwind of the source, utilizing ground-based samplers (usually hi-vol samplers) under known meterological conditions. Atmospheric dispersion equations are used to back-calculate the emission rate which most nearly produces the measured concentrations. The Gaussian dispersion equations are often applied to cases of near-roadway dispersion. However, the equations generally used were not formulated for such an application.

2. MRI's <u>exposure-profiling</u>[8] method involves direct measurement of the total passage of open dust source emissions immediately downwind of the source by means of simultaneous multipoint sampling over the effective cross-section of the open dust source emission plume. This technique uses a mass balance calculation scheme similar to EPA Method 5 rather than requiring indirect calculation through the application of a generalized atmospheric dispersion model.

The most suitable and accurate technique for quantifying unpaved road emissions in the iron and steel industry has been shown to be exposure profiling. The method is source-specific and its increased accuracy over the upwind/downwind method is a result of the fact that emission factor calculation is based on direct measurement of the variable sought, i.e., mass of emissions per unit time.

In addition to the above measurement techniques, the study design must also include a control application plan. Two major types of plans have been used:

1. Testing is conducted on two or more contiguous road segments. One segment is left untreated and the others are treated with a separate dust suppressant.

2. Uncontrolled testing is initially performed on one or more road segments, generally under worst-case (dry) conditions. Each segment is then treated with a different chemical; there is no segment left untreated as a reference. A normalization of emissions is required to allow for differences in vehicle characteristics during the uncontrolled and controlled tests because they do not occur simultaneously.

It is important to note that, for the purpose of estimating annual controlled emissions from unpaved roads, average control efficiency values based on worst-case (i.e., dry) uncontrolled emission levels are required.

This is true simply because the AP-42 unpaved road predictive equation,[6] which is routinely used for inventorying purposes, is based on source tests conducted under dry conditions. Extrapolation to annual average emissions estimates is accomplished by assuming that emissions are occurring at the estimated rate on days without measurable precipitation, and conversely are absent on days with measurable precipitation. This assumption has never been verified in a rigorous manner; however, MRI's experience with hundreds of field tests indicate that it is a reasonable assumption if the source operates on a fairly "continuous" basis.

The uncontrolled emission factor for a specific unpaved road will increase substantially after a precipitation event as the surface dries. However, in the absence of data sufficient to describe this growth as a function of traffic parameters, amount of precipitation, time of day, season, cloud cover, and other variables, uncontrolled emissions are estimated using the simple assumption given above. Thus, in order to definitively estimate emission reductions attributable to a dust suppressant, control efficiency should be referenced to uncontrolled emissions under dry conditions.

The work plan for this study originally called for field testing to be conducted over two summers. However, because the study began in June 1984, no testing was possible until the spring of 1985. Furthermore, it was not possible to extend the project duration to include the summer of 1986. Because of the constraint of only one summer available for testing, the program was designed to obtain as much useful data as possible during the period. In order to achieve this goal, modifications to MRI's prior dust control evaluation protocol were made.

The first modification was the adoption of a Type 1 control application plan. The simultaneous testing of both controlled and uncontrolled emissions from the test road under this plan allowed a more flexible set of acceptability criteria for testing. For example, light rainfall during the night did not require that the road dry out prior to testing. Thus, adoption of a Type 1 control application plan allowed more tests to be completed. However, control efficiency would still be referenced to dry conditions.

The second change (again made possible by the Type 1 plan) also allowed more information to be collected during the field program. This modification entailed deploying an "abbreviated" sampling array on days that were not totally acceptable for exposure profiling. In this case, control efficiency was determined on the basis of net reduction in concentration values rather than mass emission rates. In addition to providing additional control performance data, this information proved valuable (a) in evaluating prior control effectiveness studies for inclusion in model development, and (b) in assessing the capability of simplified sampling protocols (i.e., not requiring extensive equipment or labor resources) for estimating control efficiency.

Thus, the study design for this testing program employed exposure profiling as the primary technique to quantity uncontrolled particulate emissions from vehicular traffic on unpaved roads and to determine the control performance of the various suppressants. This design not only allowed the evaluation of effectiveness for each suppressant but could also provide information on the seasonal variation of uncontrolled emissions. Finally, the inclusion of a secondary sampling array had the additional benefits described above.

The rest of this section describes the detailed test methodology, including air and surface material sampling equipment and techniques, field and laboratory analysis techniques, and calculation procedures.

2.5 QUALITY ASSURANCE

As part of the QC 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 and control efficiency calculation. Specially designed reporting forms for field sampling and laboratory analysis data aided in the auditing procedure. Further detail on specific sampling and analysis procedures are provided in the following sections.

2.6 AIR SAMPLING EQUIPMENT AND TECHNIQUE

Exposure profiling, which was the primary air sampling technique in this study, is based on the isokinetic profiling concept 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.

In addition, an abbreviated sampling array was deployed when conditions at the site were not fully suitable for exposure profiling. This secondary system was designed to provide particulate concentration data (rather than mass emissions data) for calculation of control efficiency. Use of this system during periods of marginal wind conditions was designed to provide as much control efficiency data as possible in the 1 year available to MRI for testing. The air samplers that were used in the field testing are listed in Table 2-3. The two sampling arrays are discussed separately below.

TABLE 2-3. AIR SAMPLING EQUIPMENT

Location	Sampler	Intake height (m) Full array	Intake height (m) Abbreviated array
Upwind[a]	Standard hi-vol/ impactor	2.2	2.2
Downwind station	Profiling head	1.5	-
		3.0	-
		4.5	-
		6.0	-
	Cyclone/impactor	2.2	2.2
	37-mm cassette	2.2	2.2

[a] This deployment was modified for testing at Indiana Harbor because of the potential difference in upwind concentrations. Standard hi-vol/impactor combinations (each at a 2.2-m height) may be located upwind of each test strip.

The MRI exposure profiler (developed under EPA Contract No. 68-02-0619) was used in the "full" array. Each profiler (Figure 2-4) consist of a portable tower (4 to 6 m height) supporting an array of sampling heads. During testing, each sampling head was operated as an isokinetic exposure sampler directing passage of the flow stream through a settling chamber and then upward through a standard 20.3- x 25.4-cm (8- x 10-in.) glass fiber filter positioned horizontally. Sampling intakes were pointed into the wind, and sampling velocity of each intake was adjusted to match the local mean wind speed, as determined by 5- to 10-min averages prior to and during the test.

High-volume, parallel-slot cascade impactors (Sierra Instruments, Model No. 230) with 34-m^3/hr (20-cfm) flow controllers were used to measure the downwind particle size distribution along side the exposure profiler. The height selected for the downwind samplers was based on an examination of previous MRI testing.[1-3] This height reasonably approximates the point in the dust plume at which half the mass emissions are above and half below.

The downwind impactor units (as shown in Figure 2-5) were equipped with Sierra Model No. 230CP cyclone preseparators to remove coarse particles which otherwise would tend to bound off the glass fiber impaction substrates, causing fine particle measurement bias. To further reduce particle bounce problems, each substrate was sprayed with stopcock grease solution to provide a sticky impaction surface. The upwind particle size distribution was measured using hi-vol/impactor combinations. Experience has shown that the background size distribution is essential in determining control efficiencies for fine particulate emissions. Each impactor consisted of five

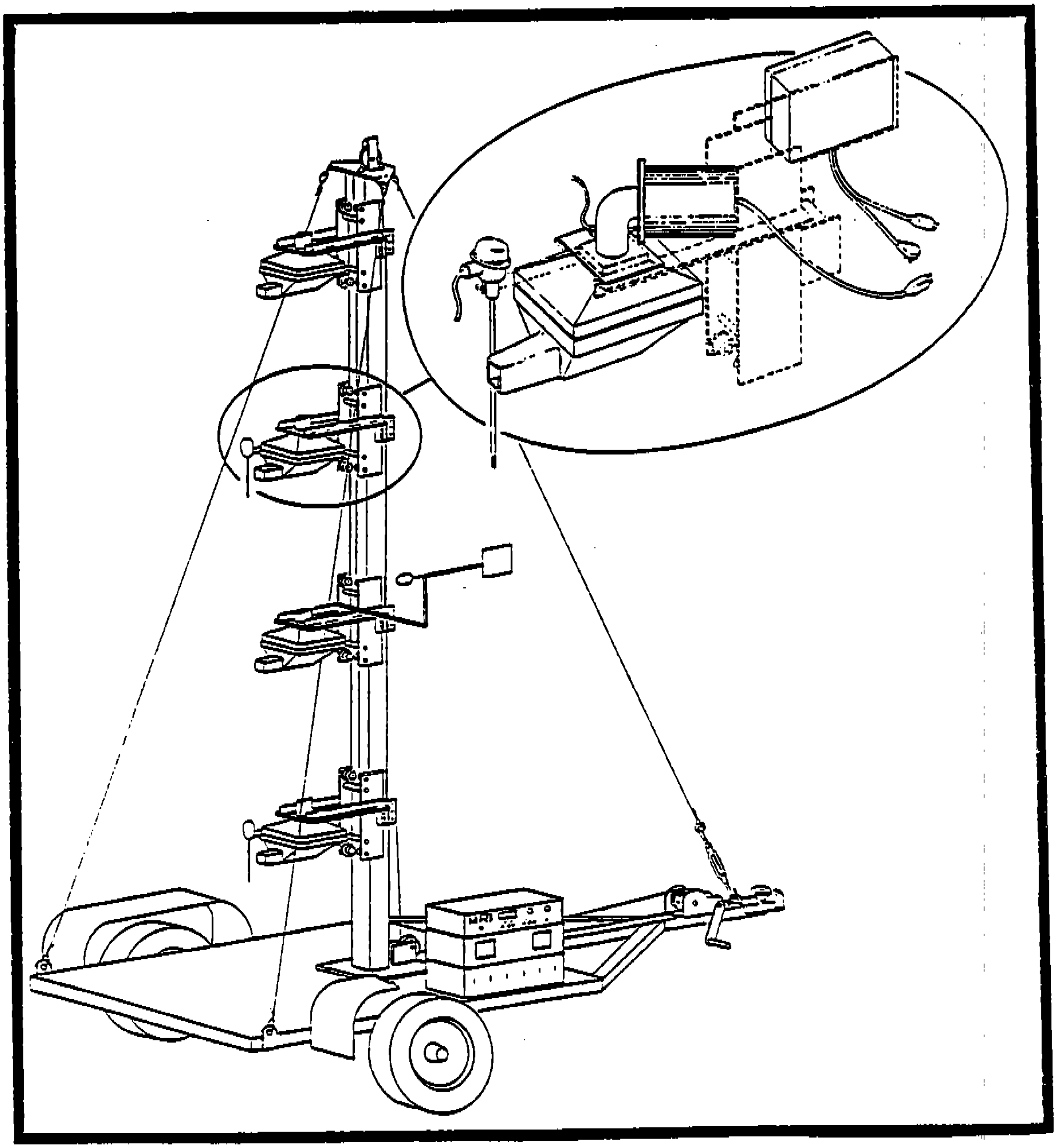

Figure 2-4. MRI exposure profiler.

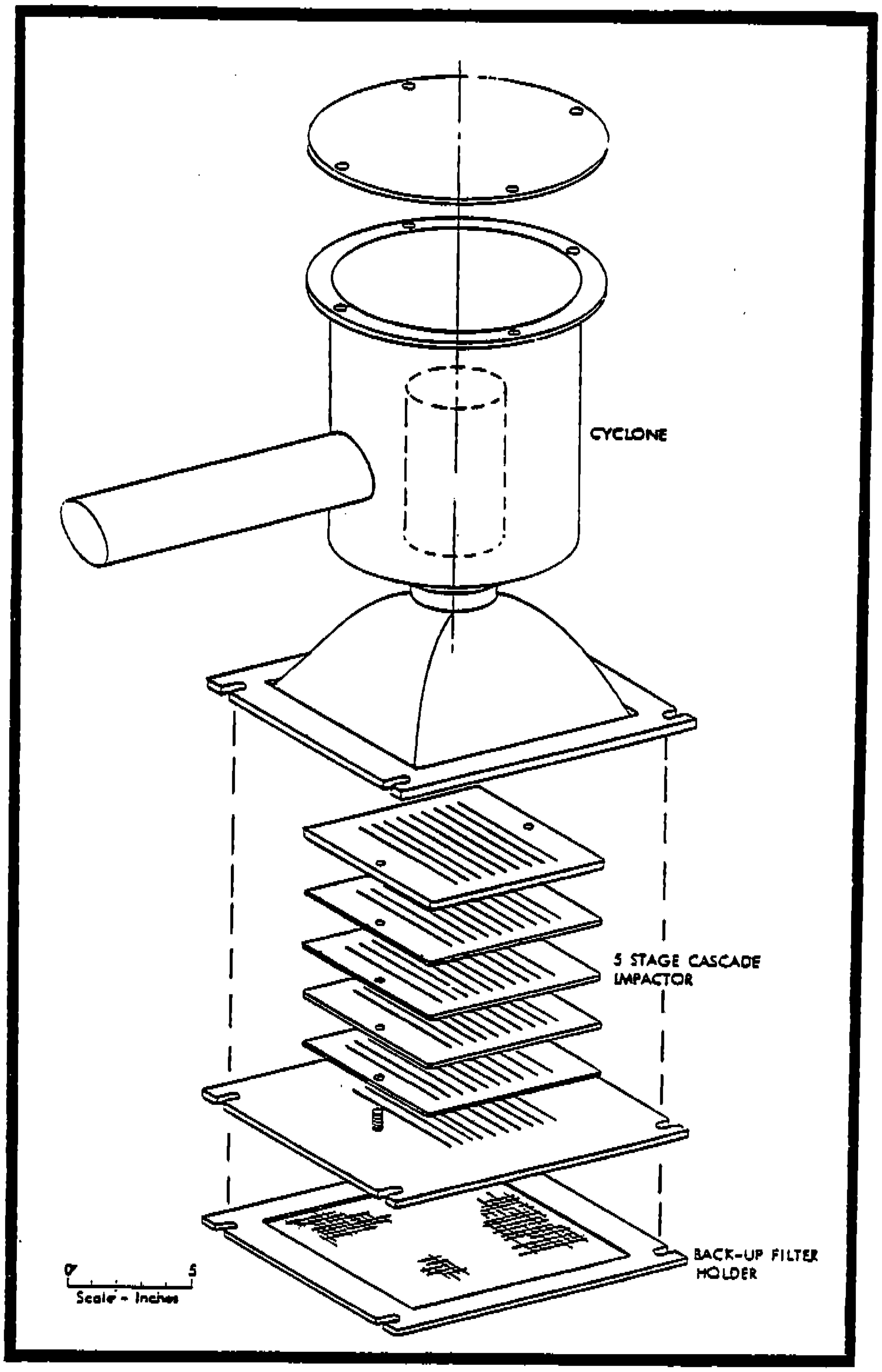

Figure 2-5. Cyclone preseparator/cascade impactor combination.

impaction stages (cut-offs for 50% collection are 10.2, 4.2, 2.1, 1.4, and 0.73 μmA at 20 ACFM). In order to determine the particle size distributions at the coarse particle end of the spectrum by microscopy, 37-mm cassette samplers were deployed at the same locations as the cyclone/impactors.

Throughout each test, wind speed was monitored by warm-wire anemometers (Kurz Model 465) at two heights, and the vertical wind speed profile was determined by assuming a logarithmic distribution. An integrating Biram's vane anemometer was used as a backup system. Horizontal wind direction was monitored by a wind vane at a single height, and 5- to 10-min averages were determined electronically prior to and during the test. The sampling intakes were adjusted for proper directional orientation based on the average wind direction.

2.7 EMISSION TESTING PROCEDURE

2.7.1 Preparation of Sample Collection Media

Particulate samples were collected on Type A slotted glass fiber impactor substrates and on Type AE grade glass fiber filters. As noted in the last section, all glass fiber cascade impactor substrates were greased to reduce the problem of particle bounce. The grease solution was prepared by dissolving 140 g (4.9 oz) of stopcock grease in 1 L (0.26 gal) of reagent grade toluene. No grease was applied to the borders and backs of the substrates. The substrates were handled, transported, and stored in frames which protected the greased surfaces.

Prior to the initial weighing, the filters and greased substrates 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 (Class S) weights to assure accuracy. The filters and substrates remained in the same controlled environment for another 24 hr, after which a second analyst reweighed them as a precision check. If a substrate or filter could not pass audit limits, the entire lot was reweighed. 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 2-4.

2.7.2 Pretest Procedures/Evaluation of Sampling Conditions

Prior to equipment deployment, a number of decisions were made as to the potential for acceptable source testing conditions. These decisions were based on forecast information obtained from the local U.S. Weather Service office. Sampling was not planned if there was a high probability of measurable precipitation.

If conditions were considered acceptable, the sampling equipment was transported to the site, and deployment was initiated. The deployment procedure normally took 1 to 2 hr to complete. 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 2-5.

TABLE 2-4. 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 2-5. QUALITY ASSURANCE PROCEDURES FOR SAMPLING FLOW RATES

Activity	QA check/requirement
Calibration	
• Cyclone/impactors	Calibrate flows in operating ranges using calibration orifice upon arrival and every 2 weeks thereafter at each plant prior to testing.
• Profiler heads	Calibrate flows in operating ranges using calibration orifice upon arrival and every 2 weeks thereafter at each regional site prior to testing.
• Orifice and electronic calibrator	Calibrate against displaced volume test meter annually.

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

a. Exposure profiler - Start/stop times, wind speed profiles, and sampler flow rates (5- to 10-min average), and wind direction relative to the roadway perpendicular (5- to 10-min average).

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

c. Traffic count by vehicle type and speed.

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

From the information in (a), adjustments could be made to insure isokinetic sampling of both profiler heads (by changing the intake velocity and orientation) and cyclone preseparators (by changing intake nozzles and orientation). Table 2-6 outlines the pertinent QA procedures.

Sampling time was long enough to provide sufficient particulate mass and to average over several cycles of the fluctuation in the emission rate (i.e., vehicle passes on the road). Sampling lasted from 16 min to over 4 hr depending on source activity and control measure (if any). Occasionally, sampling was interrupted due to occurrence of unacceptable meteorological conditions and then restarted when suitable conditions returned. Table 2-7 presents the criteria used for suspending or terminating a source test.

TABLE 2-6. 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 samplers during time span not exceeding 1 min.
• Isokinetic sampling (profilers only)	Adjust sampling intake orientation whenever mean wind direction changes by more than 30 degrees.
	Adjust intake velocity whenever mean wind speed approaching sampler changes by more than 20%.
• Isokinetic sampling (cyclone/impactors)	Adjust sampling intake orientation whenever adjustments are made to the exposure profiler intake orientation.
	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 0-6 mph, and unique nozzles for each of the wind speed ranges 6-8, 8-11, 11-15, and 15-20 mph.
• Prevention of static mode deposition	Cap sampler inlets prior to and immediately after sampling.

[a] All means refer to 5- to 10-min averages.

TABLE 2-7. 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 1.3- to 8.9-m/sec (3- to 20-mph) acceptable range for more than 20% of the sampling time.
3. The angle between mean wind direction and the perpendicular to the path of the moving point source during sampling exceeds 45 degrees for two consecutive averaging periods.
4. Daylight is insufficient for safe equipment operation.
5. Source condition deviates from predetermined criteria (e.g., occurrence of truck spill, or accidental water splashing prior to uncontrolled testing).

[a] "Mean" denotes a 5- to 10-min average.

2.7.3 Sample Handling and Analysis

To prevent particulate losses, the exposed media were carefully transferred at the end of each run to protective containers for transportation. In the field laboratory, exposed filters were placed in individual glassine envelopes and then into numbered file folders. Impactor substrates were replaced in the protective frames. Particulate that collected on the interior surfaces of profiler intakes and cyclone preseparators was rinsed with distilled water into separate sample jars which were then capped and taped shut.

When exposed substrates and 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.

To determine the sample weight of particulate collected on the interior surfaces of samplers, the entire wash solution was passed through a 47-mm (1.8-in.) Buchner-type funnel holding a glass fiber filter under suction. 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) profiler intakes in the field and following the above procedures.

2.7.4 Emission Factor Calculation Procedure

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

Particulate Concentrations--

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)

The specific particulate matter concentrations were determined from the various particulate catches as follows:

Size range	Particulate catches
TP	Profiler filter + intake or cyclone + impactor substrates + backup filter
IP	Impactor substrates + backup filter
PM_{10}	Impactor substrates + backup filter
FP	Impactor substrates + backup filter

To be consistent with the National Ambient Air Quality Standard for total suspended particulate (TSP), all concentrations and flow rates were expressed in standard conditions (25°C and 101 kPa or 77°F and 29.92 in. Hg).

Isokinetic Flow Ratio--

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.

Occasionally it is necessary to sample at a superisokinetic flow rate (IFR > 1.0), to obtain sufficient sample under light wind conditions. Correction factors for nonisokinetic TP concentrations are based on a relationship developed by Davies.[9] The relationship as applied to exposure profiling in the ambient atmosphere is as follows:

$$\frac{C_n}{C_t} = \frac{1}{IFR} - \frac{(1/IFR) - 1}{4Y + 1}$$

where: C_n = nonisokinetic concentration of particles of diameter d
C_t = true concentration of particles of diameter d
Y = inertial impaction parameter = $d^2 \, c \, (\rho_p - \rho) \, U/18\mu \, D$
D = diameter of probe
d = diameter of particle
ρ = density of air
μ = viscosity of air
ρ_p = density of particle
c = Cunningham correction factor

From Davies' equation, it is clear that, for very small d, $C_n = C_t$, and that, for large values of d, $C_n = C_t/IFR$. These observations lead to the multiplicative correction factors presented in earlier MRI reports.[2-4]

A value for the average ratio ($\bar{R}$) of nonisokinetic to true concentration can be found by integrating the product of the particle size distribution and Davies' relationship over all possible particle diameters. An isokinetically corrected concentration can then be calculated as

$$C_t = C_n/\bar{R}$$

Note that, because the particle-size distribution and the isokinetic corrections are interrelated, isokinetic corrections are of an iterative nature. In the present study, isokinetic corrections based on Davies' method described above were iterated until a convergence criterion of 1% difference between successive TP concentration values was satisfied.

Using a log-normal distribution of particle diameters, the isokinetically corrected concentrations obtained by the $\bar{R}$-method and by MRI's earlier multiplicative correction factor method differ by less than 20% for IFR values between 0.2 and 1.5, by less than 30% in the IFR range of 1.5 to 2.0, and by less than 60% for IFR values between 2.0 and 3.0.[1]

Downwind Particle-Size Distributions--

Particle-size distributions were determined by plotting ratios of the cumulative concentrations measured by each impactor stage to the total concentration against the 50% cutoff diameters presented earlier. These data were fitted to a lognormal mass size distribution after correction for particle bounce.

The technique used in this study to correct for the effects of particle bounce has been discussed in earlier MRI studies.[1,2,3] Simultaneous cascade impactor measurements of airborne particle-size distribution with and without a cyclone precollector indicate that the cyclone precollector is quite effective in reducing fine particle measurement bias. However, even with the cyclone precollector, a monotonic decrease in collected particle weight on each successive impaction stage is frequently followed by a several-fold increase in weight collected on the back-up filter. But, because the assumed value (0.2 μm) for the effective cutoff diameter of the glass fiber backup filter fits the progression of cutoff diameters for the impaction stages, the weight collected on the back-up filter should be consistent with the decreasing pattern shown by the weight collected on the impactor stages.[2] The excess particulate on the back-up filter is postulated to consist of coarse particles that penetrated the cyclone (with small probability) and bounced through the impactor. Although particle bounce is further reduced by greasing impaction substrates, it is not completely eliminated. A more complete discussion of techniques used to reduce the effects of particle bounce is given elsewhere.[1]

To correct the measured particle size distribution for the effects of residual particle bounce, the following procedure was used:

1. The calibrated cutoff diameter for the cyclone preseparator is used to fix the upper end of the particle-size distribution.

2. The lower end of the particle size distribution is fixed by the cutoff diameter of the last stage and the measured (or corrected, if necessary) mass fraction collected on the back-up filter. The corrected fraction collected on the back-up filter is calculated as the average of the fractions measured on the last two stages (Stages 4 and 5).

When a corrected mass is required, excess particulate mass is effectively removed from the back-up filter. However, because no clear procedure existed for apportioning the excess mass back onto the impaction stages, the size distribution determined for tests with evidence of particle bounce was constructed using the log-normal assumption and two points--the mass fraction collected in the cyclone and the corrected mass fraction collected on the back-up filter. The mass fractions associated with the first few impaction stages usually lie very near this line.

Prior examination of particle bounce corrections has shown only negligible changes in size fractions for PM_{10} and above. Furthermore, FP fractions generally are within a factor of 1.2 when compared to fractions developed without any correction for particle bounce.[10]

Particulate Exposures and Profile Integration--

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

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

where:
- E = total particulate exposure (mg/cm²)
- C = net TP concentration (μg/m³)
- U = approaching wind speed (m/s)
- t = duration of sampling (s)

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-mg/cm²)
- E = particulate exposure (mg/cm²)
- 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.

Total Particulate Emission Factor--

The emission factor for total airborne particulate generated by vehicular traffic on a straight road segment expressed in grams of emissions per vehicle-kilometer-traveled (VKT) is given by:

$$e = 10^4 \frac{A}{N}$$

where:
- e = total particulate emission factor (g/VKT)
- A = integrated exposure (m-mg/cm^2)
- N = number of good vehicle passes (dimensionless)

Other Emission Factors--

Emission factors for the other particle size ranges were obtained by multiplying the emission factors by net mass fractions. These mass fractions are found by dividing the net (i.e., downwind minus upwind) concentration for the size range of interest by the net TP concentration.

2.7.5 Control Efficiency Calculation Procedure

Although controlled and uncontrolled tests were conducted at the same site, it was necessary to obtain normalized values of emission factors in order to make meaningful comparisons. This was true simply because the vehicle mix on the test road varied not only from day to day but also during different shifts on an individual day. Thus, measurement-based ("raw") emission factors required normalization in order that a change in vehicle mix was not mistakenly interpreted as part of the efficiency of the control measure being tested.

The method used in this study to normalize emission factors is based on MRI's experimentally determined predictive emission factor equation for uncontrolled unpaved roads and is identical to the process used in earlier reports.[1,2] 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 control efficiency 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 controlled road

$\bar{e}_u$ = geometric mean of normalized emission factors for uncontrolled roads

This value of efficiency represents the (instantaneous) level of control over a specific test (and, hence, at a particular time after application).

Another important measure of control performance is average efficiency, defined as:

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

where: C(T) = average control efficiency during period ending T days after application (percent)

c(t) = instantaneous control efficiency at t days after application (percent)

T = time period over which average control efficiency is desired (days)

This value enables one to determine mass reductions in emissions for the purpose of determining cost-effectiveness.

2.8 AGGREGATE MATERIAL SAMPLING AND ANALYSIS

Samples of the loose road surface were taken from lateral strips of known area (generally, the width of the road by 30 cm) during the course of this study. These were analyzed for silt (those particles passing a 200-mesh screen) and moisture contents and to determine road surface loading values. Detailed steps for collection and analysis of samples for silt and moisture are given in a previous report.[8] An abbreviated discussion is presented below.

Roadway surface dust samples were collected by sweeping the loose layer of soil, slag, or crushed rock from the hardpan road base with a broom and dust pan. Sweeping was performed so that the road base was not abraded by the broom, and so that only the naturally occurring loose dust was collected. The sweeping was performed slowly so that dust was not entrained into the atmosphere.

Once the field sample was obtained, it was prepared for analysis. The field sample was split (if necessary) with a riffle to a sample size amenable to laboratory analysis. The basic procedure for moisture analysis was determination of weight loss upon oven drying. Table 2-8 presents a step-by-step procedure for determining moisture content. The basic procedure for silt analysis was mechanical, dry sieving. A step-by-step procedure is given in Table 2-9.

2.9 AUXILIARY EQUIPMENT AND SAMPLES

Provision was made to quantify additional parameters which affect the performance of a control measure applied to unpaved roads. These parameters include:

1. Intensity of the control application;

2. Number of vehicle passes following application;

3. Vehicle mix of traffic on the controlled road; and

4. Vehicle speed measured by a hand-held radar gun.

TABLE 2-8. MOISTURE ANALYSIS PROCEDURES

1. Preheat the oven to approximately 110°C (230°F). 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 overnight.[a]

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.

[a] Dry materials composed of hydrated minerals or organic materials like coal and certain soils for only 1-1/2 hr. Because of this short drying time, material dried for only 1-1/2 hr must not be more than 2.5 cm (1 in.) deep in the container.

TABLE 2-9. 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 1,600 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.

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

Because the efficiency associated with a control measure is only directly applicable to a particular dilution ratio and application intensity, it is important that these variables be quantified.

By either working closely with plant personnel or actually contracting the work, MRI was able to directly oversee the mixing and application of the solution. To measure the application intensity, tared sampling pans were placed at various locations on the road surface prior to application. These pans were deep enough (~ 15 cm) that material splashing on the bottom did not escape.

After the control was applied, the sample pans were reweighed and the density of the solution determined. The application intensity measured by each pan is given by:

$$a = \frac{m_f - m_t}{\rho A}$$

where: a = application intensity (volume/area)

m_f = final weight of the pan and solution (mass)

m_t = tare weight of the pan (mass)

ρ = weight density of solution (mass/volume)

A = area of the pan (area)

Application intensities measured by each pan were examined for any spatial variation.

In order to define decay as a function of traffic rate as well as time, pneumatic tube axle counters were deployed at the site after control application. In addition to vehicle counts during testing, independent counts determining the distribution of vehicles by number of axles were taken during each shift at the plant. This information was used to convert axle counts into the number of vehicle passes.

SECTION 3.0

CHRONOLOGY OF THE FIELD TESTING PROGRAM AND TEST RESULTS

The preceding section described the study design and testing plan for this field program; however, several unanticipated events necessitated that portions of the original plans be altered. This section discusses the program as it evolved in response to these events. In addition, field results are presented and discussed.

3.1 MODIFICATIONS TO TEST PLAN

MRI field testing personnel arrived at LTV's Indiana Harbor Works on Monday, April 29, 1985. During the next few days, several conversations between MRI and Preventive Maintenance Corportion (PMC) representatives took place at the plant. (At the time, the Indiana Harbor Works was separately evaluating PMC's Dustaside® at various locations in the plant.) After several telephone calls by both parties to the project officer, PMC requested that Dustaside® not be included in the field evaluation.

Further discussions with the plant's environmental staff revealed interest in the calcium chloride dust suppressant (Liquidow™) used by the BOF slag processor. Much of this interest was due to the low cost and the fact that the supplier applied the material, thus eliminating certain costs in common dust control plans. Arrangements were made to obtain calcium chloride as the third chemical for evaluation at Indiana Harbor.

On May 17, 1985, with MRI personnel present at Indiana Harbor, LTV announced that the Aliquippa Works would be closed. Subsequent discussion with personnel at both plants revealed that, although August 17 would be the target date for cessation of many operations, steelmaking would end on June 28. Thus, only negligible traffic would be present on the slag haul road at Aliquippa after June 1985.

In a meeting with the EPA technical monitor in Kansas City on May 23, several options were discussed in order to continue the field efforts in the most productive manner possible. Both MRI and the technical monitor agreed that testing at the Kansas City Works of Armco, Inc., would be preferred for the following reasons:

1. Little time would be lost in conducting a new site survey because this road had been used in an earlier study[1]

2. Travel costs would be reduced

3. The road at Armco was long enough to permit five contiguous test sections so that all five chemicals could be evaluated on the same road

4. MRI would be able largely to control the service environment of the road in order to simulate typical industry traffic characteristics

Drums of Coherex® and Generic which had earlier been delivered to the Aliquippa Works were shipped to Kansas City. Furthermore, arrangements were made to obtain Petro Tac and Soil Sement in small lots and to have calcium chloride available for application in Kansas City.

3.2 SOURCE DESCRIPTION

The following tests were performed at two iron and steel plants - LTV's Indiana Harbor Works (designated hereafter as plant AP) and Armco's Kansas City Works (plant AQ):

<u>Plant AP</u>

- Five tests of uncontrolled emissions
- Six tests on a road treated with Coherex®
- Six tests on a road treated with Petro Tac
- Three tests on a road treated with calcium chloride (Liquidow™)

<u>Plant AQ</u>

- Two tests of uncontrolled emissions
- Nine tests on a road treated with Coherex®
- Eleven tests on a road treated with Soil Sement
- Eleven tests on a road treated with Generic 2 (QS)
- Five tests on a road treated with Petro Tac
- Six tests on a road treated with Liquidow™

Maps of the test sites at plants AP and AQ are shown as Figures 3-1 and 3-2, respectively. Areas shown as buffers at the AP test site were treated with either calcium chloride or Petro Tac; in addition, open areas in the scrap storage yard south of the road were treated with Petro Tac to reduce potential upwind impacts.

Several difficulties in controlling traffic patterns at the AP site were encountered. For example, scrap steel and processed slag haulers often entered the test area at the southwest corner of the pipe mill, traveled between the slag piles and the mill and made U-turns onto the scale. The plant erected a barricade using barrels and plastic streamers at the mill's southwest corner; this, however, did not prove effective. Later, barricades made by piling slag proved to be much more effective.

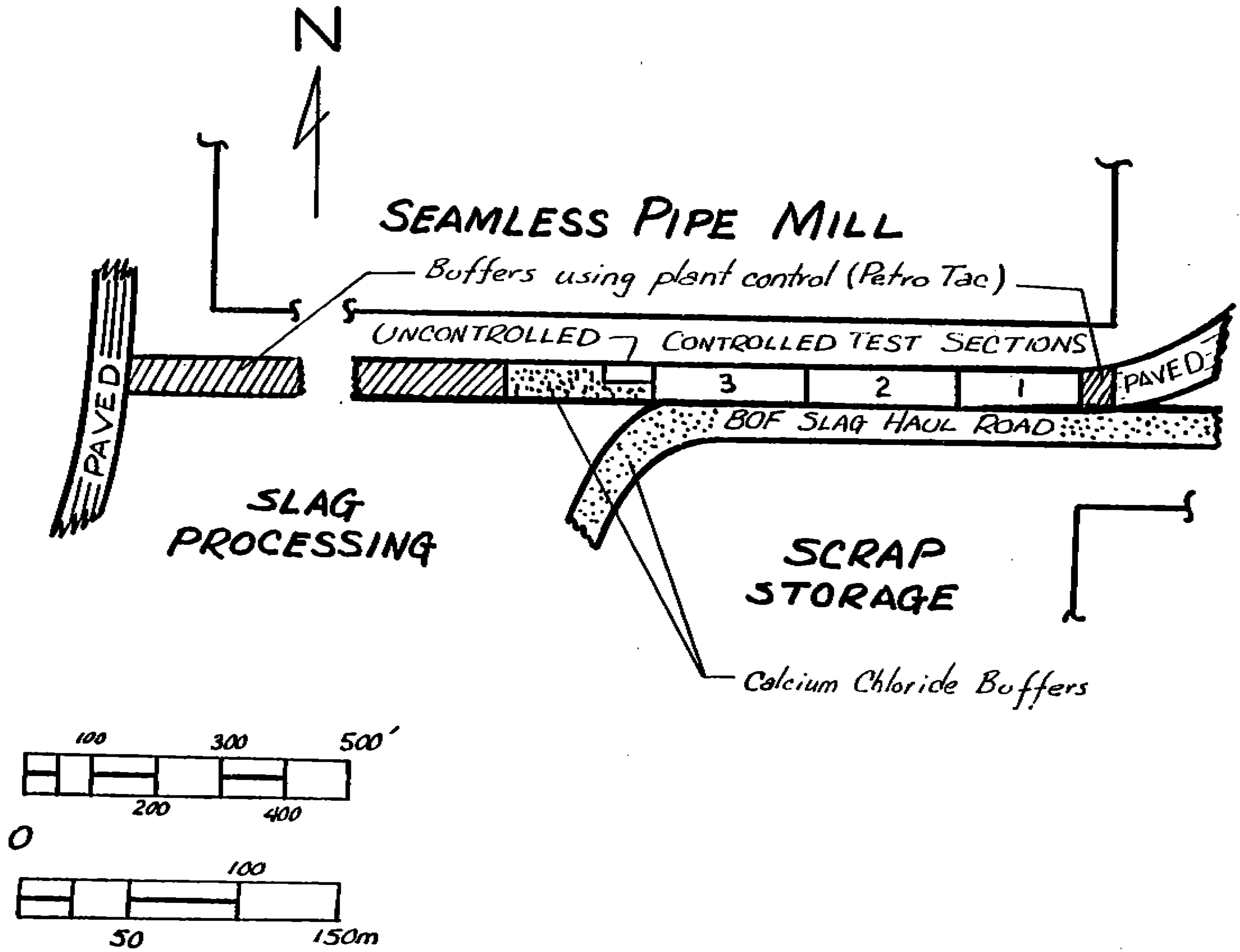

Figure 3-1. Test site at plant AP.

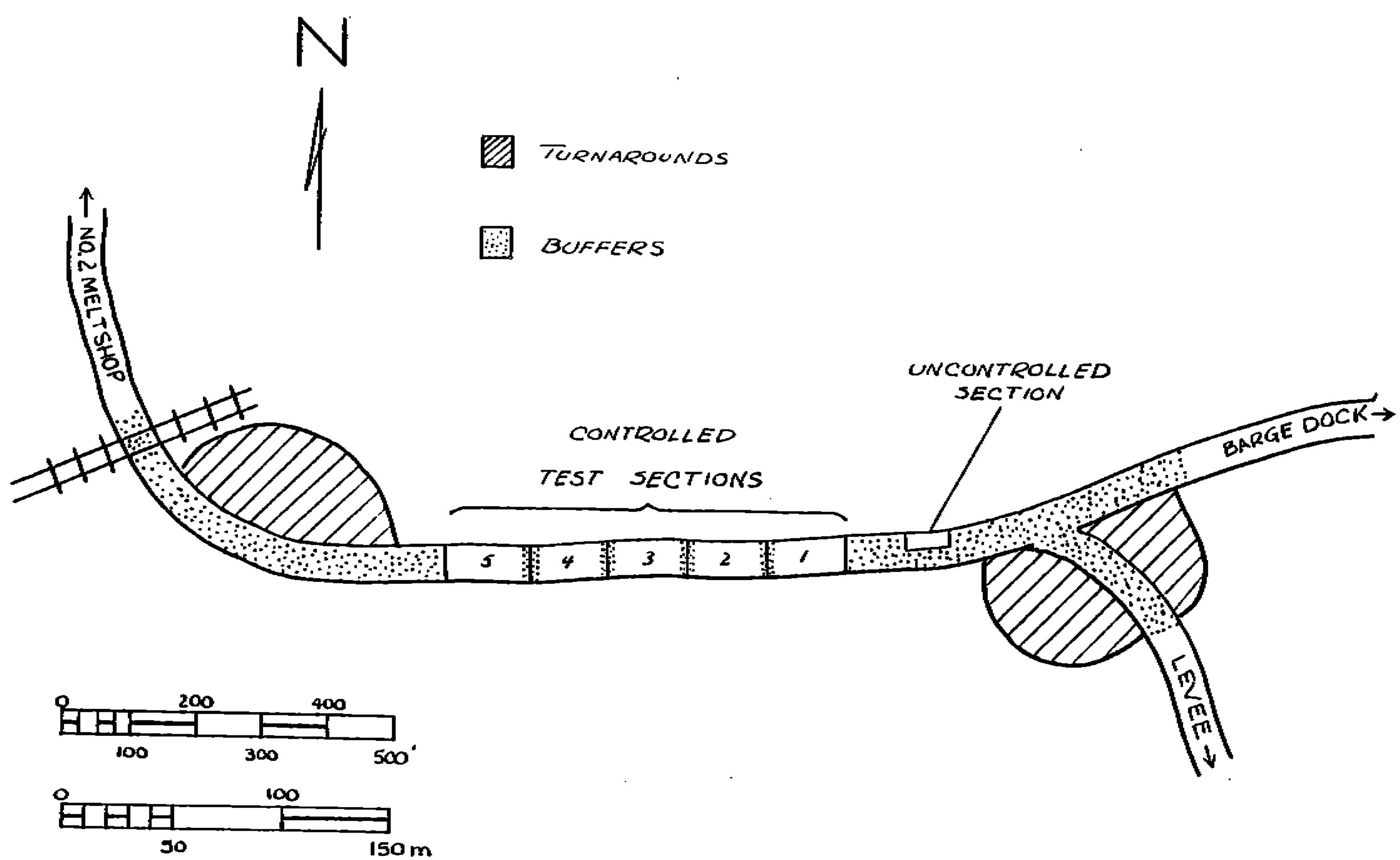

Figure 3-2. Test site at plant AQ.

The AQ test site, on the other hand, allowed MRI much greater control of the service environment for the test sections. This road was located in a remote corner of the plant and experienced only sporadic traffic related to plant security and maintenance of a levee to the southeast. Arrangements were made with the plant's slag processor to fill and grade turnarounds at the east and west ends of the road to accomodate captive traffic supplied by MRI. The captive traffic consisted of a 10-ton, 6-wheel dump truck periodically supplemented with an R-25 Euclid. All travel was confined to the north side of the road; this not only accelerated the decay rate under traffic but also decreased the road length required for a test section.

The AQ test road experienced average traffic volumes of 110 and 130 vehicle passes (VP) per working day between September 3 and October 3, 1985, and between October 21 and the end of testing, respectively. Because vehicles were restricted to one side of the road, these volumes represent 220 to 260 passes per day for two-way traffic. These two-way equivalent volumes closely approximate the mean value of 220 VP/day obtained from the data in Section 2.1. All traffic occurred at a nominal speed of 24 kph (15 mph).

The east and west ends of the road (including the turnarounds) were treated as buffer areas. Roughly 25% of the total load of each chemical (excluding calcium chloride which was applied by the delivery truck) was used on the test section and the remainder applied to the buffer areas (Generic and Soil Sement at the east end, Petro Tac and Coherex® at the west). Buffers between individual test sections were formed by overlapping chemical applications (excluding calcium chloride) by approximately 10 m. These buffers were routinely swept to reduce track-on and were periodically retreated using a new dust suppressant supplied by Syn Tech Products Corporation.

3.3 CONTROL APPLICATIONS

MRI supervised the application of all chemicals (both test sections and buffer areas) during this field program. Measurements of application rate and density were taken whenever test sections were treated. Tables 3-1 and 3-2 present the application parameters for plants AP and AQ, respectively.

The test sections were characterized in terms of silt content and total loading prior to treatment. Summary data are given below:

Mean Values of
Pre-Application Surface Characteristics

	Plant AP	Plant AQ
Total loading (g/m^2)	9,400	1,200
Silt content (%)	8.0	13.9
Silt loading (g/m^2)	750	170

TABLE 3-1. APPLICATION PARAMETERS - PLANT AP

Chemical	Test strip	Dilution ratio	Application intensity, L/m² (gal/yd²) 5/1/85	5/6/85	6/14/85	7/2/85
Petro Tac	1	5:1	2.0 (0.44)	1.0 (0.23)	3.8 (0.83)	-
Coherex®	2	5:1	2.5 (0.56)	1.0 (0.22)	4.5 (1.0)	-
Calcium chloride	3	a	1.1 (0.25)	0.86 (0.19)	1.7 (0.38)	1.5 (0.34)

[a] As received (38% solution).

[b] Application of 6/14/85 largely washed off due to heavy rains shortly after completion. Delays in scheduling distribution truck and unfavorable meterological conditions postponed reapplication until 7/2/85.

TABLE 3-2. APPLICATION PARAMETERS - PLANT AQ

Chemical	Test strip	Dilution ratio	Application intensity, L/m² (gal/yd²) 7/26/85	9/3/85	10/17-21/85
Calcium chloride	5	a	1.1 (0.24)	1.3 (0.29)	2.3 (0.51)
Coherex®	4	5:1	0.95 (0.21)	1.6 (0.36)	7.2 (1.6)
Soil Sement	3	5:1	0.72 (0.16)	2.0 (0.44)	1.3 (0.28)[b]
Generic	2	5:1	0.63 (0.14)	2.1 (0.46)	7.7 (1.70)[c]
Petro Tac	1	5:1	0.95 (0.21)	1.6 (0.35)	7.7 (1.70)

[a] As received (38% solution).

[b] Lower application intensity recommended by manufacturer's respresentative.

[c] Dilution ratio of 12:1, following recommendations of Mellon Institute.

Figure 3-3 shows the variation of these surfaces parameters over the two test roads.

3.4 RESULTS OF THE EXPOSURE PROFILING TESTS

Sixty-four exposure profiling tests of unpaved road dust emissions were conducted during the course of this study. Site parameters associated with these tests are presented in Tables 3-3 and 3-4. Several remarks about these tables are in order.

First, each test is identified by a run number composed of a plant prefix, a sequential identification number and finally, a road section suffix. The suffix serves to identify the type of control applied to the road segment. The letter "U" indicates an uncontrolled surface. In addition, each suppressant has been assigned a code letter as follows:

Code letter	Suppressant	Test section	
		Plant AP	Plant AQ
P	Petro Tac	1	1
G	Generic	-	2
S	Soil Sement	-	3
X	Coherex®	2	4
C	Calcium chloride	3	5

Code letters are used here to discourage selective citation of test results. Because the selection of a dust control product necessarily entails evaluation of both performance characteristics and cost considerations (such as capital equipment costs), no individual table of results taken from this report can provide all the information required. Therefore, the reader is strongly cautioned against taking any results out of context. The report as a whole provides a better basis for decisions than does any single data set.

Secondly, four tests (AP-1) were performed using the abbreviated sampling array discussed in Section 2.0. In these tests, upwind concentrations were larger than three of the four downwind values. Much of the difficulty associated with the abbreviated array at plant AP stemmed from the very irregular flow patterns caused by surrounding structures. No further attempts were made to use the abbreviated array at this plant. Although plant AQ would have proved more amenable to the abbreviated sampling array, the orientation of the road to prevailing wind direction and the site's proximity to MRI's main laboratories made this array unnecessary.

No tests of calcium chloride took place at plant AP after run AP-3. The shorter lifetime of calcium chloride compared to the other two chemicals made it difficult to avoid possible contamination of adjacent sections.

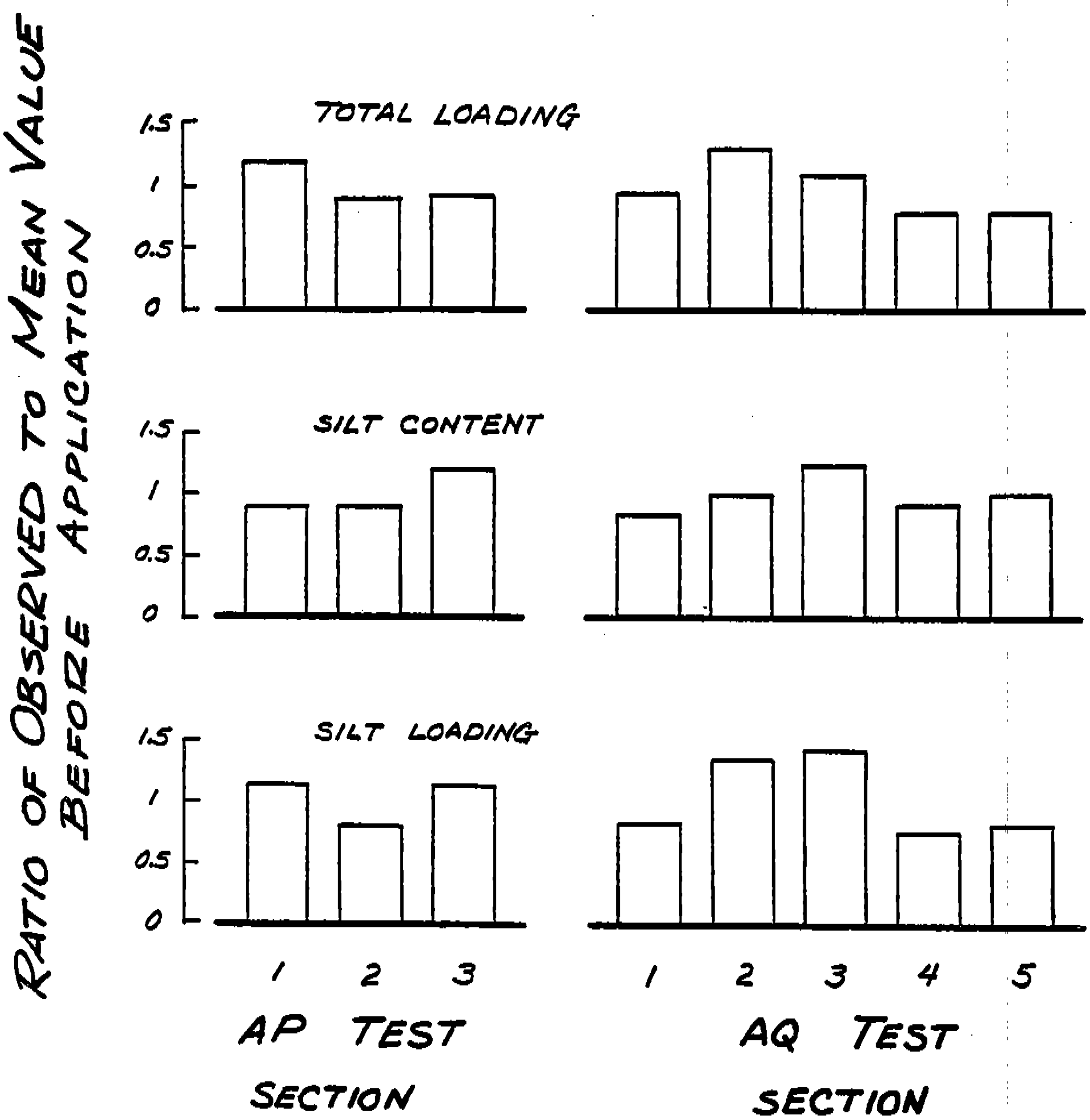

Figure 3-3. Variation of surface material properties (before control) over test sections (see text for mean values).

TABLE 3-3. TEST SITE PARAMETERS - PLANT AP

Run	Date	Ambient air temperature (°C)	Mean wind speed[a] (m/s)	Mean wind speed[a] (mph)	Test start time	Duration (min)	Number of vehicle passes	Average vehicle weight (Mg)	Average vehicle weight (ton)	Average No. of wheels
AP1 P[b]	5/07/85	21[c]		-	1227	10	8	27	30	15.5
X[b]				-	1227	27	16	26	28	14.9
C[b]				-	1227	76	48	26	29	15.4
U[b]				-	1227	37	19	29	32	15.0
AP2 P	5/09/85	21[c]	4.8	11	903	128	68	24.6	27	12.3
X			3.4	7.6	903	128	68	24.6	27	12.3
C			1.9	4.2	903	128	65	25.5	28	11.8
U			1.9	4.2	904	127	8	30.0	33	7.0
AP3 P	5/10/85	21[c]	4.9	11	850	119	50	26.4	29	7.08
X			3.8	8.5	850	119	50	26.4	29	7.08
C			3.8	8.5	850	119	50	26.4	29	7.08
U			2.8	6.2	850	119	10	33.7	37	5.20
AP5 P	8/17/86	23	1.2	2.6	945	84	34	25.5	28	13.9
X			1.7	3.9	943	82	34	25.5	28	13.9
AP6 P	8/19/85	24	0.91	2.0	1437	59	51	23.7	26	17.4
X			1.6	3.7	1440	56	51	23.7	26	17.4
U			1.6	3.7	1450	46	51	23.7	26	17.4
AP7 P	8/23/85	22	0.41	0.92	825	104	87	23.7	26	13.5
X			0.72	1.6	821	109	90	23.7	26	13.4
U			0.72	1.6	823	87	85	22.8	25	13.4

a Measured at 4.5 m height just prior to, during, and immediately after tests.

b Abbreviated array.

c Estimated value.

TABLE 3-4. TEST SITE PARAMETERS - PLANT AQ

Run	Date	Ambient air temperature (°C)	Mean wind speed[a] (m/s)	(mph)	Test start time	Duration (min)	Number of vehicle passes[b]	Average vehicle weight (Mg)	(ton)	Average No. of wheels
AQ1 U	9/16/85	28	3.8	8.4	1025	64	50	9.1	10	6.0
G					1024	66	50	9.1	10	6.0
S					1012	75	50	9.1	10	6.0
X					1015	75	50	9.1	10	6.0
AQ2 U	9/16/85	28	3.9	8.7	1241	69	68	8.9	9.8	5.9
G					1229	82	68	8.9	9.8	5.9
S					1226	85	68	8.9	9.8	5.9
X					1229	82	68	8.9	9.8	5.9
AQ3 P	9/17/85	24[c]	5.1	11	954	105	76	8.8	9.7	5.9
G			4.0	9.0	943	52	19	8.5	9.3	5.8
S			4.0	9.0	945	50	19	8.7	9.6	5.9
X			4.0	9.0	948	47	19	8.7	9.6	5.9
AQ4 G	9/17/85	24[c]	4.9	11	1630	22	50	22	24	6.0
S			4.5	10	1531	28	50	22	24	6.0
X			5.2	12	1720	22	50	22	24	6.0
C			5.8	13	1535	33	50	22	24	6.0
AQ5 P	10/02/85	17	2.6	5.9	1055	21	34	22	24	5.9
G					1208	20	34	22	24	5.9
S					1045	29	34	22	24	5.9
C					1054	20	34	22	24	5.9
AQ6 P	10/02/85	24[c]	2.2	5.0[d]	1537	18	44	22	24	6.0
G					1436	28	36	22	24	6.0
S					1436	23	36	22	24	6.0
C					1436	23	36	22	24	6.0

(continued)

TABLE 3-4 (continued)

Run		Date	Ambient air temperature (°C)	Mean wind speed[a] (m/s)	Mean wind speed[a] (mph)	Test start time	Duration (min)	Number[b] of vehicle passes	Average vehicle weight (Mg)	Average vehicle weight (ton)	Average No. of wheels
AQ7	P	10/03/85	18	2.9	6.5[d]	1149	30	50	22	24	6.0
	G					1245	25	48	22	24	6.0
	S					1150	28	50	22	24	6.0
	X					1150	28	50	22	24	6.0
AP8	P	10/03/86	21	2.2	5.0[d]	1558	22	36	22	24	6.0
	G					1520	16	34	22	24	6.0
	S					1518	17	34	22	24	6.0
	X					1518	17	34	22	24	6.0
AP9	G	10/25/85	18	2.9	6.5	1117	110	125	9.1	10	6.0
	S					1117	110	125	9.1	10	6.0
	X					1143	62	79	9.1	10	6.0
	C					1124	267	125	9.1	10	6.0
AP10	G	11/05/85	16	2.9	6.6	954	138	200	6.9	7.6	5.3
	S					954	134	200	6.9	7.6	5.3
	X					954	129	200	6.9	7.6	5.3
	C					1000	133	200	6.9	7.6	5.3
AP11	G	11/05/85	13	3.9	8.7	1349	127	250	5.9	6.5	5.0
	S					1349	127	250	5.9	6.5	5.0
	X					1349	130	250	5.9	6.5	5.0
	C					1348	130	250	5.9	6.5	5.0

a 4.5-m equivalent prior to, during and after tests, except as noted.

b During profiler operation.

c Estimated value.

d 3.0-m height.

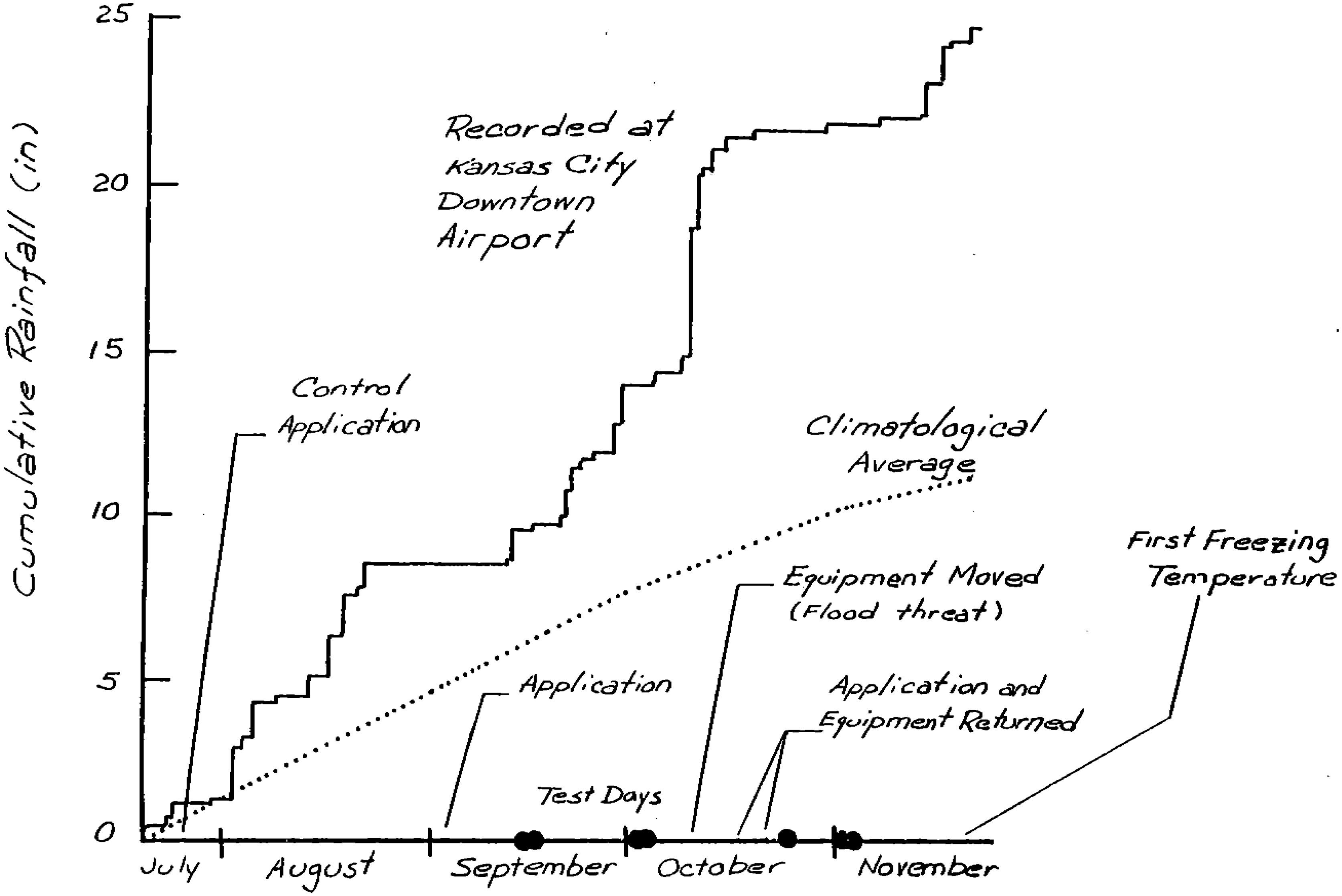

Figure 3-4. Cumulative rainfall and chronology of events at plant AQ.

Furthermore, as noted in Table 3-1, the treatment of June 14 was largely washed off by heavy rains a few hours after application. Problems in scheduling the distributor truck and unfavorable meteorological forecasts delayed reapplication. It appeared that at least the section treated with Coherex® was contaminated during the 2 weeks between applications. The decision to abandon the C test strip and to treat both this strip and the surrounding buffers as part of the plant's Petro Tac rotation was made in conjunction with the project officer.

Further difficulties were encountered with standing water and rutting of the road at plant AP. The first 2 weeks of August produced 100% of normal precipitation for the month. The south sides of the X test section and of the buffer were found to be badly rutted once the water was removed. To ensure safe vehicle operation and to reduce spillage, these areas were slagged and treated with Petro Tac. All subsequent tests restricted traffic to the north side of the road.

During the same period, the uncontrolled section at plant AP also contained standing water. After drying, the surface resembled caked mud and was not representative of the road prior to application of controls.

Finally, testing at plant AQ was hampered by one of the wettest falls on record. Figure 3-4 compares the 1985 precipitation record with the climatological record; in addition, important events are noted along the time line. During the four months after the initial control applications, recorded rainfall represented 224, 160, 306, and 263% of normal. The heavy rains of mid-October caused flooding in areas surrounding the test site and all sampling equipment was moved to higher ground. Standing water during this period caused severe rutting in the P test section. Regrading was necessary for safe vehicle operation; this, however, required that the surface be abandoned for further testing. After regrading, this segment was heavily retreated periodically as were the other buffer areas.

Tables 3-5 and 3-6 compare, for each run, raw concentration values both upwind and downwind of the test road. It should be noted that direct comparison of TP concentrations measured by the profiler and cyclone/impactor samplers is hindered by the fact that the latter units were often operated for a longer time period to obtain adequate sample mass on each substrate.

Table 3-7 and 3-8 gives measured wind speeds and isokinetic flow ratios for the profile or sampling heads. These values, in conjuction with the aerodynamic particle size data presented in Tables 3-9 and 3-10, were used to determine isokinetically corrected TP concentrations as needed, using the procedure described in Section 2.7. Note that some tests at plant AP are characterized by wind speed profiles which decrease with height. It is believed that this is the result of irregular flow patterns due to surrounding obstructions.

TABLE 3-5. REPRESENTATIVE CONCENTRATIONS[a] (μg/m³) - PLANT AP

Run		Upwind hi-vol	Downwind cyclone	Downwind profiler[b]
AP2	P	552	421	721[c]
	X	1,660	483	810[c]
	C	1,020	787	736[c]
	U	609	1,130	1,520
AP3	P	357	277	545
	X	537	364	554
	C	371	503	508
	U	796	1,040	1,400
AP5	P	705	3,830	2,890
	X	487	6,730	5,250
AP6	P	2,200	7,330	5,400[d]
	X	2,590	12,400	9,740
	U	1,190	2,080	2,830
AP7	P	284	12,800	6,160
	X	209	5,610	3,730
	U	535	12,800	7,330

[a] At 2.2-m height, except as noted.

[b] Interpolated from profiler heads nearest 2.2-m height.

[c] 1.5-m value.

[d] Estimated value.

TABLE 3-6. REPRESENTATIVE TP CONCENTRATIONS[a] (μg/m³) - PLANT AQ

Run		Upwind hi-vol	Downwind cyclone	Downwind profiler[b]
AQ1	U	54	2,340	2,810
	G	54	1,330	3,020
	S	54	741	1,280
	X	54	2,300	5,330
AQ2	U	54	2,340	3,050
	G	54	1,330	2,320
	S	54	741	647
	X	54	2,300	2,300[c]
AQ3	P	121	709	1,330
	G	121	693	453
	S	121	567	299
	X	121	1,170	318
AQ4	G	121	4,730	22,600
	S	121	3,480	7,080
	X	121	6,610	14,800
	C	121	5,320	8,480
AQ5	P	190	6,790	14,100
	G	190	3,670	6,040
	S	190	3,560	6,780
	C	190	7,860	23,600
AQ6	P	190	6,860	22,800
	G	190	5,970	9,840
	S	190	9,810	7,030
	C	190	13,500	22,800
AQ7	P	112	5,720	3,990
	G	112	2,980	4,560
	S	112	2,770	6,130
	X	112	8,750	12,700
AQ8	P	112	3,270	5,900
	G	112	4,190	5,300
	S	112	3,090	6,390
	X	112	3,210	15,800
AQ9	G	32	670	856
	S	32	126	230
	X	32	278	181
	C	32	171	121
AQ10	G	63	863	1,170[d]
	S	63	301	407[d]
	X	63	330	343
	C	63	230	453
AQ11	G	63	863	1,600
	S	63	301	452
	X	63	330	387
	C	63	227	378

[a] At 2.2-m height, except as noted.

[b] Interpolated from profiler heads nearest 2.2-m height.

[c] Estimated value.

[d] 3.0-m value.

TABLE 3-7. ISOKINETIC CORRECTION PARAMETERS - PLANT AP

Run		Wind speed 1.5 m (cm/s)	Wind speed 1.5 m (fpm)	Wind speed 4.5 m (cm/s)	Wind speed 4.5 m (fpm)	Profiler isokinetic flow ratios 1.5 m	3 m	4.5 m	6 m
AP2	P	167	328	486	957	1.59	0.85	0.68	0.74
	X	149	294	339	667	1.40	-	1.13	1.03
	C	130	256	206	406[a]	1.01	-	-	2.09
	U	158	312	197	387[a]	1.01	0.96	-	1.03
AP3	P	305	600	481	947	1.02	0.99	1.04	1.03
	X	283	558	372	732	1.00	1.22	1.42	1.36
	C	283	558	395	778[a]	0.86	1.23	-	1.44
	U	266	524	268	528[a]	1.00	0.99	-	1.15
AP5	P	168	330	117	231	0.57	0.44	0.74	0.78
	X	165	324	179	352	0.86	0.92	0.93	0.93
AP6	P	167	328	90	178	1.02	1.29	1.89	3.51
	X	173	341	160	315	0.93	1.00	1.06	1.11
	U	168	330	149	294	0.95	1.02	1.11	1.04
AP7	P	48	94	40	78	4.34	2.42	2.80	3.83
	X	67	132	73	143	1.73	1.84	1.56	1.41
	U	63	124	68	134	1.53	1.46	1.70	1.41

[a] 6.0-m value.

TABLE 3-8. ISOKINETIC CORRECTION PARAMETERS - PLANT AQ

Run		Wind speed 1.5 m (cm/s)	Wind speed 1.5 m (fpm)	Wind speed 4.5 m (cm/s)	Wind speed 4.5 m (fpm)	Profiler isokinetic flow ratio 1.5 m	3 m	4.5 m	6 m
AQ1	U	115	226	458	902	1.01	0.67	0.63	0.60
	G	115	226	458	901	1.01	0.67	0.63	0.60
	S	113	222	440	866	1.03	0.70	0.67	0.64
	X	114	224	445	876	1.02	0.68	0.65	0.62
AQ2	U	235	463	389	766	1.06	0.91	0.97	1.01
	G	228	448	401	789	0.97	0.91	0.87	-
	S	225	443	384	756	0.98	0.91	0.96	1.00
	X	225	443	386	759	-	-	0.96	1.00
AQ3	P	252	496	504	992	1.16	0.91	0.80	0.87
	G	277	546	465	915	0.66	0.79	-	-
	S	281	554	468	922	0.72	0.78	0.86	0.88
	X	287	565	473	932	1.81	-	0.85	0.88
AQ4	G	247	487	494	973	1.54	1.07	1.05	0.99
	S	144	283	443	872	2.05	1.13	1.05	0.98
	X	250	493	497	978	1.28	0.88	0.74	0.80
	C	280	551	559	1100	1.44	1.00	0.98	0.93
AQ5	P	215	424	356	700	0.76	0.82	0.86	0.86
	G	206	405	233	458	0.95	0.97	0.98	1.00
	S	200	394	348	686	0.75	0.69	0.71	0.75
	C	222	438	374	737	0.74	0.78	0.82	0.82
AQ6	P	104	205	190	374	2.11	1.62	1.25	1.20
	G	171	337	313	617	1.28	0.98	0.76	0.73
	S	189	372	345	680	1.06	0.70	0.69	0.95
	C	189	372	345	680	1.16	0.70	0.69	0.66
AQ7	P	182	359	331	652	0.89	0.88	0.86	0.90
	G	192	378	367	722	1.03	1.02	0.79	1.01
	S	175	345	321	632	0.91	0.90	0.90	0.92
	X	175	345	321	632	0.91	0.90	0.90	0.91
AQ8	P	148	291	271	533	1.48	1.14	1.01	0.97
	G	143	282	247	486	1.53	1.38	1.27	1.27
	S	142	279	241	475	1.42	1.36	1.34	-
	X	142	279	241	475	1.29	1.36	1.34	1.32
AQ9	G	163	321	287	565	0.99	0.94	0.94	-
	S	163	321	287	565	0.99	0.94	0.94	0.87
	X	186	366	326	641	1.01	0.95	0.98	0.94
	C	166	326	286	563	1.04	1.01	1.00	0.96
AQ10	G	109	215	292	574	1.03	1.01	1.01	1.02
	S	110	216	294	578	1.04	1.09	0.83	-
	X	111	218	294	578	1.21	0.97	1.12	-
	C	110	217	295	582	1.02	1.00	-	1.01
AQ11	G	178	350	379	747	1.03	0.46	1.02	1.00
	S	178	350	377	742	1.03	1.04	1.03	-
	X	175	344	388	763	1.05	1.01	1.04	-
	C	177	348	378	744	1.03	1.01	1.02	1.00

TABLE 3-9. AERODYNAMIC PARTICLE SIZE DATA - PLANT AP

Run		Percent less than stated size[a]					
		% < 15 μm		% < 10 μm		% < 2.5 μm	
		UW	DW	UW	DW	UW	DW
AP2	P	88	19	83	15	60	6
	X	85	32	80	25	61	10
	C	86	34	81	28	57	11
	U	82	42	76	34	53	10
AP3	P	84	31	79	26	56	14
	X	84	31	79	26	56	11
	C	84	40	78	35	51	16
	U	87	42	83	34	62	13
AP5	P	67	28	57	22	22	8
	X	75	24	70	19	50	7
AP6	P	72	28	64	22	32	6
	X	76	31	68	24	36	8
	U	71	42	62	31	29	7
AP7	P	79	11	73	9	54	3
	X	74	14	68	12	50	4
	U	76	18	63	13	26	4

[a] UW denotes upwind, DW downwind.

TABLE 3-10. AERODYNAMIC PARTICLE SIZE DATA - PLANT AQ

Run		Percent less than stated size[a]					
		% < 15 μm		% < 10 μm		% < 2.5 μm	
		UW	DW	UW	DW	UW	DW
AQ1	U	93	24	86	17	66	4
	G		26		21		9
	S		18		14		5
	X		12		10		3
AP2	U	93	24	86	17	66	4
	G		26		21		9
	S		18		14		5
	X		12		10		3
AQ3	P	87	29	62	26	45	16
	G		20		16		6
	S		20		16		5
	X		9		7		2
AQ4	G	87	19	62	15	45	6
	S		17		13		4
	X		10		7		2
	C		8		7		2
AQ5	P	96	21	88	17	85	7
	G		22		18		6
	S		20		16		6
	C		24		19		7
AQ6	P	96	17	88	12	85	3
	G		17		12		3
	S		18		14		5
	C		22		16		6
AQ7	P	85	16	58	12	48	4
	G		21		16		5
	S		15		10		2
	X		20		14		5
AQ8	P	85	25	58	18	44	6
	G		27		21		8
	S		24		18		4
	X		25		19		7
AQ9	G	100	34	100	26	100	7
	S		38		29		6
	X		28		20		5
	C		31		22		5
AQ10	G	86	34	75	26	42	7
	S		38		29		6
	X		28		20		5
	C		32		24		7
AQ11	G	86	34	75	26	42	7
	S		38		29		6
	X		28		20		5
	C		32		24		7

[a] UW denotes upwind, DW downwind.

Individual point values of isokinetic TP exposure (net mass per sampling intake area) within the open dust source plume are presented in Tables 3-11 and 3-12. These are values integrated over the height of the plume to develop emission factors, as discussed in Section 2.0.

Tables 3-13 and 3-14 present size-specific emission factors for plants AP and AQ, respectively. Also shown in these tables are surface aggregate material properties. These values have been normalized using the procedure described in Section 2.7.

Finally, mean uncontrolled normalized emission factors for the two plants were obtained in order to determine control efficiency:

Mean Normalized Uncontrolled Emission Factors (g/VKT)[a]

Plant	Particle size fraction			
	TP	IP	PM_{10}	FP
AP[b]	8,850	1,860	1,510	186
AQ[c]	3,690	821	561	101

[a] Normalized to 25 Mg (28 tons) and 12 wheels for plant AP, and 9.1 Mg (10 tons) and 6 wheels for plant AQ. All tests were conducted with a nominal 24-kph (15-mph) average vehicle speed.

[b] Only runs AP-2 and -3 used because later tests were characterized by muddy and caked surface.

[c] Corrected to average silt content of treated sections before application.

Several remarks about these mean values are in order. First, it was necessary to correct the AQ uncontrolled emissions to reflect the silt content of the treated sections before application.

TABLE 3-11. PLUME SAMPLING DATA - PLANT AP

Run		Sampling rate (m^3/hr)				Net TP exposure[a] (mg/cm^2)			
		1.5 m	3 m	4.5 m	6 m	1.5 m	3 m	4.5 m	6 m
AP2	P	37	57	60	77	0.457	0	0	0
	X	36	-	70	76	0	0	0	0
	C	24	-	-	75	0	0	0	0
	U	27	30	-	36	1.33	0.952	(0.809)	0.665
AP3	P	29	38	46	50	0.527	0.380	0.0647	0
	X	26	38	49	52	0.271	0	0	0
	C	23	38	-	52	0.510	0.0194	(0.00970)	0
	U	25	25	-	28	1.34	0.955	(0.619)	0.283
AP5	P	17	11	15	13	2.15	1.27	0	0.462
	X	25	28	29	30	4.02	3.87	3.26	1.51
AP6	P	30	29	30	32	3.13[b]	2.23	1.10[b]	0.0348[b]
	X	28	29	30	30	4.47	3.66[b]	1.87	0.336[a]
	U	28	29	29	32	0.617	0.877	0.517	0.215
AP7	P	35	19	20	24	1.54	1.84	0.764	0.280
	X	20	23	20	18	1.83	1.29	0.624	0.227
	U	17	17	20	17	2.29	2.08	1.04	0.803

[a] Values in parentheses are interpolations. Zeroes indicate no net mass flux.

[b] The filters for this run were lost; these estimates are based on scaling of profiler wash catches by cyclone TP concentration.

TABLE 3-12. PLUME SAMPLING DATA - PLANT AQ

Run		Sampling rate (m³/hr) 1.5 m	3 m	4.5 m	6 m	Net TP exposure[a] (mg/cm²) 1.5 m	3 m	4.5 m	6 m
AQ1	U	20	39	51	58	1.80	1.60	0.815	0.242
	G	20	39	51	58	2.29	0.848	0.0691	0
	S	20	39	51	58	0.992	0.593	0.133	0
	X	20	39	51	58	4.34	2.45	0.533	0.0888
AQ2	U	23	28	35	40	4.02	2.38	0.797	0.391
	G	20	28	32	-	3.06	2.81	0.156	0
	S	20	27	34	39	0.982	0.491	0.278	0
	X	-	-	34	39	(3.10)[b]	(2.60)[b]	0.841	0.092
AQ3	P	27	35	38	46	2.78	1.56	0.692	0.194
	G	17	29	-	-	0.341	0.324	(0.0610)	0
	S	19	29	37	43	0.256	0.218	0.104	0
	X	48	-	37	43	0.189	(0.178)	0.104	0.0760
AQ4	G	35	40	48	51	10.5	6.23	1.93	0.800
	S	27	34	43	47	2.39	2.03	0.980	0.334
	X	30	33	34	42	6.72	4.43	1.60	0.487
	C	37	43	51	54	6.43	4.24	0.634	0.137
AQ5	P	27	42	53	59	4.91	3.56	2.30	0.836
	G	34	38	40	42	1.66	1.30	0.395	0.0872
	S	25	36	44	51	3.07	2.08	0.933	0.388
	C	27	43	53	59	7.91	6.28	2.47	0.295
AQ6	P	20	24	22	24	3.43	2.34	0.904	0.383
	G	20	24	22	24	3.55	2.90	1.73	0.635
	S	19	19	22	34	2.32	1.79	0.644	0.300
	C	20	19	22	24	7.70	5.85	2.25	0.418
AQ7	P	29	43	50	59	1.61	1.35	0.547	0.153
	G	35	53	51	70	1.18	2.13	0.854	0.320
	S	28	42	51	56	2.24	1.89	0.755	0.179
	X	28	42	51	58	5.03	3.41	1.12	0.0535
AQ8	P	20	24	26	27	1.63	0.867	0.306	0.188
	G	20	26	28	31	0.586	1.23	0.378	0.0828
	S	19	25	29	-	1.03	1.10	0.564	0
	X	17	25	29	36	3.10	1.87	0.523	0
AQ9	G	28	40	47	-	1.36	0.529	0.219	0
	S	28	40	47	49	0.317	0.143	0.0436	0.0169
	X	33	46	56	60	0.152	0.0693	0	0
	C	30	43	50	54	0.379	0.112	0.0550	0
AQ10	G	20	40	52	61	1.48	0.957	0.350	0.116
	S	20	43	42	-	0	0.628	0.122	0
	X	23	35	57	-	0.453	0	0	0
	C	19	40	-	61	0.539	0.252	(0.142)	0
AQ11	G	32	26	36	40	2.69	2.42	0.561	0.178
	S	32	56	36	-	0.980	0.0274	0.0460	0
	X	32	54	37	-	0.690	0.216	0	0
	C	32	54	36	40	0.641	0.346	0	0

[a] Values in parentheses are interpolations; zeros indicate no net (i.e., downwind minus upwind) contribution.

[b] These values based on linear interpolation/extrapolation using cyclone and 4.5-m profiler values.

TABLE 3-13. SURFACE PROPERTIES AND EMISSION FACTORS - PLANT AP

	Silt content (%)	Moisture content (%)	Total loading (kg/m²)	Emission factor (g/VKT)[a]				
				Raw[b]	Normalized[c]			
				TP	TP	IP	PM_{10}	FP
AP2 P	1.9	0.46	6.4	179	182	21.4	13.5	5.33
X	d	0.50	0.73	-	-	-	-	-
C	2.7	1.2	5.4	-	-	-	-	-
U	8.1	0.64	6.7	9,110	10,600	2,230	1,810	223
AP3 P	2.6	0.36	8.5	369	468	55.3	35.0	13.8
X	d	1.4	0.88	145	184	30.5	22.0	3.07
C	4.3	1.4	4.6	279	355	-	-	-
U	8.3	1.1	6.3	5,920	7,390	1,550	1,260	155
AP5 P	6.1	0.12	4.8	2,330	2,170	412	305	104
X	11	0.14	2.0	6,460	6,010	1,200	902	216
AP6 P	6.8	0.13	8.7	1,480	1,290	118	50.2	-
X[e]	10	0.08	5.1	3,720	3,240	620	389	19.5
U[e]	7.3	0.10	2.0	711	620	18.0	-	-
AP7 P[f]	11	-	-	877	871	81.8	65.1	15.7
X[f]	12	-	-	846	843	101	82.6	18.6
U[e]	6.0	-	2.0[g]	1,430	1,470	220	162	44.0

[a] Blank entries denote cases of no net mass detected.

[b] Because the normalization process does not affect size fractions, raw emission factors for the other size ranges can be obtained by scaling the normalized values by the ratio of the TP results.

[c] Normalized to 25 Mg (28 tons) and 12 wheels per vehicle.

[d] Less than 0.05%.

[e] These tests were characterized by a muddy and caked uncontrolled surface. See discussion in text.

[f] These sections had been flushed and vacuumed 3 days prior to test. See discussion in Section 4.0.

[g] Estimated value.

TABLE 3-14. SURFACE PROPERTIES AND EMISSION FACTORS - PLANT AQ

		Silt content (%)	Moisture content (%)	Total loading (kg/m²)	Emission factor (g/VKT)[a]				
					Raw[b] TP	Normalized[c]			
						TP	IP	PM_{10}	FP
AQ1	U	7.0	1.5	2.8	1,600	1,600	352	240	43.1
	G	7.6	1.5	1.6	1,390	1,390	319	250	87.4
	S	0.6	0.94	0.33	682	682	81.8	56.7	-
	X	15	1.2	1.3	2,960	2,960	296	228	38.4
AQ2	U	7.0	1.5	2.8	2,160	2,210	485	333	59.8
	G	7.6	1.5	1.6	1,590	1,630	375	293	103
	S	0.6	0.94	0.33	527	539	62.9	44.6	-
	X	15	1.2	1.3	1,800	1,840	184	142	23.9
AQ3	P	3.1	1.8	1.4	1,300	1,340	148	113	24.2
	G	6.8	1.5	1.3	620	663	113	92.8	33.3
	S	1.5	1.1	0.45	336	347	48.5	38.1	7.64
	X	12	1.6	0.93	468	485	41.7	29.0	3.84
AQ4	G	6.8	1.5	1.3	7,560	4,090	694	572	204
	S	1.5	1.1	0.45	2,080	1,125	169	124	24.8
	X	12	1.6	0.93	5,080	2,750	236	165	21.7
	C	-	-	-	4,430	2,400	161	127	28.8
AQ5	P	5.0	1.1	1.3	6,150	3,360	637	502	164
	G	10	1.3	1.5	1,830	998	180	140	22.0
	S	4.4	0.99	0.34	3,500	1,910	305	230	26.8
	C	12	1.4	3.6	9,020	4,940	1,090	840	260
AQ6	P	5.0	1.1	1.3	3,020	1,640	246	160	18.0
	G	10	1.3	1.5	4,460	2,410	338	229	14.7
	S	4.4	0.99	0.34	2,580	1,400	223	182	41.7
	C	12	1.4	3.6	8,430	4,570	960	685	219
AQ7	P	3.6	1.2	2.7	1,340	725	109	79.8	25.4
	G	7.0	1.2	2.0	1,450	784	141	110	26.6
	S	2.9	0.95	0.20	1,850	1,000	120	80.1	2.51
	X	6.7	-	3.8	3,720	2,020	384	262	88.8
AQ8	P	3.6	1.2	2.7	1,650	891	205	151	41.7
	G	7.0	1.2	2.0	1,050	567	142	113	38.1
	S	2.9	0.95	0.20	1,370	742	163	119	20.8
	X	6.7	-	3.8	3,210	1,740	400	313	94.2
AQ9	G	0.76	0.95	0.17	360	361	112	79.5	8.29
	S	1.2	0.77	0.15	85.4	85.4	14.5	4.09	-
	X	1.1	0.78	0.21	58.7	58.7	11.1	5.64	-
	C	1.6	2.1	0.49	59.5	59.5	8.94	2.38	-
AQ10	G	2.9	1.3	0.40	277	358	118	78.7	15.0
	S	-	-	-	43.7	56.4	14.1	9.59	-
	X	-	-	-	53.3	68.8	9.64	4.74	-
	C	-	-	-	96.7	125	13.7	5.74	-
AQ11	G	2.9	1.3	0.40	420	541	179	119	22.7
	S	-	-	-	109	141	35.3	23.9	-
	X	-	-	-	80.9	104	14.6	7.19	-
	C	-	-	-	80.1	103	11.4	4.54	-

a Blank entries denote cases of no net mass detected.

b Because the normalization process does not affect size fractions, raw emission factors for the other size ranges can be obtained by scaling the normalized values by the ratio of the TP results.

c Normalized to 9 Mg (10 tons) and six wheels per vehicle.

The five treated sections had a preapplication average silt content of 13.9% with a standard deviation of 2.2%. However, the uncontrolled tests at this site were characterized by a silt content of approximately 7%. This lower value may be the result of different drainage characteristics at the uncontrolled section. Because uncontrolled particulate emissions from unpaved roads show a linear relationship with silt content,[6] the mean uncontrolled test results were scaled linearly to reflect a silt value of 13.9% in order to relate control efficiency to the preapplication state.

Secondly, because of the muddy and caked conditions found on the uncontrolled surface at plant AP during August 1985, only the AP-2 and -3 uncontrolled tests were used in determining mean values.

SECTION 4.0

CONTROL EFFICIENCIES AND COST EFFECTIVENESS VALUES

This section uses the test results given in the preceding section to develop control efficiency and cost-effectiveness values for the chemical dust suppressants evaluated. Particular attention is paid to average control efficiency values which are required to estimate emission reductions and cost-effectiveness. In addition, a discussion of control performance indicators based on surface material properties is also presented.

It should be noted that this discussion is limited to the AQ series of tests. As noted in preceding sections, the AP series was hindered by numerous problems and, as a result, only a small number of tests was performed at that site. Furthermore, because all five chemicals were evaluated concurrently at the AQ site, consideration of only tests at this site simplifies comparisons.

One important finding from the AP test series, however, should be mentioned. Run AP-7 was conducted on test surfaces which had been flushed and vacuumed 3 days earlier. A control efficiency of 90% or more was found for all size ranges considered. Thus, it would appear that paved road cleaning techniques may be used to periodically increase the control efficiency of chemically treated unpaved roads.

Control performance was examined in terms of several nonparametric statistical tests.[10] A 10% level of significance ($\alpha = 0.10$) was selected for comparisons involving only one chemical; for comparisons involving two or more chemicals, α was set equal to 0.05 (5%).

Finally, calcium chloride is included only in the discussion of cost-effectiveness. The rationale for this decision is based on the facts that this product is not commonly used in the main iron and steel districts and that, on the basis of the two test series, this product may not exhibit a control lifetime similar to the other four suppressants evaluated.

The difficulties encountered due to the washoff of calcium chloride at plant AP were described in Section 3.4. In addition, the heavy rains during the second half of September may have seriously affected the control performance of calcium chloride at plant AQ; emissions at the uncontrolled level were found at the end of 1 month. However, it is important to note that the test results from late October and early November show that calcium chloride provided a level of control easily the equal of the other three suppressants. During this time, the calcium chloride test section appeared visibly wet even after 3 to 4 hr of steady traffic.

4.1 COMPARISONS INVOLVING ONLY ONE CHEMICAL

This section presents a discussion of comparisons of point (instantaneous) values of control efficiency for a single dust suppressant. The most important comparison involves temporal dependence of control efficiency because the results obtained determine the functional forms for c(t) and C(T), as defined in Section 2.7. In cases of significant decay with time, instantaneous and average control efficiency are treated as linear functions of time. Otherwise, average efficiency is considered as a constant value over the time period of interest.

Other comparisons involving a single dust suppressant are also described. These examine whether there is a significant difference in a product's control performance for various size fractions and whether a repeat, higher intensity application results in a higher level of control.

To assess the time dependence of control, the results of runs AQ-1 to -4 were compared to those of AQ-5 to -8. These two groups of tests were conducted at 13 to 14 and 29 to 30 days after application, respectively. The Mann-Whitney U test[11] was employed to determine whether control performance for a given chemical decreases with time over the first 30 days after application. The results of the comparisons for TP and PM_{10} are shown below:

Chemical	Size fraction	Significant decrease in control[a]
P	TP	no
	PM_{10}	no
G	TP	no
	PM_{10}	no
S	TP	yes
	PM_{10}	yes
X	TP	no
	PM_{10}	yes

[a] One-tailed alternative hypothesis.

Only three comparisons showed a decrease (significant at the 10% level) in control over the time period of interest. As noted earlier, this information was used to determine the forms for the average control efficiency functions presented in the next section.

A U test of the results from runs AQ-1 to -4 and AQ-9 to -11 was also performed. Because all these tests were conducted at approximately the same time after application, this comparison tested whether there was a significant increase in control after the repeat application in October. All comparisons showed increases significant at the 5% level.

To determine whether control efficiency is significantly different for various size ranges, a two-way analysis of variance by ranks (Friedman test[11]) was employed with a two-tailed alternative hypothesis. Of the four chemicals, only Soil Sement exhibited a significant (α = 10%) difference in control between the TP, IP and PM_{10} size fractions during the period of runs AQ-1 through -8. No significant differences were found for runs AQ-9 through -11.

4.2 AVERAGE CONTROL EFFICIENCY

Least-squares lines of best fit were developed for those suppressant/size fraction combinations which showed significant temporal dependence over the period of AQ-1 to -8. Average control efficiency functions were then determined from the lines of best fit. In instances where no significant difference with time was found, all control efficiency values were averaged and the mean value applied over the period of the first eight runs (i.e., first 13 to 30 days after application).

Figure 4-1 presents average, size-specific control efficiency as a function of time for the four dust suppressants. Because of the nature of the field program conducted at plant AQ, these functions may be viewed as representative of typical values of application and dilution rates, daily traffic volume and average vehicle weight for unpaved roads in the iron and steel industry. Furthermore, because most plants in the industry reapply chemicals within 1 month (cf Table 2-1), these average control efficiency functions should be of considerable use to both iron and steel and regulatory agency personnel in assessing the emission reductions and cost-effectiveness of dust control programs.

As can be seen from the figure, average control values for the four dust suppressants tend to be more closely clustered for the IP and PM_{10} size fractions than for the two extreme size ranges (TP and FP). The question of whether there is a significant difference in control performance between the various suppressants is addressed in the following section.

As a final remark, it should be noted that these results are based upon field tests after a second control application. Thus, some residual effect of the initial application is included. A further discussion of the effect of repeated applications on average control efficiency is presented in Section 5.0.

4.3 INTERCHEMICAL COMPARISONS

The results given as Figure 4-1 indicate the dust suppressants evaluated during this program exhibited varying levels of control over the time

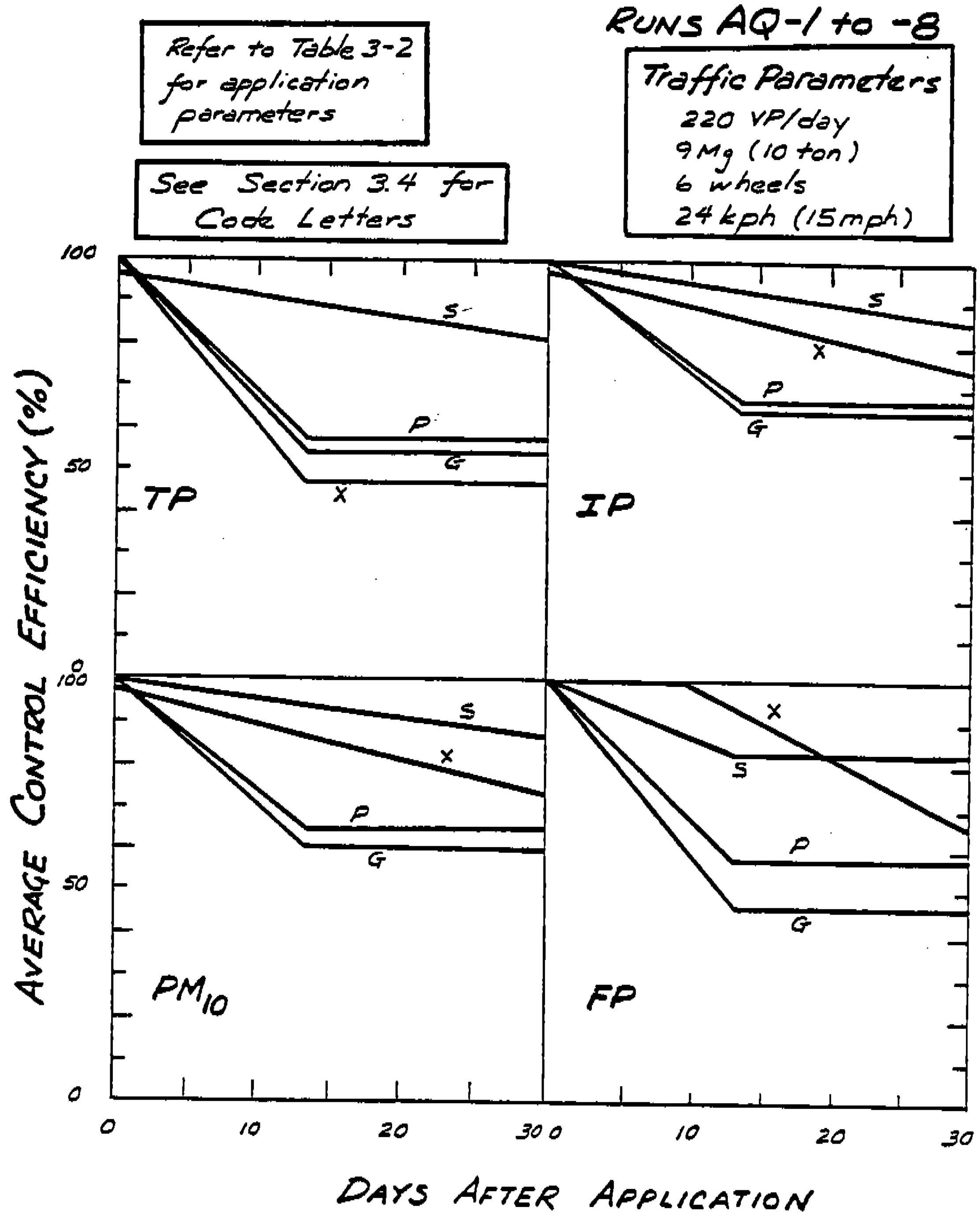

Figure 4-1. Average control efficiency as a function of time over 30 days.

period covered by runs AQ-1 to -8. This section discusses whether there are significant differences between the products in terms of control performance. In order to keep the number of comparisons at a manageable level, only TP and PM_{10} control efficiencies are considered.

In making interchemical comparisons it was first necessary to factor out any temporal variation. This step was required simply because (a) it was not possible to evaluate each chemical during each run (i.e., fewer profilers available than test sections during the first eight tests) and (b) some chemicals exhibited time-dependent control. For runs AQ-1 to -8, normalized emission factors were scaled by the mean (controlled) emission factor observed during the test. A two-tailed U test was then applied to the six pairwise combinations of suppressants. Note that a two-tailed test was employed because there was no a priori reason to suspect that one chemical suppressant would perform "better" than another. The results of these comparisons for runs AQ-1 to -8 are shown below:

Chemicals compared[a]	Size fraction	Significant difference[b]
P and G	TP	no
	PM_{10}	no
P and S	TP	no[c]
	PM_{10}	no[c]
P and X	TP	no
	PM_{10}	no
G and S	TP	no[c]
	PM_{10}	yes
G and X	TP	no[c]
	PM_{10}	no
S and X	TP	yes
	PM_{10}	yes

[a] See caution at the end of this section.

[b] Two-tailed alternative hypothesis.

[c] Significance levels between 5 and 10%.

Although only three of the comparisons showed significant (at the 5% level) differences in control performance, it should be noted that all comparisons involving Soil Sement show differences at the 10% level of significance. Only one pairwise comparison involving the other three suppressants exhibited a difference significant at this level.

A final interchemical comparison involved the results of runs [illegible] through -11. After the October rain damage, only four test sections remained. Because all suppressants were evaluated simultaneously during the final three runs, there was no need to consider temporal variation between tests. The Friedman test indicated no differences in either TP or PM_{10} control at the 5% level of significance.

The reader is cautioned against the possible misuse of these results to conclude that one dust suppressant is "better" than another. The relative cost-effectiveness of each chemical is an important consideration when selecting a product for use in a dust control program. For example, a lower-priced chemical with moderate performance characteristics may be preferred to a highly effective yet more expensive product in a situation where spillage onto a road requires frequent reapplication. Cost-effectiveness is addressed in the following section.

Furthermore, the interchemical comparisons presented above are based on a two-tailed alternative hypothesis. That is, these comparisons do not test whether product A is "better" than product B, but rather examine whether there is a <u>difference</u> in performance between the two.

Finally, although this program represents the most comprehensive study of dust control for unpaved roads in the iron and steel industry to date, the underlying data base is still limited. Consequently, any decision that the reader may make based on the results presented here should take data limitations into consideration.

4.4 RELATIVE COST-EFFECTIVENESS OF THE SUPPRESSANTS EVALUATED

As noted above the relative cost-effectiveness of various dust suppressants should be considered in selecting a product for use in a dust control program. While the discussion in this section takes into account major factors affecting cost-effectiveness, the presentation cannot be considered exhaustive and appropriate for use in all instances, for reasons given below.

To carry the example begun in the prior section further, suppose that a plant also contains a road with no problem of spillage. In this instance, the most cost-effective suppressant for one road may be different from that for the other. However, it is quite possible that additional costs (associated with storage and with increased maintenance of application equipment) may make the use of two chemicals impractical.

Because each plant in the industry faces a unique set of needs, no attempt has been made in this report to include all possible costs involved in a dust control program. For example, some facilities may be forced to install new storage tanks while others may only need to refurbish unused tanks in the plant. Still others may find it more efficient to retain an outside contractor to store and apply the suppressants. In order to make comparisons as meaningful as possible and to provide the industry with information required to determine appropriate programs for individual facilities, only purchase, delivery, and application costs are considered below.

The following table gives 1985 costs for the dust suppressants evaluated during the program:

Suppressant	Cost ($/gal) Small lot[a]	Bulk[b]
P	3.40	1.50[c]
G	1.65	-
S	2.32	1.49
X	2.10	1.45
C	0.70[d]	0.46[d]

a FOB costs for 55-gal. drums (except C). Data taken from MRI's cost records for the field program.

b Data developed from telephone conversations with vendors and plant personnel. All prices FOB, except as noted.

c No plant currently produces this product. See discussion in text.

d Cost includes delivery and application.

Because no one currently produces generic products, definitive costs are unavailable. The Mellon Institute has estimated that on-site production of this type of product would cost between $1.14 and $0.86/gal., with required capital costs ranging from $9,000 to $30,000, respectively.[5] The actual cost per gallon would be a function of the production rate and would decrease after the capital costs are recovered. In addition, it may be feasible for neighboring plants to pool their resources and retain an outside firm to produce the product. Because of the variety of costs possible, a value of $1.15/gal. has been assigned. This value represents a 5-year average for an annual on-site production of 20,000 gal.

The reader should, of course, assess all costs involved in any specific program in which the use of a generic product is contemplated. The price given above has been assigned only for the purpose of comparison.

As a final remark about dust suppressant costs, note that the cost for calcium chloride includes delivery and application. This fact, combined with a substantially lower unit cost, has resulted in some interest in the industry in the use of salts for unpaved road dust control.

For runs AQ-1 through -8, the following cost-effectiveness values were obtained:

Suppressant	Unit application costs ($/km)[a]	30-Day cost-effectiveness ($/kg)[b] TP	IP	PM_{10}
P	1,720	0.17	0.65	1.00
G	1,640[c]	0.15	0.64	1.03
S	2,150	0.15	0.63	0.91
X	1,720	0.21	0.57	0.87
C	2,190	0.24[d]	1.10[d]	1.61[d]

[a] Based on application of September 3, 1985. Bulk costs used with 10% increase for delivery (except C) and $0.15 per gallon of concentrate for application. See discussion in text.

[b] Cost per kg of emissions reduced. Based on 30-day average control, 160 vehicles per day and the mean, normalized uncontrolled emission factors in Section 3.0.

[c] Assumes no delivery cost (on-site production). See text for discussion of chemical cost.

[d] Because this application produced a control lifetime of less than 30 days, an average control of 50% has been assigned. The resulting cost-effectiveness values should be considered lower bounds.

Several remarks about this table are in order. First, the increases over bulk costs for delivery and application are based on delivered prices quoted by consumers and vendors as well as past MRI data.[1,2] Once again, the geographic location and any particular application requirements for a plant may change these values. The 30-day cost-effectiveness values may be scaled using other delivery and application cost data.

Second, although the road section treated with calcium chloride had the highest unit cost, this does not necessarily imply that this treatment would always be the most expensive. The other chemicals may require storage facilities and application equipment which could substantially increase the total cost per treatment.

For the first test series (AQ-1 to -8), the cost-effectiveness values for calcium chloride do not compare favorably with those of the other suppresants. As noted above, the cost-effectiveness values for calcium chloride may be considered lower bounds and are between 40 and 80% higher than the average values for the other four suppressants. However, as discussed in Section 3.4, rainfall during this period was 160% of normal, with a total of 108 mm (4.27 in.) of rain falling in the 2 weeks between runs AQ-4 and

AQ-5. It is possible that this product would have produced more favorable cost-effectiveness values under drier conditions as was the case during runs AQ-9 through -11.

Cost-effectiveness values associated with runs AQ-9 through -11 are not particularly relevant because weather curtailed field testing long before an adequate description of decay (and, thus, control lifetime) could be obtained. However, it is possible to use results of earlier testing of Coherex® at the AQ test site to estimate relative cost-effectiveness for different application intensities.[1] Although these earlier tests involved a substantially higher average vehicle weight, the AQ series of tests was characterized by a higher daily traffic rate. Assuming that these differences balance one another such that the control decay and the daily emission rates are comparable, the following results are obtained:

Test series	Unit application cost ($/km)[a]	30-Day average control (%) TP	IP	PM_{10}
AQ1-8	1,720[b]	47	75	73
Reference 1	4,750[c]	59	72	76
Reference 1	3,580[d]	93	92	94

[a] Developed using 1985 cost data and procedure described earlier.

[b] Repeat application of September 3, 1985.

[c] Initial application of 3.8 L/m² (20% solution).

[d] Repeat application of 4.5 L/m² (12% solution).

Under the assumptions of comparable decay and emission rates, it would appear that lighter application intensities are more cost-effective over a 30-day period, which is a fairly typical time interval between treatments in the iron and steel industry (see Table 2-1). This is particularly true for the smaller particle size ranges.

4.5 EXAMINATION OF ALTERNATIVE INDICATORS OF CONTROL PERFORMANCE

Because of the high costs associated with conducting field tests of emissions from controlled unpaved roads, there has been a great deal of recent interest in developing less expensive measures of control performance. For example, suppose that a reliable estimate of a suppressant's effectiveness (at a given point in time) could be obtained by simply examining the quantity and/or texture of aggregrate material present on the road surface. This technique would be an invaluable tool to both industry and regulatory personnel in monitoring dust control programs.

Early studies of unpaved road dust control showed a strong correlation between efficiency and the silt content of the surface material.[2,12] However, it must be noted that these relationships were based on the very high (e.g., > 90%) control efficiencies and very low silt values typically found over the first few days after application. Because these conditions represent only a small, restricted portion of all possible conditions, the high degree of correlation is somewhat misleading.

Later study of long-term control indicated no significant correlation between silt content and efficiency. In addition, fairly high (~ 50%) control efficiencies were found to occur with silt contents at or above the uncontrolled level.[1] Because of these findings, attention turned to the use of the amount of silt per unit area as a performance indicator.

Figure 4-2 presents the relationship between controlled PM_{10} emission factors (and, hence, control efficiency) and silt loading for Runs AQ-1 through -8. The arrows connecting like data points denote the time history. As can be seen, although emission levels vary over an order of magnitude, silt loading values vary over two orders and do not appear to follow a specific trend with time. Furthermore, the results for the different suppressants tend to be clustered together; this would indicate that the various suppressant types do not affect silt loading in the same way. The procedure presented in Section 4.3 was used to compare silt loadings on the different surfaces. Silt loadings on the surface treated with Soil Sement differed from those on both the Coherex® and Generic sections at a significance level of 5%. In the comparisons involving the Petro Tac surface, no significant differences were found.

Reasonably strong correlations between silt loading and emissions appear to exist for both Soil Sement and Coherex®; however, the two relationships bear little resemblance to one another. For example, both products appear to produce essentially the same level of control although the silt loading values differ by a factor of 50.

It does not currently appear possible to develop a meaningful expression that relates the control performance of chemical suppressants to the amount of silt loading present on the road surface. When suppressants are considered individually, only Coherex® exhibits a significant correlation. This is not the case, however, when the other petroleum resin (Generic) is considered as well.

Finally, it should be noted that the AP-42 industrial paved road emission factor equation may be used to <u>conservatively</u> overestimate controlled emissions. This equation is shown in Figure 4-2, over the range of silt loading values in the supporting data base. As can be seen, the equation tends to overestimate emissions by a factor of 1.5 to 2 when applied to situations with typical application intensities over the first 30 days. Estimation is appreciably better for the Soil Sement section, possibly because the silt loadings associated with this surface more closely match typical values for paved roads.[6] Silt loadings for the other three test sections are clustered near the extreme value used in developing the paved road equation. As a result, it may not be particularly surprising that the paved road equation overestimates emissions from these surfaces to a greater degree.

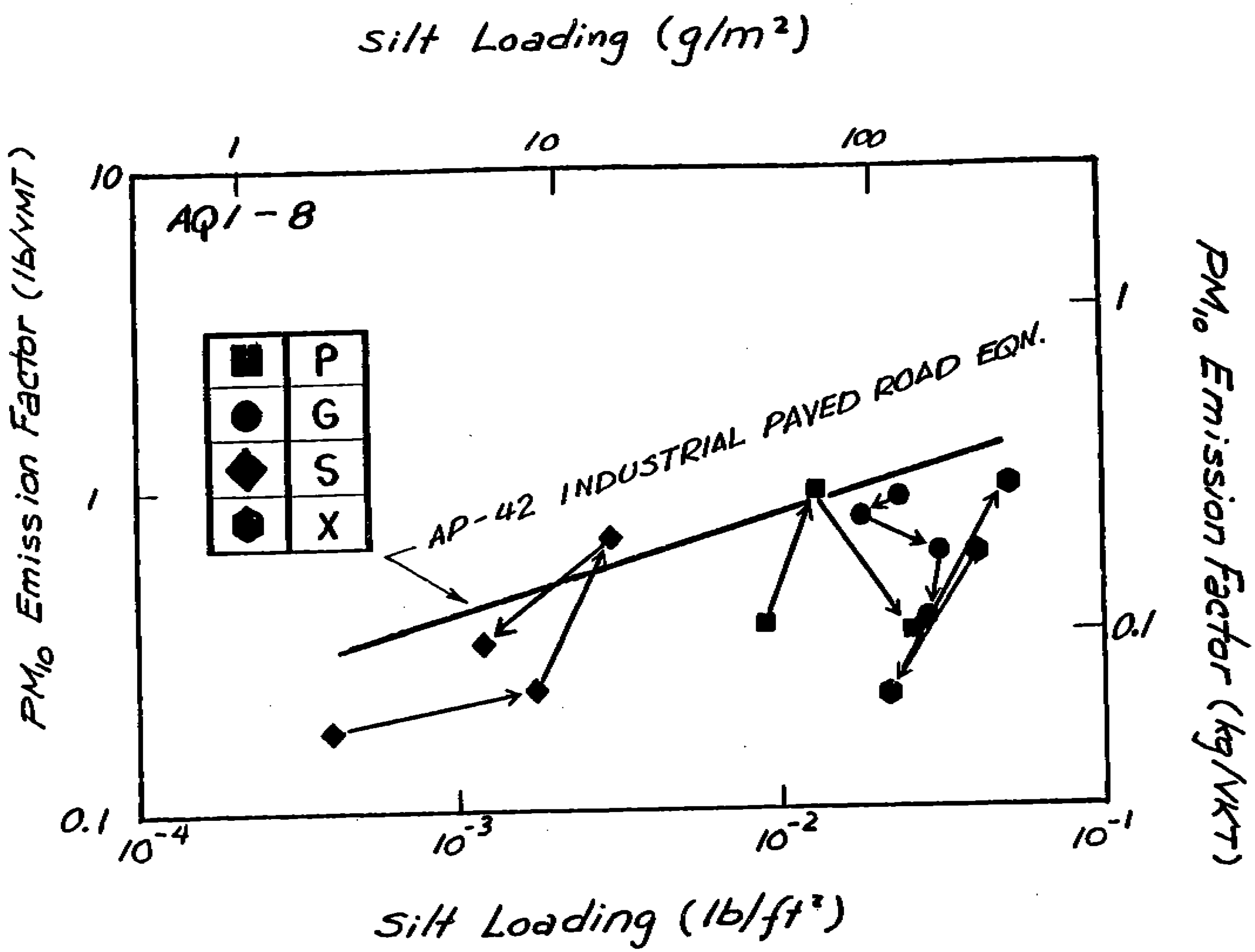

Figure 4-2. Relationship between controlled PM_{10} emission factors and silt loading. Arrows indicate chronology of testing.

SECTI... 5.0

CONTROL PERFORMANC... ...DEL DEVELOPMENT

One of the secondary objectives ... this program was to examine means of estimating the average dust control pe...mance of a suppressant. Although many field tests of road dust control ... been conducted in the steel and other industries, it is important to ...ize that a given test series can only provide one estimate of average ...ol efficiency. This is true simply because the various test results ... different times after application must be combined to obtain a decay ra... Thus, although there may be a data base of, say, 100 controlled tests, ... data base may only provide, say, 10 pieces of information about average ...ntrol.

The following sections discuss t... objectives of the model, examine previous studies of unpaved road dust ... the model, and, finally, present the m... ...trol effectiveness for inclusion in

5.1 OBJECTIVES OF THE AVERAGE CONTROL ...RFORMANCE MODEL

It is generally conceded that the ... owing factors may influence average control performance for a chemica... ... suppressant over time:

Direct relationship	Indirect relationship
• Amount of chemical applied per unit area	• ...erage vehicle weight
• Number of previous applications	• ...erage number of wheels per vehicle
	• ...ly traffic volume

There are, of course, other varia... (such as the texture of the untreated surface aggregate, applicatio... ...cedures or dilution ratio), that may influence average control. Howeve... ... is not intuitively obvious how these variables affect control and the... only a very limited data base to draw upon. Consequently, no attempt h... ...en made to include these factors in the model development.

It is advantageous to combine som... the variables shown in the earlier table. For example, MRI's experie... has shown a high intercorrelation between average vehicle weight and ave... number of wheels. Thus, as a first approximation, only one of the t... required.

In addition, because of the limited data base available, it is beneficial to combine traffic volume and average vehicle weight into a single measure of the service environment of the test road. Let the quantity

$$\begin{pmatrix}\text{Average Weight} \\ \text{per Vehicle}\end{pmatrix} \times \begin{pmatrix}\text{Vehicles} \\ \text{per Day}\end{pmatrix}$$

be defined as V, the vehicle activity factor. The data presented in Section 2.1 show a mean V for the 9 iron and steel plants of 2,400 Mg/day (2,600 ton/day) with a 91% coefficient of variation.

Finally, because reapplications of dust suppressants have been found to be more effective than the original application, a new factor was devised for the two variables shown as having direct relationships with average control. This factor, g, is termed the (cumulative) ground inventory and is found by adding together the total volume (per unit area) of concentrate (not solution) since the start of the dust control season. For example, if a plant originally applied 2 L/m^2 of a 20% solution on April 1, and followed with 1.5 L/m^2 of a 16% solution on the first of each following month, then after the June 1 application, $g = 0.88\ L/m^2$.

5.2 REVIEW OF PREVIOUS STUDIES

The first field evaluation of unpaved road dust control in the iron and steel industry was conducted in August 1978. Since that time, dozens of additional tests have been conducted in the industry; Table 5-1 summarizes those tests. As can be seen, several studies entailed evaluation only a short time after application; some tested only light-duty traffic; and still others did not provide enough information on either application parameters or the service environment of the test road.

The primary selection criteria for inclusion of data in the model development pertained to (a) spanning a period somewhat representative of the time intervals in the iron and steel industry between applications, and (b) reporting the information needed for model development.

Upon review of controlled emission tests in the iron and steel industry, it soon became obvious that only petroleum resins have been evaluated in enough studies to warrant an attempt at model development. Furthermore, this finding was unchanged when tests in other industries were considered.[15-18] As a result, only results from tests of petroleum resins in the iron and steel industry are considered below. Note that tests of generic formulations are included with Coherex® because no significant difference was found between the two in Section 4.3.

Table 5-2 presents average efficiency values for TP and PM_{10} control from tests of petroleum resins in the iron and steel industry. Correlations are given below:

TABLE 5-1. SUMMARY OF MAJOR UNPAVED ROAD CONTROL EFFICIENCY TESTS PERFORMED AT IRON AND STEEL PLANTS

Research organization	Dust suppressant tested	No. of valid controlled tests	Test site	Measurement method	Time after application (days)	Application intensity (gal. sol./yd²)	Dilution ratio (gal. chem:gal. H_2O)	Avg. vehicle weight (ST)
MRI[1,2,3]	Coherex®	2	Armco-Middleton	Profiling	< 7	Unknown	1:9	3
	Coherex®	9	Armco-Middleton	Profiling	1-2	0.19	1:6	3-54
	Coherex®	8	Armco-Kansas City	Profiling	7-41	0.83 (initial)	1:4 (initial)	27-50
	Coherex®	4	Armco-Kansas City	Profiling	4-35	1.0 (repeat)[a]	1:8 (repeat)[a]	31-56
	Petro Tac	8	J&L Indiana Harbor	Profiling	2-116	0.70	1:4	23-34
Mellon Institute[5,13]	Coherex®	5	Shenango	Upwind/downwind	3-30	1.5	1:4	3
	Oil well brine	5	Shenango	Upwind/downwind	3-30	3.8	Neat	3
	Arcote 220/ Flambinder	5	Shenango	Upwind/downwind	3-30	1.9	1:4	3
	Generic 1	3	Shenango	Profiling	3-21	0.51 (initial)	1:9	3[b]
	Coherex®	3	Shenango	Profiling	3-21	0.52 (initial)	1:9	3[b]
	Generic 1	1	Shenango	Profiling	9	0.36 (repeat)[c]	1:12	3[b]
	Coherex®	1	Shenango	Profiling	9	0.36 (repeat)[c]	1:12	3[b]
EIA[14,15]	Coherex®	4	Shenango	Profiling	Unknown	Unknown	Unknown	4-19
	Coherex®	2	USS-Homestead	Profiling	14-15	Unknown	1:4 - 1:7	26

[a] The main test section of the road was retreated 44 days after the initial application at the Kansas City Works.

[b] Estimated value.

[c] Road retreated 24 days after initial application.

TABLE 5-2. AVERAGE CONTROL EFFICIENCY FROM TESTS OF PETROLEUM RESINS[a] IN THE IRON AND STEEL INDUSTRY

V (Mg/day)	g (L/m²)	Average control (%) over nominal period				Reference
		14-Day		30-Day		
		TP	PM_{10}	TP	PM_{10}	
850	1.3	96[b]	-	90[b]	-	13
2,000	0.43	47	86	47	73	AQ-1 to -8
2,400	1.6	98	99	-	-	AQ-9 to -11
3,200	0.75	70	86	59	76	1
3,900	1.2	95	96	93	94	1
500[f]	0.24	94	-	87[c]	-	5
2,000	0.45[d]	59	60	59	60	AQ-1 to -8
2,400	1.0[d]	88	84	-	-	AQ-9 to -11
500[f]	0.23[e]	89	-	77[c]	-	5

[a] All Coherex®, except as noted.

[b] TSP values.

[c] Extrapolated from 21 days after application.

[d] Generic 2 (QS) formulation.

[e] Original generic formulation.

[f] Assumes value of 2.7 Mg/vehicle. Average weight not given in reference.

Size fraction	Nominal averaging period	Correlation of control with		Sample size
		V	g	
TP	14 days	-0.14	0.50	9
	30 days	0.51	0.76	7
PM_{10}	14 days	-0.17	0.45	6
	30 days	0.88	0.91	4

The expected (i.e., negative) correlation between control and V was found only in two cases and, in each of those cases, the degree of linear correlation was very weak. Because of this finding, V was dropped from consideration as a model parameter.

Additional remarks concerning Table 5-2 are in order. The vehicle activity factors for Reference 5 are based on an assumed average weight of 2.7 Mg (3 tons) because no other information was provided. Also, the results from these two tests appear inconsistent with the other studies; in fact, if the two results are deleted from the data base, average control and V show a very weak, positive correlation. For these reasons, the results from Reference 5 were excluded in developing the model.

5.3 AVERAGE CONTROL MODEL FOR PETROLEUM RESINS

The data base discussed in the preceding section was used in developing the least-squares models of average control performance presented in Figure 5-1 and shown below:

Size fraction	Nominal averaging period	Sample size	Estimated average efficiency (%)[a]	Correlation coefficient
TP	14 day	7	37 + 44 g	0.948
	30 day	5	28 + 52 g	0.939
PM_{10}	14 day	6	64 + 23 g	0.755
	30 day	4	50 + 36 g	0.915

[a] The variable "g" represents ground inventory (L/m^2). See text for a discussion of g.

These TP models all show correlations significant at the 2% level, while for PM_{10}, the corresponding level is only 10%.

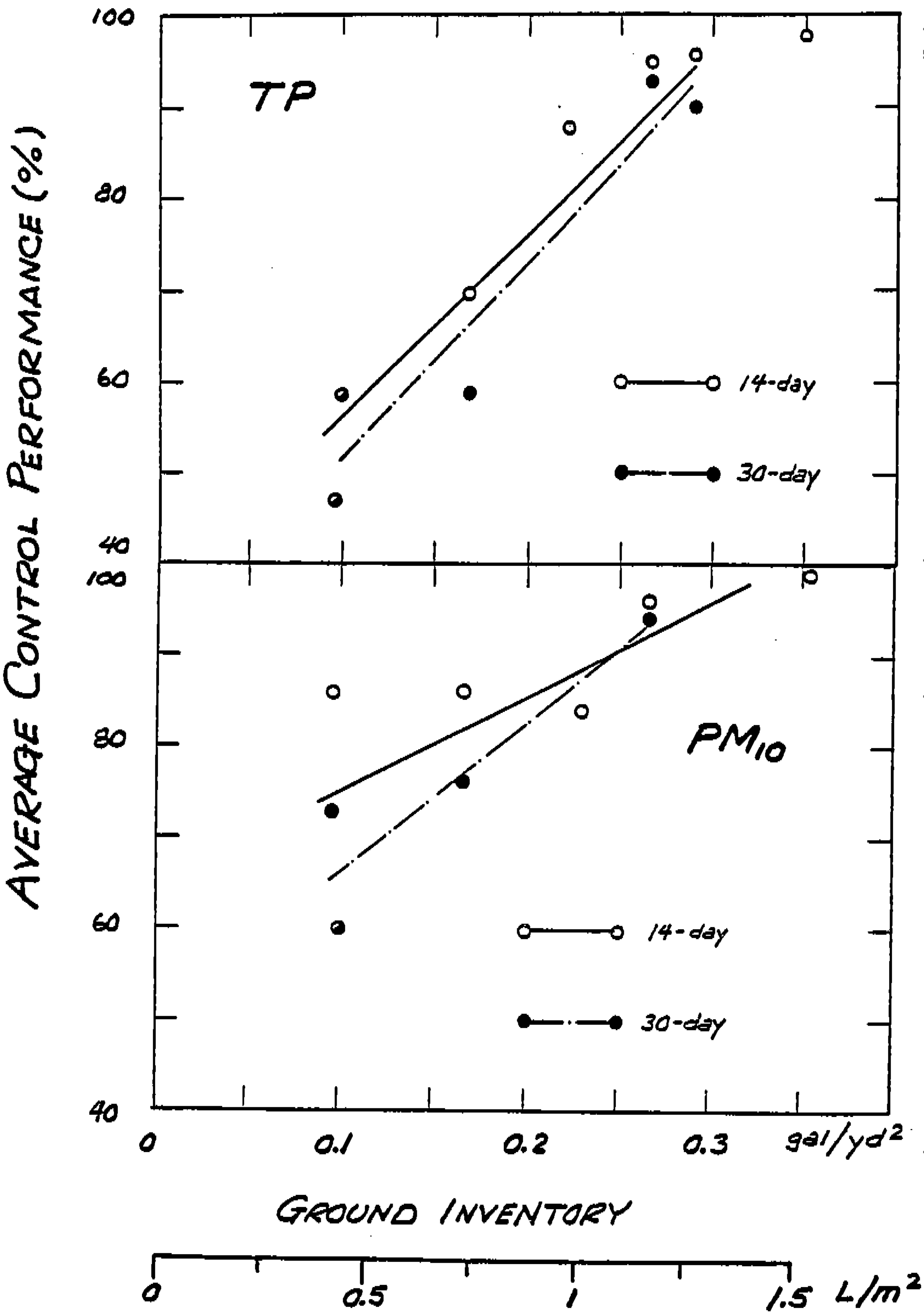

Figure 5-1. Average control performance model for petroleum resins.

It is important to note that these models are largely designed to meet typical needs in the iron and steel industry. The two averaging periods are representative of common time intervals between control treatments in the industry. Also, the vehicle activity factor values supporting the models have a mean of 2,650 Mg/day, which closely matches the mean value for the traffic study data presented in Section 2.1.

How well the model performs for vastly different service environments (e.g., western surface mining or unpaved rural roads) is not known at this time. As a result, the reader should be cautious when applying this model to situations far different than the conditions of the underlying data base.

The following example illustrates the use of this average control model for petroleum resins. Suppose a steel plant applies 2 L/m² of a 20% solution on May 1, and reapplies each month (until October) with 1 L/m² of a 10% solution. Then the following average control values are estimated by the model:

Period	Ground inventory (L/m²)	Ground inventory (gal/yd²)	Average control (%) over period: TP	Average control (%) over period: PM_{10}
May	0.4	0.09	49	64
June	0.5	0.11	54	68
July	0.6	0.13	59	72
August	0.7	0.15	64	75
September	0.8	0.18	70	79

It is recommended that average control efficiency estimates be limited to a maximum of 90% over 30-day periods and 95% over 14 days. This is suggested in order to (a) limit estimated efficiencies to the approximate maximum values in the underlying data base, and (b) avoid any difficulty due to model estimates of 100% or more.

SECTION 6.0

REFERENCES

1. Muleski, G. E., T. Cuscino, Jr., and C. Cowherd, Jr. Extended Evaluation of Unpaved Road Dust Suppressants in the Iron and Steel Industry. EPA-600/2-84-027 (NTIS PB84-154350), U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, February 1984.

2. Cuscino, T., Jr., G. E. Muleski, and C. Cowherd, Jr. Iron and Steel Plant Open Source Fugitive Emission Control Evaluation. EPA-600/2-83-110 (NTIS PB84-110568), U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, October 1983.

3. Cowherd, C., Jr., R. Bohn, and T. Cuscino, Jr. Iron and Steel Plant Open Source Fugitive Emission Evaluation. EPA-600/2-79-103 (NTIS PB299385), U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1979.

4. Bohn, R., T. Cuscino, Jr., and C. Cowherd, Jr. Fugitive Emissions from Integrated Iron and Steel Plants. EPA-600/2-78-050 (NTIS PB281322), U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, March 1978.

5. Russell, D., and S. C. Caruso. The Relative Effectiveness of a Dust Suppressant for Use on Unpaved Roads Within the Iron and Steel Industry. Presented at EPA/AISI Symposium on Iron and Steel Pollution Abatement. Cleveland, Ohio, October 1984.

6. Environmental Protection Agency. Compilation of Air Pollution Emission Factors, Volume I, AP-42 (GPO 055-000-00251-7), Research Triangle Park, North Carolina, September 1985.

7. Kolnsberg, H. J. Technical Manual for Measurement of Fugitive Emissions: Upwind/Downwind Sampling Method for Industrial Emissions, EPA-600/2-76-089a (NTIS PB253092), U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1976.

8. Cowherd, C., Jr., K. Axetell, Jr., C. M. Guenther (Maxwell), and G. Jutze. Development of Emission Factors for Fugitive Dust Sources. EPA-450/3-74-037 (NTIS PB238262), U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974.

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

10. Muleski, G. E. Critical Review of Open Source Particulate Emissions Measurements: Field Comparison. MRI Final Report Prepared for Southern Research Institute, MRI Project No. 7993-L(2). August 1984.

11. Hollander, W., and J. Wolfe. Nonparametric Statistical Methods. J Wiley and Sons, New York, 1973.

12. Cuscino, T., Jr., G. E. Muleski, and C. Cowherd, Jr. Determination of the Decay in Control Efficiency of Chemical Dust Suppressants on Unpaved Roads. In: Proceedings: Symposium on Iron and Steel Pollution Abatement Technology for 1982. EPA-600/9-83-016 (NTIS PB83-258665), U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1983, pp. 136-148.

13. Russell D., and S. C. Caruso. A Study of Cost-Effective Chemical Dust Suppressants for Use on Unpaved Roads in the Iron and Steel Industry. Report prepared for the American Iron and Steel Institute, December 1982.

14. Energy Impact Associates. An Alternative Emission Reduction Option for Shenango Incorporated Coke and Iron Works, January 1981.

15. Roffman, A., et al. A Study of Controlling Fugitive Dust Emissions from Nontraditional Sources at the United States Steel Corporation Facilities in Allegheny County, Pennsylvania. Report prepared for U. S. Steel Corporation, 600 Grant Street, Pittsburgh, Pennsylvania, December 1981.

16. Schanche, G. W., M. J. Savoie, J. E. Davis, V. Scarpetta, and P. Weggel. Unpaved Road Dust Control Study (Ft. Carson, Colorado). Draft Final Report, U. S. Army Construction Engineering Research Laboratory, Champaign, Illinois, October 1981.

17. Rosbury, K. D., and R. A. Zimmer. Cost-Effectiveness of Dust Controls Used on Unpaved Haul Roads - Volume 1 of 2. Draft Final Report for U. S. Bureau of Mines, Minneapolis, Minnesota, December 1983.

18. Axetell, K. H., and C. Cowherd, Jr. Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources, EPA-600/7-84-048 (NTIS PB84-170802), U. S. Environmental Protection Agency, Cincinnati, Ohio, July 1984.

19. Cuscino, T., Jr. Taconite Mining Fugitive Emissions Study. Minnesota Pollution Control Agency, Roseville, Minnesota, June 1979.

SECTION 7.0

GLOSSARY

Application Frequency - Number of applications of a control measure to a specific source per unit time; equivalently, the inverse of time between two applications.

Application Intensity - Volume of water or chemical solution applied per unit area of the treated surface.

Control Efficiency, Average - Mean value of the (instantaneous) control efficiency function over a specified period of time.

Control Efficiency, (Instantaneous) - Percent decrease in controlled emissions at a given instant in time from the uncontrolled state.

Cost-Effectiveness - The cost of control per unit mass of reduced particulate emissions.

Decay Rate - The absolute value of the slope of the (instantaneous) control efficiency function.

Dilution Ratio - Ratio of the number of parts of chemical to the number of parts of solution, expressed in percent (e.g., one part of chemical to four parts of water corresponds to a 20% solution).

Dry Day - Day without measurable (0.01 in. or more) precipitation.

Dry Sieving - The sieving of oven-dried aggregate by passing it through a series of screens of descending opening size.

Dust Suppressant - Water or chemical solution which, when applied to an aggregate material, binds suspendable particulate into larger less suspendable particles.

Exposure - The point value of the flux (mass/area-time) of airborne particulate passing through the atmosphere, integrated over the time of measurement.

Exposure, Integrated - The result of mathematical integration of spatially distributed measurements of airborne particulate exposure downwind of a fugitive emissions source.

Exposure Profiling - Direct measurement of the total passage of airborne particulate immediately downwind of the source by means of simultaneous multipoint isokinetic sampling over the effective cross-section of the emissions plume.

Exposure Sampler - Directional particulate sampler with a fiberglass intake serving as a settling chamber followed by a backup filter. The sampler has variable flow control to provide for isokinetic sampling at wind speeds of 1.8 to 8.9 m/s (4 to 20 mph).

Fugitive Emissions - Emissions not originating from a stack, duct, or flue.

Moisture Content - The mass portion of an aggregate sample consisting of unbound surface moisture as determined from weight loss in oven drying.

Normalization - Procedure that ensures that emission reductions not attributable to a control measure are excluded in determining an efficiency of control.

Particle Diameter, Aerodynamic - The diameter of a hypothetical sphere of unit density (1 g/cm^3) having the same terminal settling velocity as the particle in question, regardless of its geometric size, shape, and true density. Units used in the report are microns aerodynamic (μmA).

Particulate, Fine - Airborne particulate smaller than 2.5 μm in aerodynamic diameter.

Particulate, Inhalable - Airborne particulate smaller than 15 μm in aerodynamic diameter.

Particulate, PM_{10} - Airborne particulate smaller than 10 μm in aerodynamic diameter.

Particulate, Total - All airborne particulate regardless of particle size.

Particulate, Total Suspended - Airborne particulate matter as measured by a standard high-volume (hi-vol) sampler.

Road, Paved - A roadway constructed of rigid surface materials, such as asphalt, cement, concrete, and brick.

Road, Unpaved - A roadway constructed of nonrigid surface materials such as dirt, gravel (crushed stone or slag), and oil and chip surfaces.

Road Surface Dust Loading, Paved - The mass of loose surface dust on a paved roadway, per length of roadway, as determined by dry vacuuming preceded by broom sweeping, if necessary.

Road Surface Dust Loading, Unpaved - The mass of loose surface dust on an unpaved roadway, per unit area, as determined by broom sweeping.

Road Surface Material - Loose material present on the surface of an unpaved road.

Silt Content - The mass portion of an aggregate sample smaller than 75 micrometers in diameter as determined by dry sieving.

Silt Loading - The mass of loose surface dust per unit area on a road multiplied by its silt content.

Source, Open Dust - Any source from which emissions are generated by the forces of wind and machinery acting on exposed aggregate materials.

Vehicle, Heavy-Duty - A motor vehicle with a gross vehicle travelling weight exceeding 30 tons.

Vehicle, Light-Duty - A motor vehicle with a gross vehicle travelling weight of less than or equal to 3 tons.

Vehicle, Medium-Duty - A motor vehicle with a gross vehicle travelling weight of greater than 3 tons, but less than 30 tons.

SECTION 8.0

ENGLISH TO METRIC UNIT CONVERSION TABLE

English unit	Multiplied by	Metric unit
gal/yd^2	4.53	L/m^2
lb/vehicle mile	0.282	kg/vehicle km
lb	0.454	kg
ton	0.907	Mg
mph	0.447	m/s
mile	1.61	km
ft	0.305	m
gal.	3.78	L
yd^2	0.836	m^2

Example: 5 miles x 1.61 = 8 km.

TECHNICAL REPORT DATA *(Please read Instructions on the reverse before completing)*		
1. REPORT NO. EPA-600/2-87-102	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Evaluation of the Effectiveness of Chemical Dust Suppressants on Unpaved Roads		5. REPORT DATE November 1987
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) G.E. Muleski and C. Cowherd, Jr.		8. PERFORMING ORGANIZATION REPORT NO. 8127-L (MRI)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Midwest Research Institute 425 Volker Boulevard Kansas City, Missouri 64110		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. P.O. 5200-868236*
12. SPONSORING AGENCY NAME AND ADDRESS **EPA, Office of Research and Development** Air and Energy Engineering Research Laboratory **Research Triangle Park, NC 27711**		13. TYPE OF REPORT AND PERIOD COVERED Project Report; 6/84 - 11/86
		14. SPONSORING AGENCY CODE **EPA/600/13**
15. SUPPLEMENTARY NOTES AEERL project officer is Robert C. McCrillis, Mail Drop 62B, 919/541-2733. (*) LTV Steel Co. (formerly Jones and Laughlin Steel Corp.) penalty credit project.		

16. ABSTRACT The report gives results of measurements of the long-term effectiveness of five unpaved-road chemical dust suppressants. Effectiveness at controlling total particulate emissions in three size fractions (<15, <10, and <2.5 micrometers) was determined over several cycles of chemical application, control effectiveness decay, and chemical reapplication. All five chemicals were tested on the same road with each chemical used on separate abutting road segments. The chemicals were applied in quantities that spanned the range of common practice in the steel industry. Traffic parameters were typical of the steel industry. Over a 30-day period, control effectiveness of each chemical decreased: in some cases by as much as 50%, and in others by as little as 10%. Control effectiveness for all chemicals was >95% immediately after chemical application or reapplication. The rate of decay was about the same for all particle size ranges investigated. Road surface silt loading was found to be a reliable indicator of relative effectiveness for some chemicals.

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Dust	Stationary Sources	11G
Roads	Dust Suppressants	
Chemical Compounds	Unpaved Roads	07B,07C
Iron and Steel Industry		11F

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to Public	Unclassified	91
	20. SECURITY CLASS *(This page)* **Unclassified**	22. PRICE

EPA Form 2220-1 (9-73)