CHARACTERIZATION OF INHALABLE PARTICULATE MATTER EMISSIONS FROM A LIME PLANT

by

George R. Cobb
Mark D. Hansen
Mark K. Small
Thomas M. Walker
Fred J. Bergman
H. Kendall Wilcox

FINAL REPORT
May 1983

VOLUME I

EPA Contract No. 68-02-3158, Technical Directive No. 9
MRI Project No. 4891-L(94)

For

Industrial Environmental Research Laboratory
Environmental Protection Agency
Cincinnati, Ohio 45268

Attn: Charles H. Darvin

PREFACE

This report was prepared for the Environmental Protection Agency (EPA), Industrial Environmental Research Laboratory, under Contract No. 68-02-3158, Technical Directive No. 4. It describes the results of emission testing conducted by Midwest Research Institute (MRI) for the study, "Characterization of Inhalable Particulate Matter Emissions from the Lime Industry." The field testing was conducted at the Pfizer, Inc., lime plant, Gibsonburg, Ohio, during the period October 15, 1980, through January 12, 1981.

The work was conducted by the Field Programs Section of the Environmental Systems Department under the general supervision of Ken Wilcox, Head, Field Programs Section. Fred Bergman was the project leader; George Cobb served as field team leader and was assisted in the field by Bob Stultz, Mark Hansen, Ed Whited, Tom Walker, Jeff Johnson, Joel Pavelonis, Barbara Dent, Ann Small, Ed Olson, and Bruce Boomer. Mark Small was responsible for the unducted source testing and was assisted by Frank Pendleton and Steve Cummins.

We would like to express our appreciation to personnel of the Pfizer plant who gave their assistance and cooperation. We especially want to thank Wayne E. McCoy, Director of Production Services, Paul MacDonald, Plant Manager, and Gary Jividen, Production Manager.

MIDWEST RESEARCH INSTITUTE

H. Kendall Wilcox

H. Kendall Wilcox, Head
Field Programs Section

Approved:

M P Schrag

M. P. Schrag, Director
Environmental Systems Department

May 1983

ABSTRACT

This report presents data for the characterization of inhalable particulate emissions from the lime industry. Both ducted and unducted sources were tested. The plant selected for this study was Pfizer, Inc., located at Gibsonburg, Ohio.

Two kilns, one with an electrostatic precipitator and the other with a baghouse, were tested for both total mass and particle size. The inlet and outlet of each control device were tested concurrently.

A dust collection system was tested in a common duct located ahead of the control device. This system used hoods to collect dust from several product transfer belts.

The only unducted source tested consisted of two product loading areas.

Emission factors were calculated for 15, 10, and 2.5 μm based on the total mass emission rate and particle size data for each source.

CONTENTS

FIGURES

FIGURES (continued)

TABLES

SECTION 1.0

PROCESS DESCRIPTION AND OPERATION

This report presents the results of testing conducted by Midwest Research Institute (MRI) during the period of October 15, 1980, through January 12, 1981. The data gathered will be used to determine the sources of inhalable particulate matter from fugitive industrial sources such as are found in the lime industry.

The tests were conducted at the Pfizer, Inc., lime plant located near Gibsonburg, Ohio. This is considered to be a typical lime plant. Both ducted and unducted sources were sampled. Paved road testing, also outlined in the work plan, was not performed because of snow and wet roads.

Ducted sources included three sampling sites. The plant operates two kilns, each kiln having separate control devices. The first site, kiln No. 7, uses three electrostatic precipitators (ESP) in parallel to control emissions. The inlet and outlet of one of the three ESP's was sampled. The second site, kiln No. 6, uses a five-chambered baghouse to control emissions. The inlet to the five-chamber baghouse and outlet of one chamber was sampled. The third test site was a duct connecting several hoods located over the product transfer belts.

Unducted source tests were conducted on the truck loading operation at the plant. Four tests were conducted on the emissions associated with the loading of agricultural limestone and one test of emissions from the loading of glass lime. In the case of the loading of limestone, both open and closed trucks were tested, whereas only emissions from closed trucks were sampled during the loading of lime.

1.1 PROCESS DESCRIPTION

Pfizer, Inc., produces both dolomite lime and limestone products at the Gibsonburg, Ohio (Sandusky County) plant. Figure 1-1 is a flow diagram of the plant's production process.

An open pit mining area is located at the perimeter of the plant site, and currently production is located southwest (upwind) of the plant. Trucks are used to transport the limestone from the blasting fall to the crushing and sizing area on the quarry floor. The sized material is then transported to storage piles by a conveyor belt system.

Limestone 12 to 20 cm (5 to 8 in.) in diameter is transferred by conveyor to a shaft kiln, then to a hydration process which converts the lime to calcium hydroxide. This process was not addressed in this study because it is no longer typical in the lime industry, accounting for only about 10% of the industry's production.

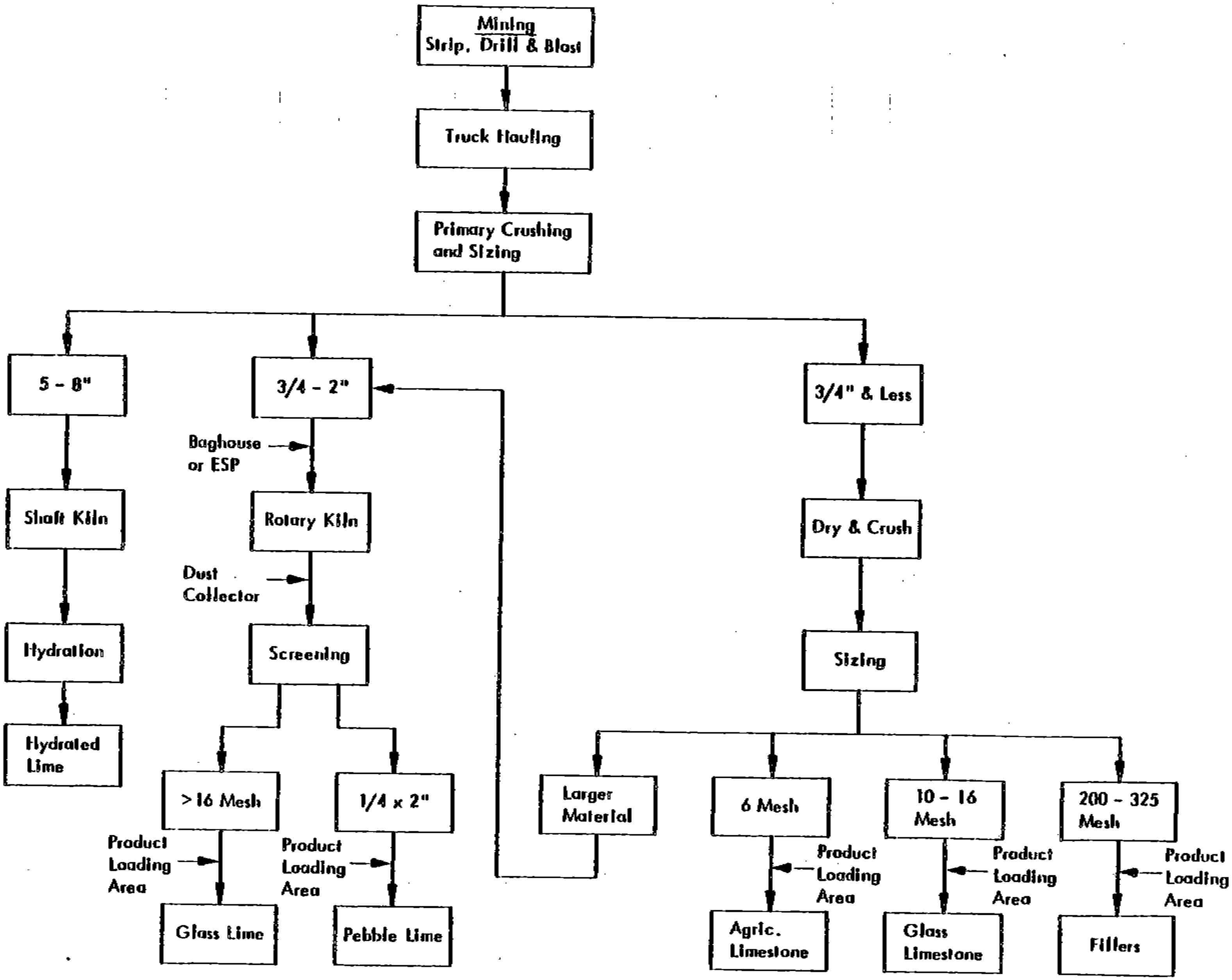


Figure 1-1. Flow diagram of production process at Pfizer plant.

Limestone 2 to 5 cm (3/4 to 2 in.) in diameter is fired in two coal-fired rotary kilns. Table 1-1 gives the design specifications of each kiln. Each kiln has an emission control device which was tested for inhalable particulates.

Kiln No. 6 is equipped with a baghouse and a cyclone between the kiln and the baghouse. The design specifications for the baghouse are listed in Table 1-2. Kiln No. 7 is equipped with three ESP chambers mounted parallel in the gas stream. The initial ESP design for the kiln was inadequate. Two existing ESPs from an inoperative kiln were moved to a parallel position with the first ESP (Figure 2-6, p. 11) which allowed for a longer retention time. Due to the lack of a good sampling location in the common duct, only one ESP could be used for testing. Table 1-2 gives the design specifications of the ESP's. The Joy Western ESP chamber located on the west side was used for testing on this task.

The product from both kilns is transferred to the screening area by a common conveyor belt system. The screening divides the lime into glass lime (> 16 mesh) and pebble lime of 0.6 to 5 cm (1/4 to 2 in.). After screening, the product is transferred by screw conveyor and elevators to storage. The transfer systems including the belt and screw conveyors and elevators are equipped with dust collectors and a common baghouse. The dust collection duct from the conveyor belt systems was selected for testing because of the availability of a suitable sampling location. The outlet of the baghouse was not sampled because it services a number of different process streams.

Limestone up to 2 cm (3/4 in.) in diameter is dryed, crushed, and reduced to the following sizes: 200 to 325 mesh for fillers; 10 to 16 mesh for glass limestone; 6 mesh for agricultural uses; and finally, large material which is added to the kiln feed. Only the loading operation for these products was sampled.

Product loading (lime or linestone) uses gravity feed from a series of storage silos into either open-bed or enclosed semitrailer trucks which have been driven into position beneath the row of silos. It takes approximately 5 to 9 minutes to load between 17 and 24 tons of product into each truck, depending on the particular material being loaded and type of vehicle. Material is loaded by lowering a chute into the bed of the truck at which time a gate valve is opened, thereby allowing the material to fall from the silo into the vehicle. As the trucks are being filled, they are moved forward periodically to assure an even distribution of the load. In the case of open-top trucks, the entire bed is open to the atmosphere, whereas the enclosed trucks are of the tanker-type having up to four hatches, two of which are used for loading purposes, with the others open to allow displaced air to escape.

The fugitive emissions associated with the loading of open-bed trucks are generated by the stream of falling material which strikes the bottom of the truck bed causing a sudden compaction of the load. This compaction results in a violent escape of air, carrying with it large quantities of fine dust. This phenomena can be referred to as splash pulvation. In the case

TABLE 1-1. ROTARY KILN DESIGN PARAMETERS

Parameter	Kiln No. 6	Kiln No. 7
Design process rate (output of lime product)	300 short tons/day	400 short tons/day
Fan rate	72,000 acfm[b]	150,000 acfm
Design temperature	510°F	550°F
Velocity	133.3 fps[c]	75.4 fps
Control device	Baghouse	Electrostatic precipitators

[a] Short ton = 2,000 lb.

[b] acfm = actual cubic feet per minute.

[c] fps = feet per second.

TABLE 1-2. BAGHOUSE AND ELECTROSTATIC PRECIPITATORS DESIGN PARAMETERS

Baghouse (Joy Western) - Kiln No. 6

Flow rate, acfm[a]	72,000 at 500°F
A/C ratio	1.6 (net)
No. of modules	5
No. bag/module	624
Bag type	Modular "Therm-o-flex"

Electrostatic Precipitators - Kiln No. 7

	Joy Western	American Standard
Unit	WP 70-366	-
Design volume, acfm	115,500	91,000
Design temperature, °F	700	700
Design inlet concentration	3.6	
No. of precipitators	1	1
Chambers wide	2	1
Cell/chamber	1	2
Fields deep	3[b]	4-1/2
Gas passages/field	21	16
Collecting surfaces	9 ft x 24 ft	6 ft x 30 ft
Collecting surface spacing	9 in.	9 in.
Face area/precipitator, ft^2	756	360
Total surface, ft^2	54,432[b]	25,922
Gas velocity, fps[c]	2.55	4.22
Retention, sec	7.1[d]	5.68

[a] acfm = actual cubic feet per minute.

[b] One field is vacant, to be filled. Total surface with two is 36,288 ft^2.

[c] fps = feet per second.

[d] For two fields.

of loading into tanker-type vehicles, air is induced along with the material as it enters the enclosure, which subsequently streams out of any available opening, carrying with it the fine dust suspended during the process of falling. This displaced air stream with its associated heavy particle loading are characteristic of this type of operation. Emissions can also be created by the movement of the vehicle during load redistribution.

As stated above, the loading of two different types of bulk material were tested during the sampling program. The first type of material is a -6 mesh crushed agricultural limestone, and the second type a -16 mesh glass lime. The particle size of both materials was determined from samples collected on-site using the standard ASTM dry sieving technique. The results of this analysis are shown in Table 1-3. It was noted during sieving of the glass lime, however, that this particular material exhibits definite electrostatic properties lending to rapid agglomeration of the particles. The significance of this property could be of major importance, as will be shown later in the report.

TABLE 1-3. PARTICLE SIZE DISTRIBUTION OF AGRICULTURAL LIMESTONE AND GLASS LIME SAMPLES FROM THE PFIZER PLANT

Particle size		Percent (weight) below stated size	
Sieve No.	Microns	Agricultural limestone[a]	Glass lime[b]
10	2,000	100	100
20	840	93	79
40	420	86	68
100	149	62	44
140	105	50	36
200	74	40	29

[a] Density = 1.21 g/cm^3.

[b] Density = 1.56 g/cm^3.

1.2 PROCESS OPERATION

Pfizer, Inc., provided daily production rates of lime product from each of the two rotary kilns for the dates of the field tests. The kiln operators from Pfizer, Inc., informed MRI personnel of all process interruptions during field testing. Table 1-4 presents the daily output of lime product from each rotary kiln.

TABLE 1-4. DAILY LIME PRODUCTION BY KILN AT PFIZER, INC., OCTOBER 23, 1980, TO JANUARY 9, 1981

Test date	Kiln No. 6 Design capacity (English tons/day)[a]	Kiln No. 6 Daily operation, % of design capacity	Kiln No. 6 Daily production of lime product (tons/day)	Kiln No. 7 Design capacity (tons/day)	Kiln No. 7 Daily operation, % of design capacity	Kiln No. 7 Daily production rate of lime product (tons/day)	Total daily production kiln Nos. 6 and 7 (tons/day)
10-23-80	300	92	276	400	Kiln Down	Kiln Down	276
10-24-80		92	276		Kiln Down	Kiln Down	276
10-25-80		92	276		60	240	516
10-27-80		92	276		75	300	576
10-28-80		Kiln down	Kiln down		75	300	300
10-29-80		92	276		75	300	576
10-30-80		92	276		75	300	576
10-31-80		92	276		75	300	576
11-3-80		92	276		75	300	576
11-4-80		-[b]	-[b]		75	300	300
11-5-80		Kiln down	Kiln down		75	300	300
12-2-80		92	276		75	300	576
12-3-80		92	276		75	300	576
12-4-80		92	276		75	300	576
12-5-80		92	276		75	300	576
12-6-80		92	276		75	300	576
1-6-81		92	276		Kiln down	Kiln down	276
1-7-81		92	276		Kiln down	Kiln down	276
1-8-81		92	276		Kiln down	Kiln down	276
1-9-81		92	276		Kiln down	Kiln down	276

[a] Tons/day: Short ton (2,000 lb) day = 24-hr period.

[b] Kiln No. 6 not tested this date.

Rotary kiln No. 6 is designed for a daily lime production of 300 short tons (one short ton equals 2,000 lb). During the field test, kiln No. 6 was operating at 92% of design capacity, yielding 276 short tons daily.

Rotary kiln No. 7 is designed for a daily lime production of 400 short tons. During the field test, kiln No. 7 was operating at 75% of design capacity, yielding 300 short tons daily. On October 25, kiln No. 7 was operating at 60% of design capacity, yielding 240 short tons daily.

Lime product from both kilns is transferred to the screening area by a common conveyor belt system. Depending upon production requirements and maintenance needs, one or both of the kilns were dumping lime product onto the conveyor belt. The actual dumping of lime product onto the conveyor belt, however, was not a continuous operation. A sampling period was chosen that would produce a representative sample from this segment of the operation. MRI personnel visually monitored the operational status of the conveyor belt system prior to and during each test.

SECTION 2.0

SAMPLING LOCATIONS, EQUIPMENT, AND PROCEDURES

This section describes the selection of sampling sites, the equipment used for sampling, and the test procedures.

2.1 SAMPLING LOCATIONS

Particle sizing and total mass sampling were conducted at four locations: the baghouse, one of the ESP's, the dust collection system, and product loading areas. Figure 2-1 is an overview of the Pfizer, Inc., lime products manufacturing facility.

2.1.1 <u>Ducted Sources</u>

2.1.1.1 Baghouse Inlet and Outlet--

The Pfizer plant kiln No. 6 utilizes a five-chambered baghouse to control emissions. A single duct connects the outlet end of the kiln to the baghouse. The inlet sampling location is between the cyclone from the kiln and the induced draft fan to the baghouse. The outlet from the five-chambered baghouse consists of five separate fans, one for each chamber, venting directly to the atmosphere. A stack extension built by Pfizer, Inc., was added to the exhaust fan from one chamber for sampling purposes. Figures 2-2 and 2-3 illustrate the Pfizer plant baghose and sample port locations.

Figure 2-4 shows the relevant physical measurements of the baghouse inlet sampling site, the sample quadrant dimensions, and the sample point locations. The physical measurements, sample quadrant dimensions, and sample point locations in the baghouse outlet sampling site are shown in Figure 2-5.

2.1.1.2 ESP Inlet and Outlet--

The Pfizer plant kiln No. 7 utilizes three ESP's mounted parallel to each other to control emissions. Exhausts from the kiln proceed through an inlet duct which branches into three sections leading to the three ESP units. Exhaust gases leaving the three ESP units exit through three sections of duct. The three sections of duct then merge, and gases are exhausted to the atmosphere through a common stack.

The strategy for determining inhalable particulate emissions from the three ESP units on kiln No. 7 involved sampling the inlet and outlet of only one of the three ESP units. Figure 2-6 illustrates the configuration of the three ESP units controlling emissions from kiln No. 7. Simultaneous sampling was conducted on the west (No. 1 in the figure) ESP inlet and outlet.

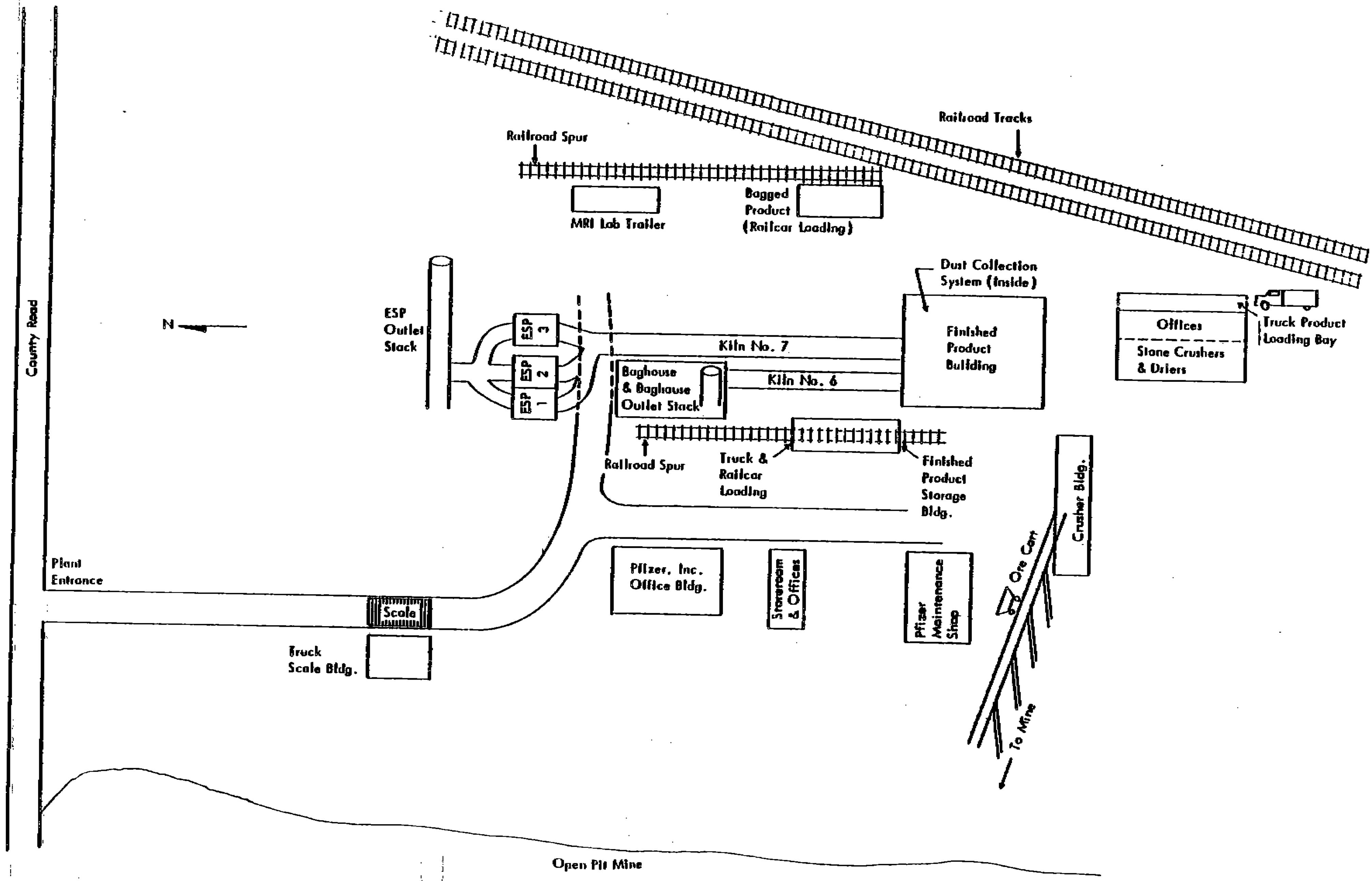


Figure 2-1. Overview of sampling areas at Pfizer, Inc., lime products plant.

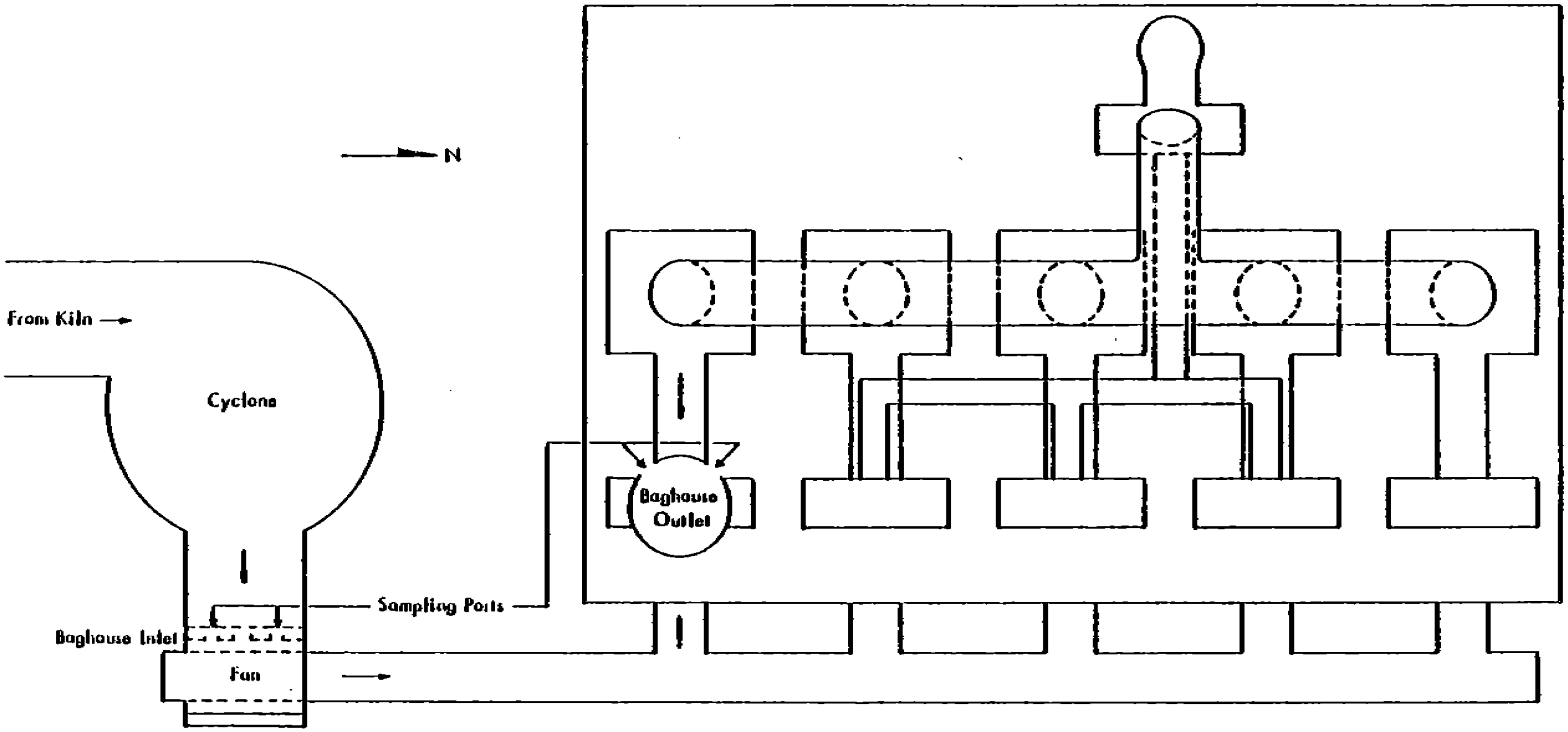


Figure 2-2. Top view of baghouse inlet and outlet sample ports at Pfizer plant.

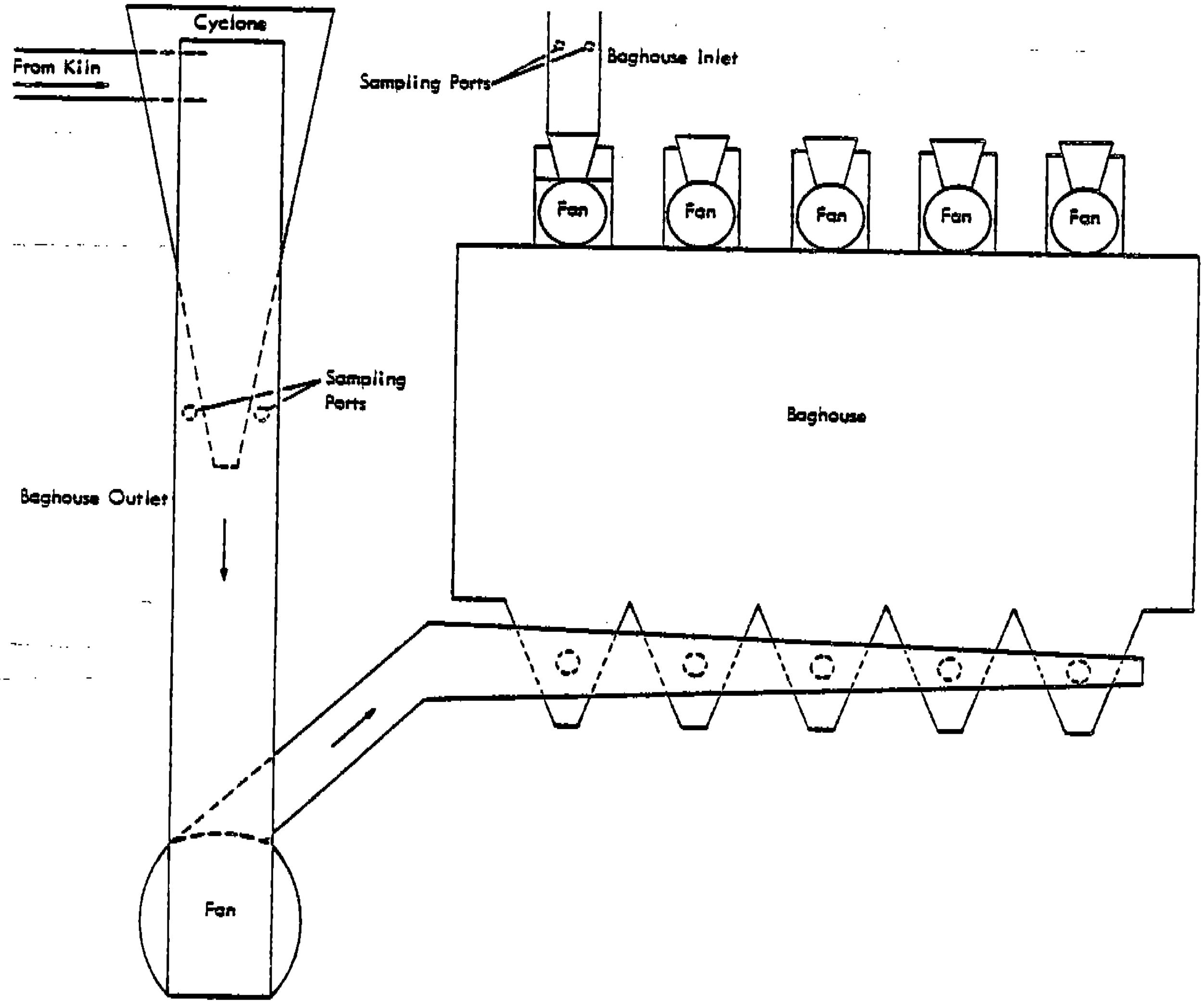


Figure 2-3. Side view of baghouse inlet and outlet sample ports at Pfizer plant.

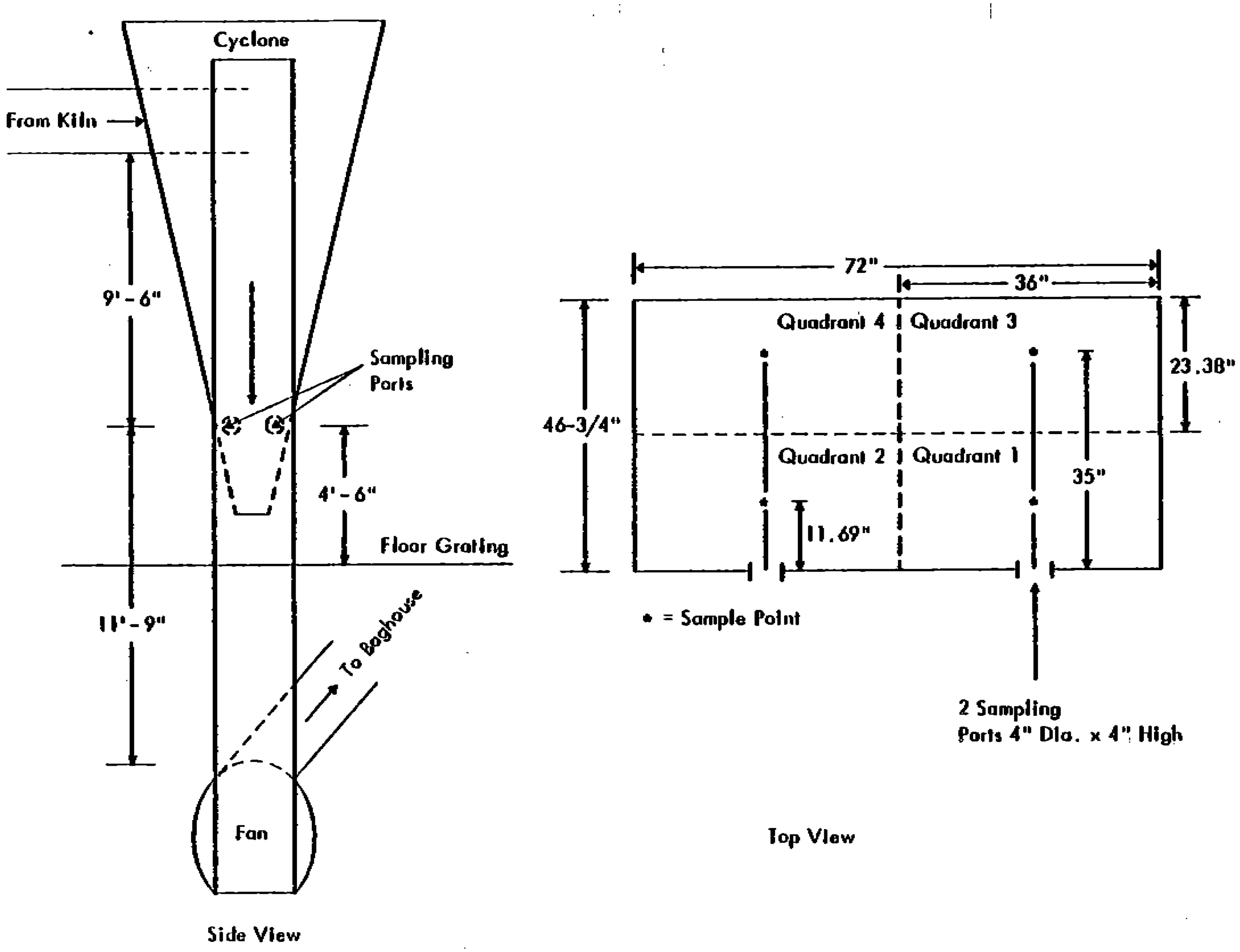


Figure 2-4. Sample ports, sample quadrants, and sample point locations at the inlet of the baghouse at the Pfizer plant.

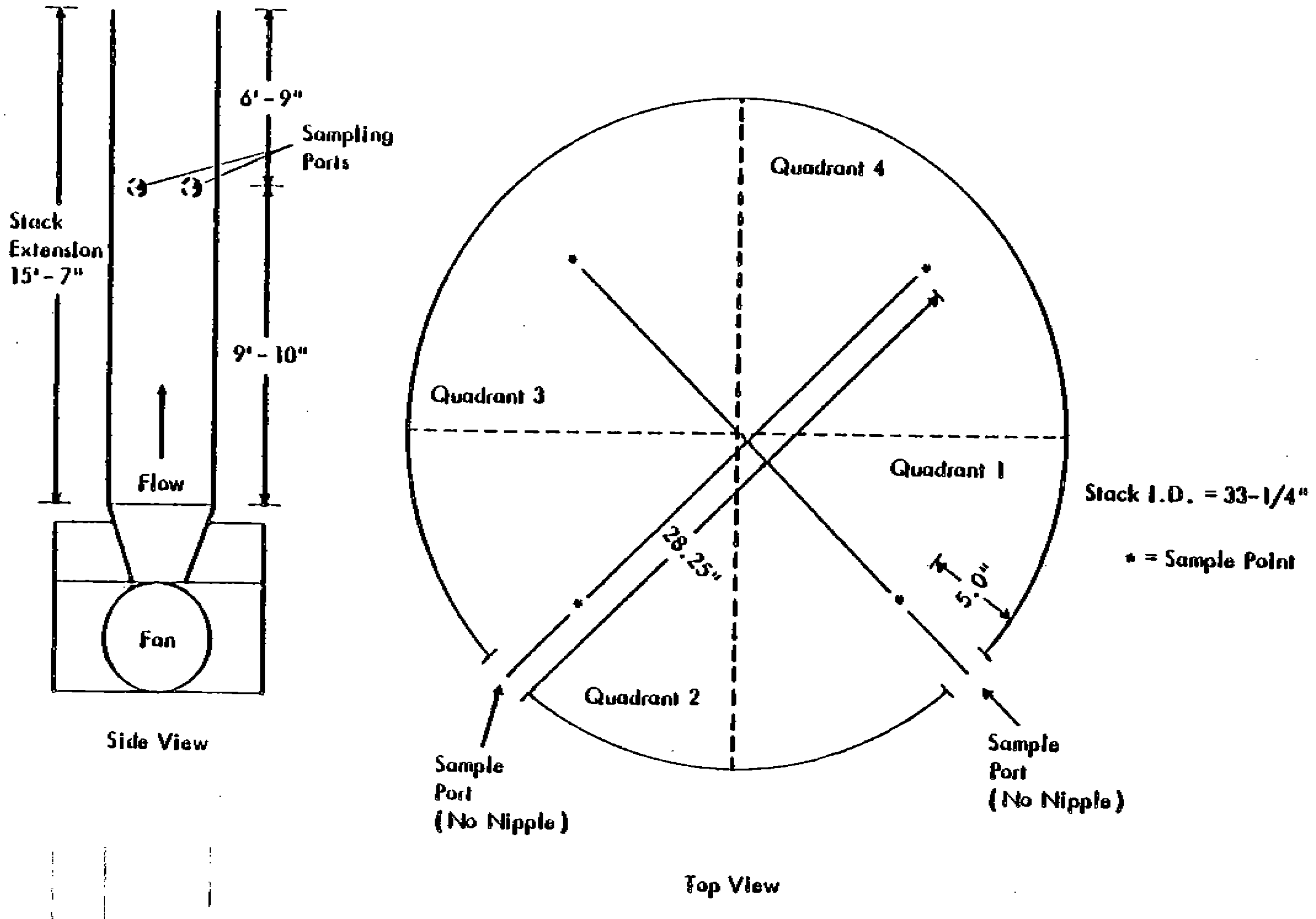


Figure 2-5. Sample ports, sample quadrants, and sample point locations at the outlet of the baghouse at the Pfizer plant.

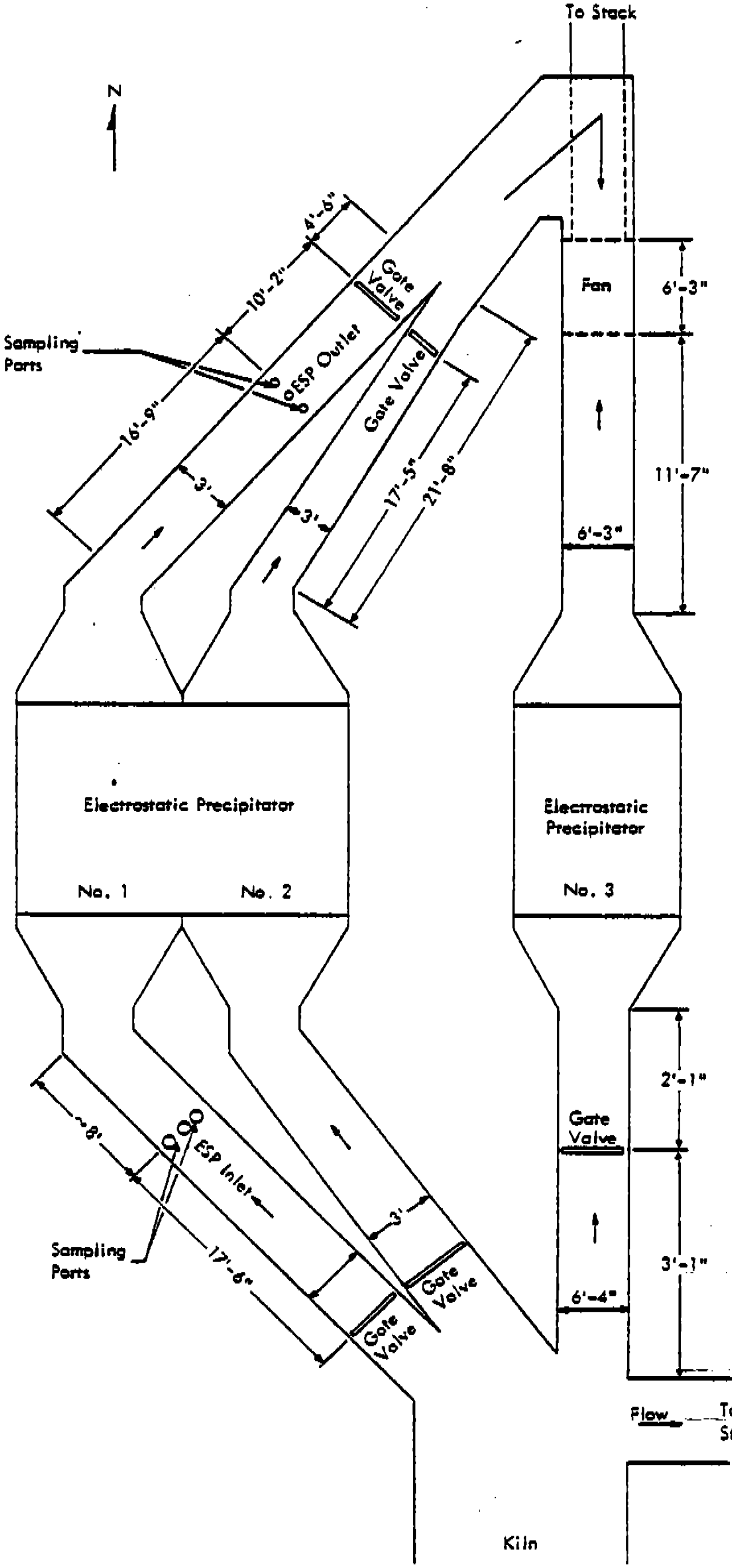


Figure 2-6. Electrostatic precipitator units and sample point locations at the Pfizer kiln No. 7.

Figures 2-7 and 2-8 presents the locations of the sample ports, sampling quadrants, and sample points and duct dimensions at the inlet to the ESP and outlet from the west ESP, respectively. An accumulation of material in the bottom of the rectangular ducts was discovered at the ESP inlet and outlet sites during EPA Method 2 determinations. The depth of accumulated material was measured at both locations. Calculations were made to adjust the total nonobstructed area of the ducts and to establish the four sample quadrants and sampling points. The depth of accumulated material at both locations is indicated in Figures 2-7 and 2-8.

2.1.1.3 Dust Collection System--

Enclosed transfer (conveyor) belts and drop points transfer the finished lime product to the screening operation. Small hoods capture lime dust generated through this process at a number of collection points. The ambient air and lime dust collected at these sites travel through 10 cm (4-in.) diameter ducts to a central dust collection duct which transports the dust to a baghouse. Sampling was conducted at the central dust collection duct that handled lime dust collected from the product transfer belts and drop points. The baghouse serving this system was not selected as a testing site since it collected dust from several other product operations as well.

Figure 2-9 is an overview of the numerous 10 cm (4-in.) diameter ducts and the central dust collection duct that transport lime dust from the product transfer belts and drop points. The sampling site on the central dust collection duct is also indicated. Figure 2-10, a close-up of Figure 2-9, details the location of each dust collection hood. Figure 2-11, a schematic of the central dust collection system duct, shows the location of sample ports, sample quadrants, and sample points.

The diagram of the sample quadrants and sample point locations in Figure 2-11 points up a necessary deviation from the centroid location criteria of two of the four sample points during particle size tests. The sample points for quadrants 3 and 4 should have been located 33 cm (13-1/8 in.) into the duct, but the nozzle on the 15-μm preseparator could not be positioned at this depth due to the length of the preseparator above the nozzle. The nozzle had to be positioned 28 cm (11-1/8 in.) into the duct at quadrants 3 and 4 to accommodate the overall length of the preseparator.

2.1.2 Unducted Sources

2.1.2.1 Product Loading Areas--

Two product loading bays were tested for inhalable particulate emissions. Figure 2-12 shows the product loading bay associated with the finished lime product storage building. The finished product is bulk loaded onto trucks and railcars at this site. Figure 2-13 shows the limestone loading bay associated with the crushed stone and dryer building. Only trucks are bulk loaded with product at this loading bay.

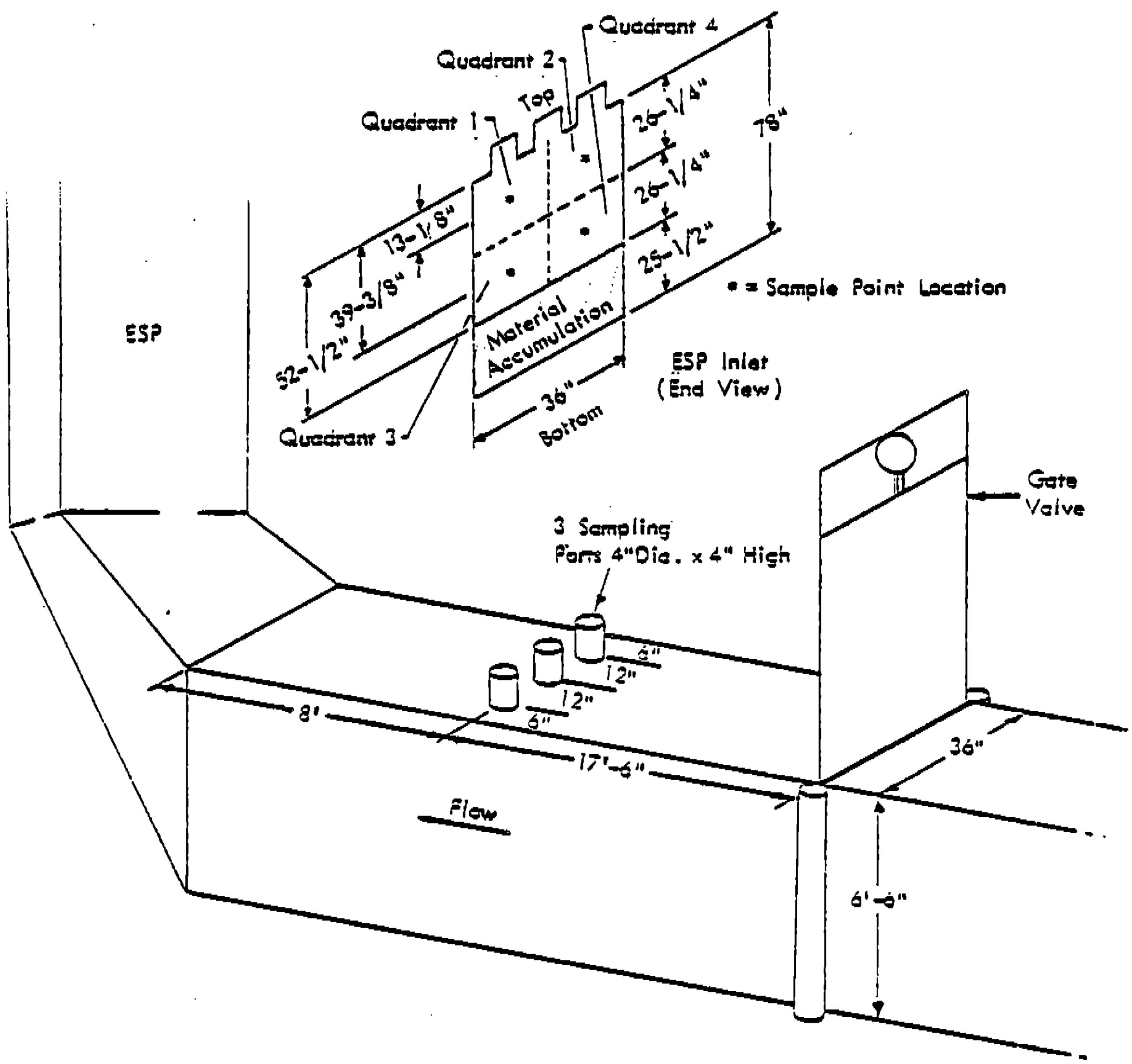


Figure 2-7. Pfizer electrostatic precipitator inlet duct showing sample ports, sample quadrants, and sample points.

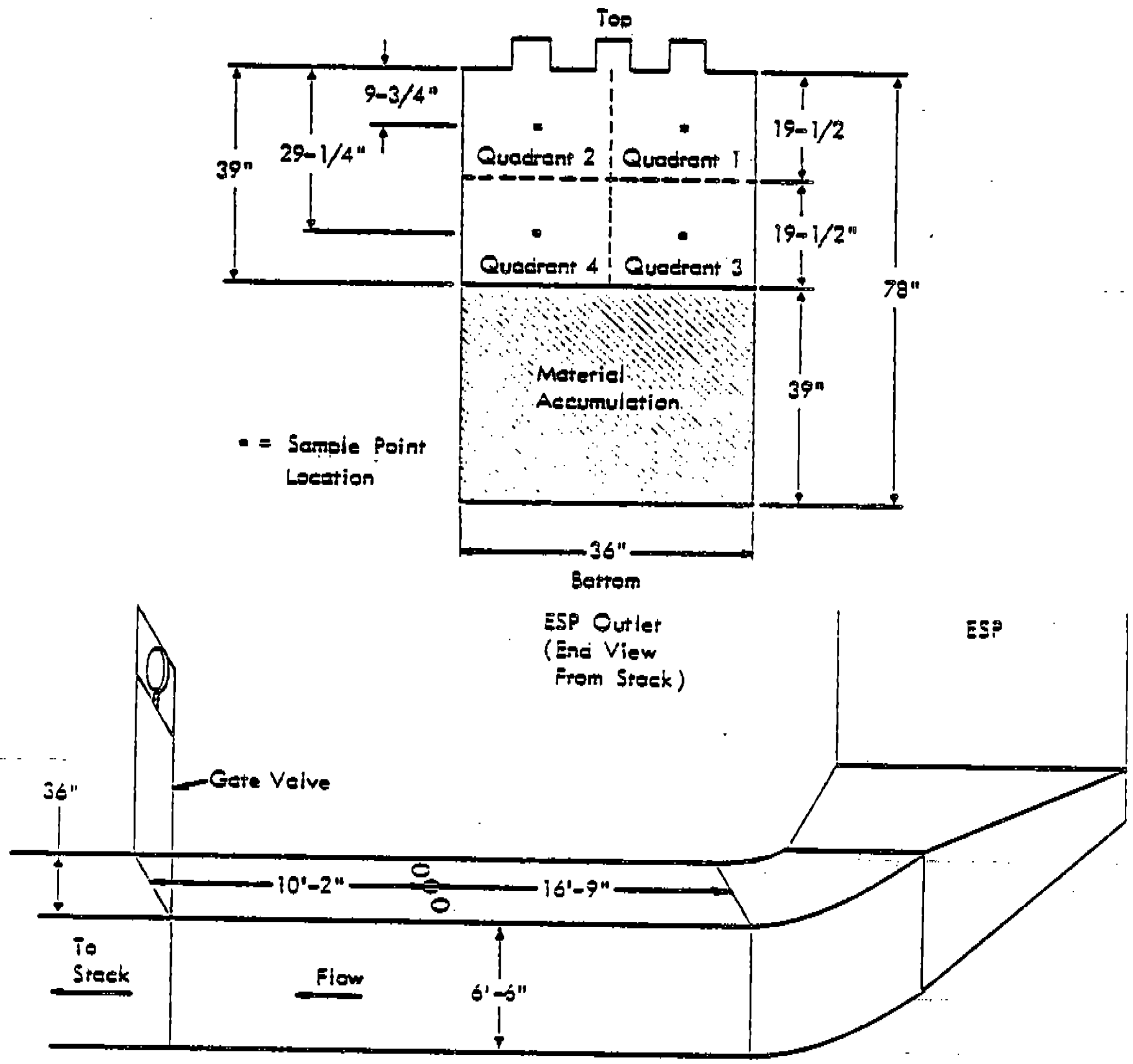


Figure 2-8. Pfizer electrostatic precipitator outlet duct showing sample ports, sample quadrants, and sample points.

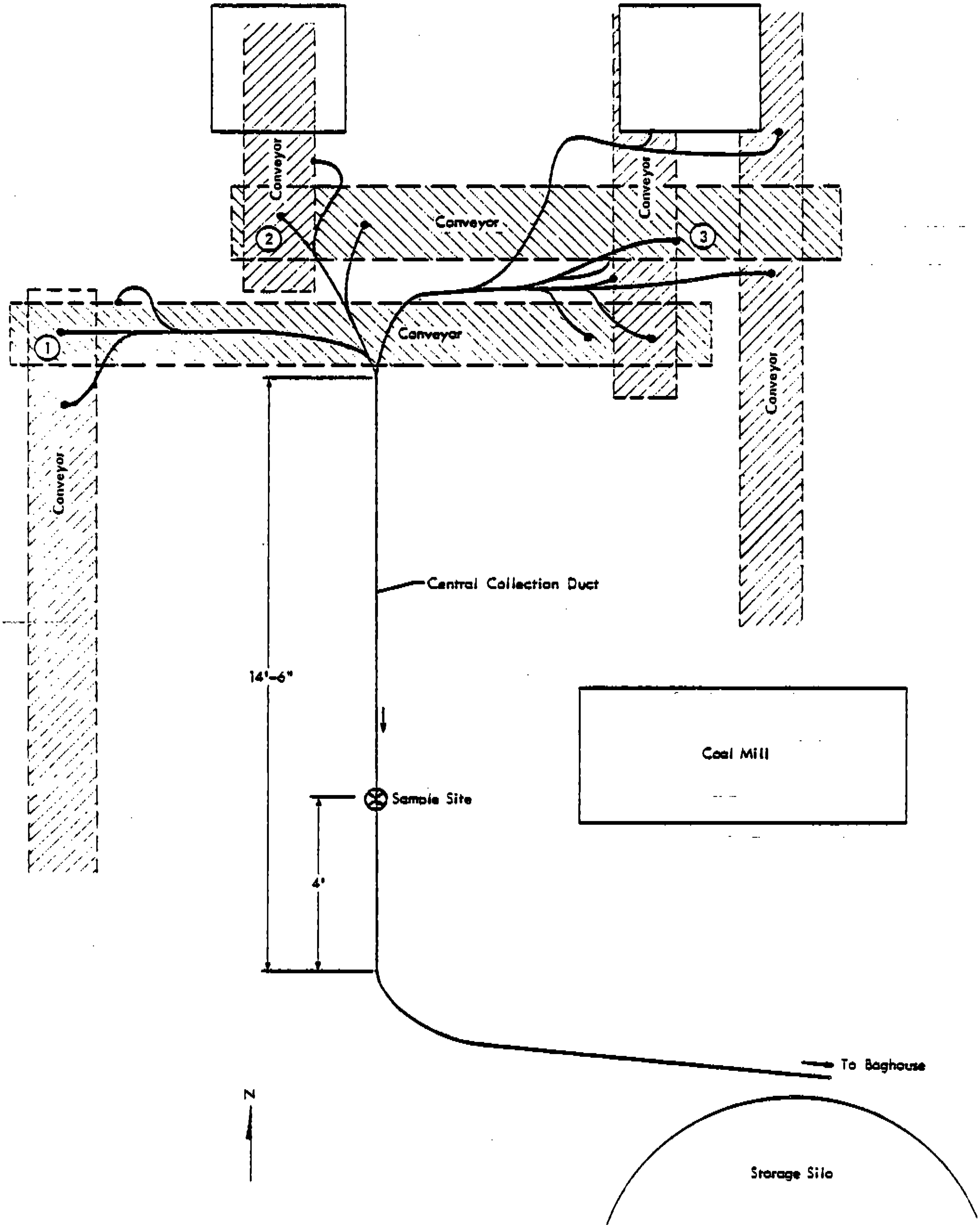


Figure 2-9. The Pfizer plant dust collection system product transfer belts and drop points.

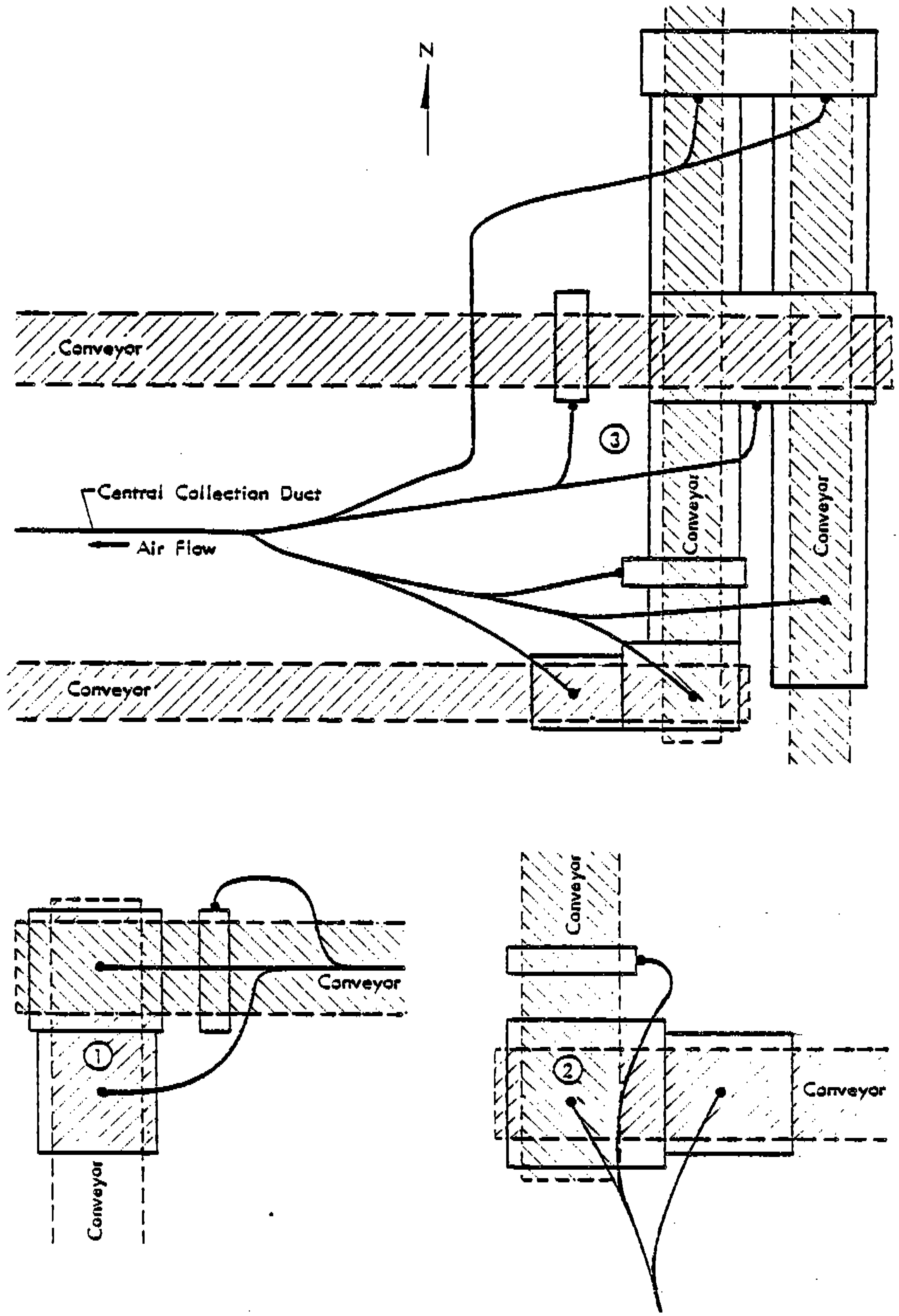


Figure 2-10. Dust collection system hood locations on the product transfer belts and drop points at the Pfizer plant.

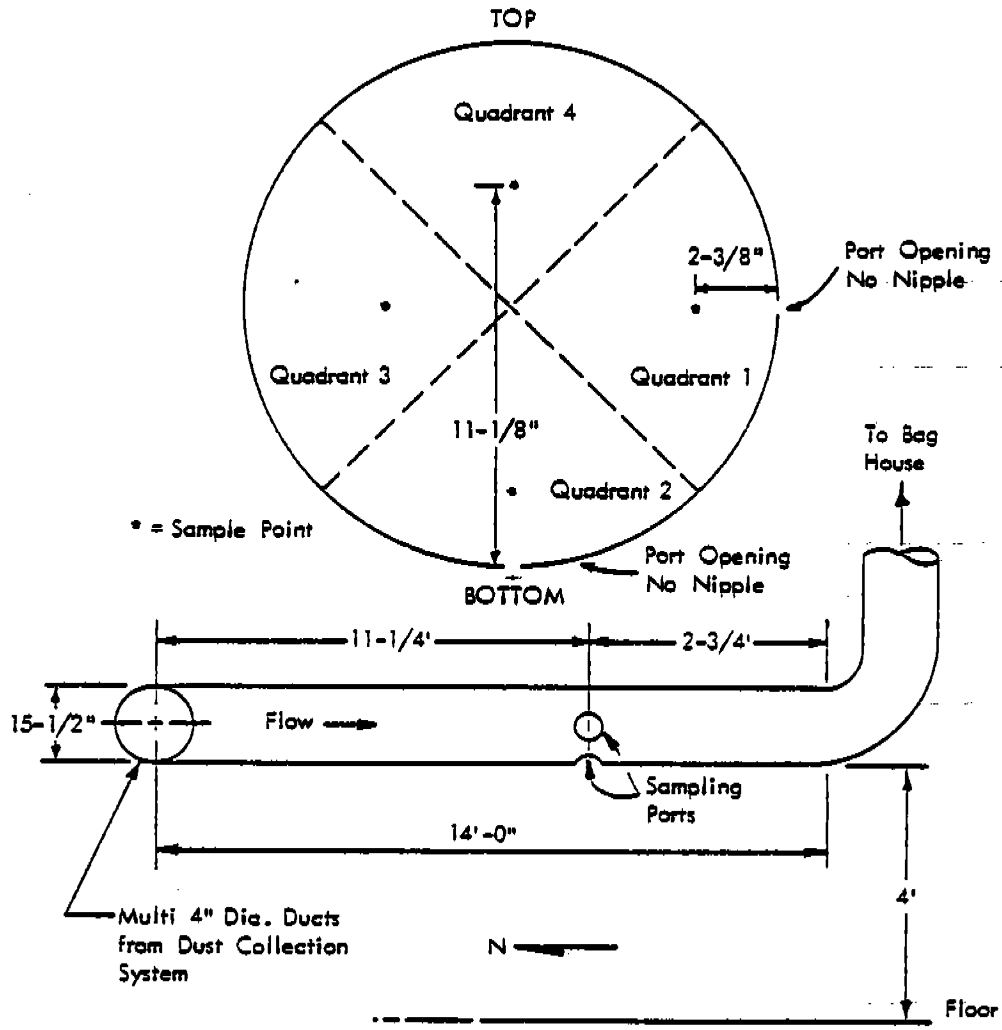


Figure 2-11. Sample ports, sample quadrants, and sample points at the duct sampling site of the Pfizer plant dust collection system.

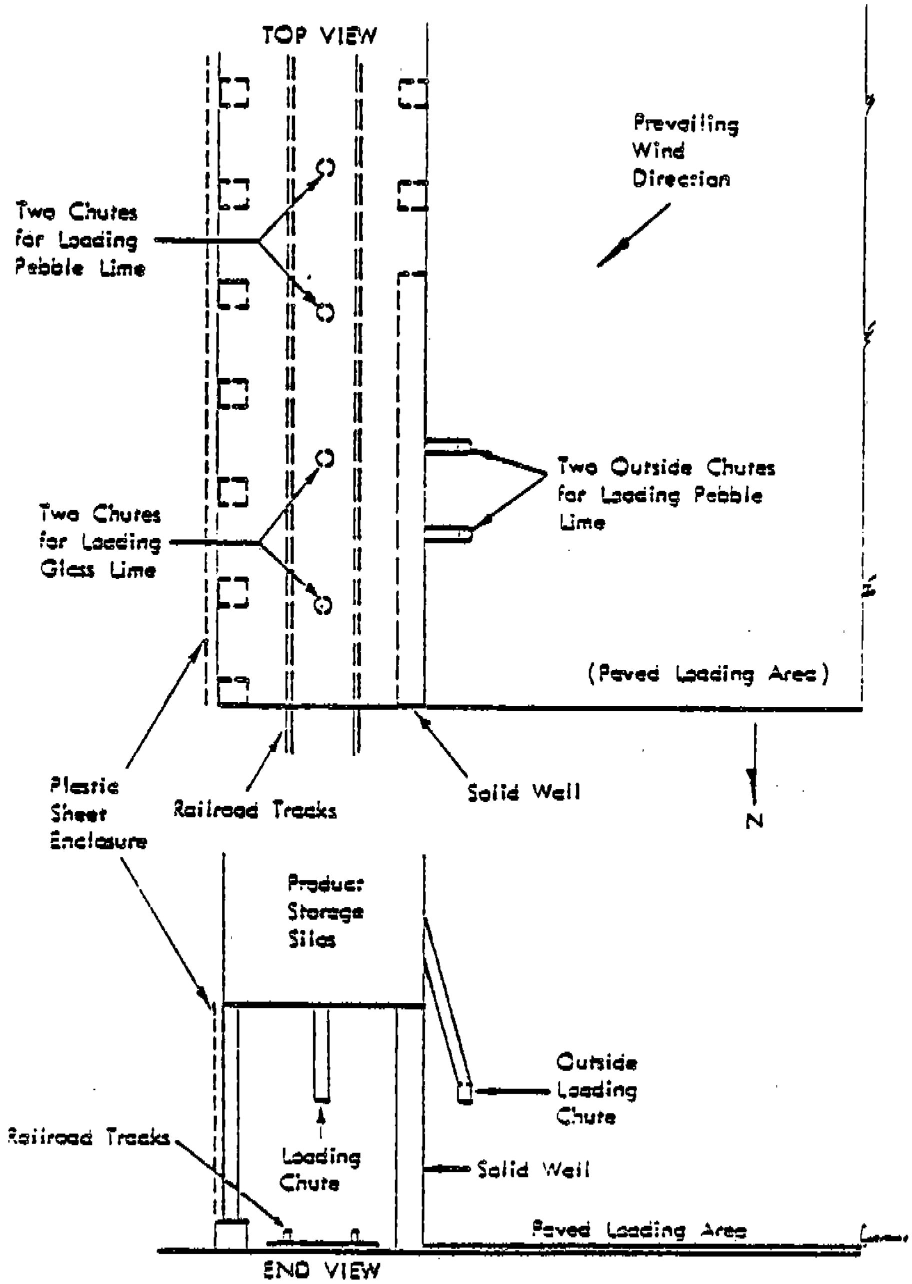


Figure 2-12. Product loading bay for trucks and railcars and finished lime product storage building, Pfizer plant.

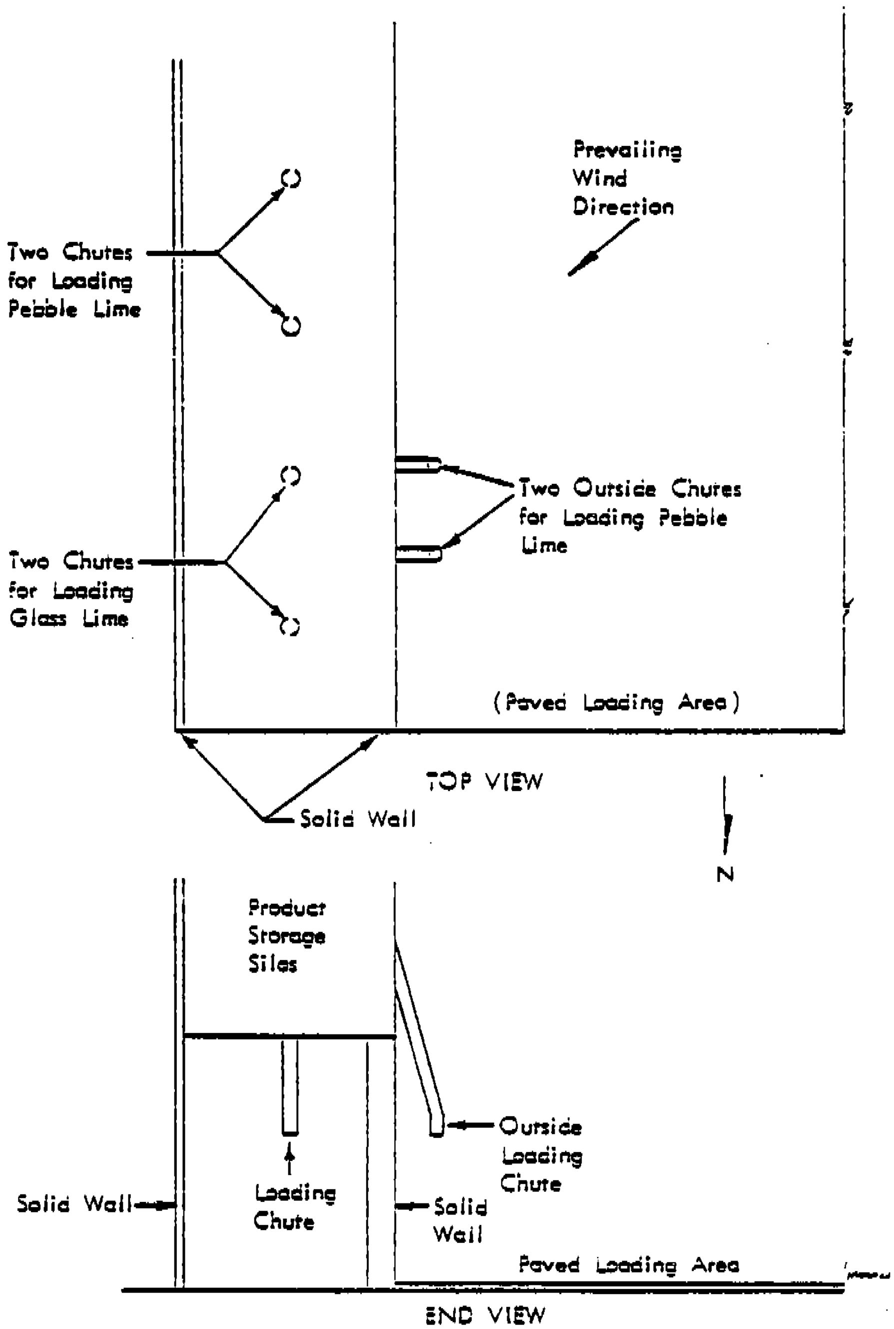


Figure 2-13. Limestone loading bay for trucks, stone crusher, and dryer building at the Pfizer plant.

2.2 SAMPLING EQUIPMENT

2.2.1 Ducted Sources

The EPA Method 5 mass train, shown in Figure 2-14, consisted of an MRI-modified Research Appliance Company (RAC) console and sample box. The probe nozzle and liner were made of No. 316 stainless steel, and the remainder of the train was made of borosilicate glass. All equipment was calibrated according to EPA requirements (Federal Register, Vol. 42, No. 160, August 18, 1977). Appendix G contains the calibration data for the MRI equipment used at Pfizer.

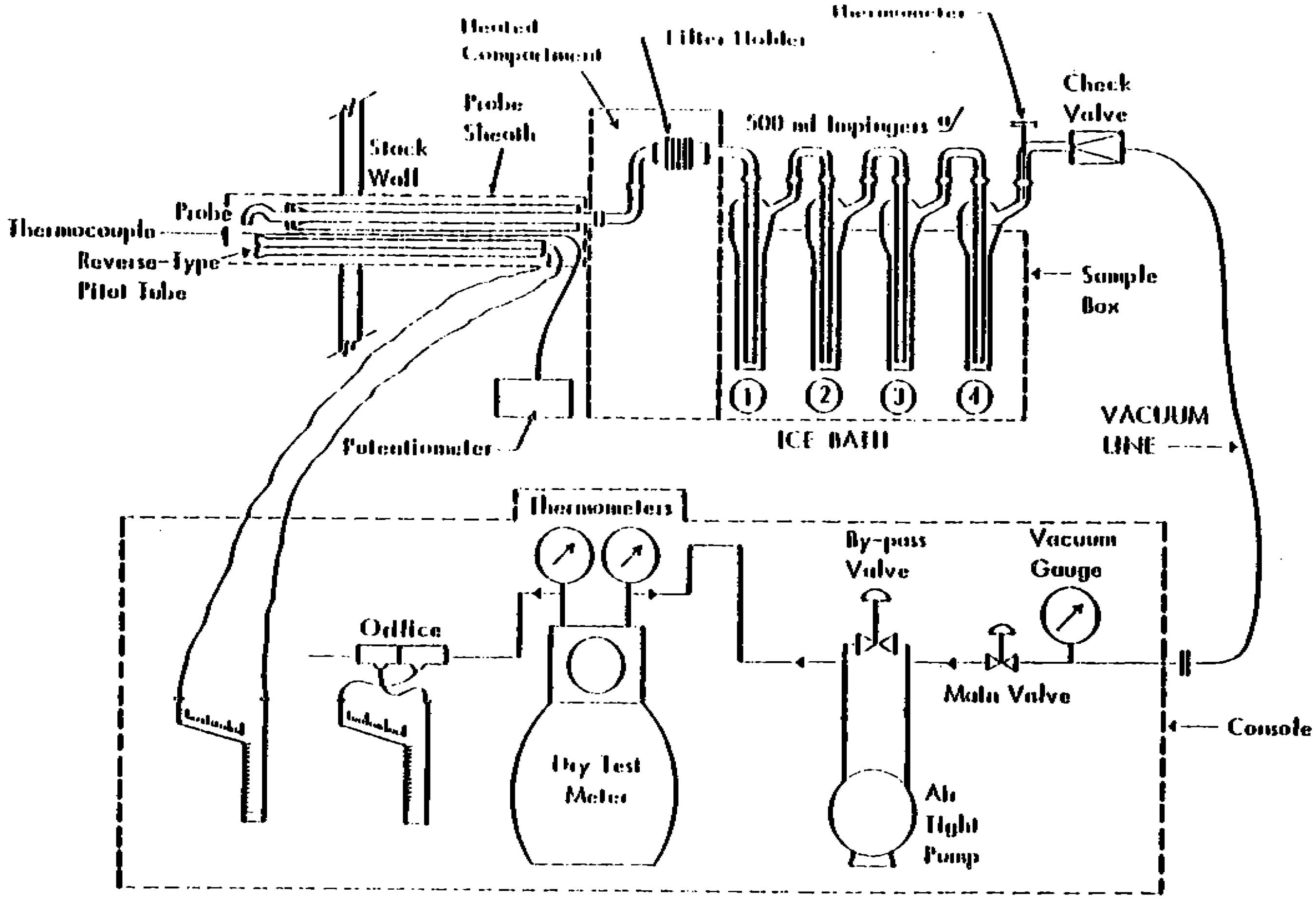
The Andersen Mark III (Andersen 2000) impactor, a multistage, multijet impactor, and a 15-μm preseparator (Sierra Instruments, Inc.) were used in sampling sites with light loading. An RAC console controlled and metered the flows. Figure 2-15 shows the Andersen impactor and preseparator in the sampling mode.

The Brink Model B (Zoltek Corp.) impactor, a multistage, single jet impactor, was used in sampling sites with heavy loading. The impactor was used in conjunction with a 7-μm cyclone developed by MRI. Figure 2-16 shows the Brink sampling train.

2.2.2 Unducted Sources

The background concentrations of total particulate, total suspended particulate (< 30 μm), inhalable particulate (< 15 μm), and fine particulate (< 2.5 μm) were determined by colocated instruments at a position approximately 5 m downwind of each truck loading bay during periods when loading was not actually taking place. Three different types of instrumentation were used for this determination. The concentration of total suspended particulate (TSP) was measured using a standard high volume air sampler (Hi-Vol) with an inlet of conventional design. The concentration of inhalable particulate (IP) was determined using a Hi-Vol equipped with an Andersen size selective inlet (SSI) designed for a cutpoint (D_{50}) of 15 μm. The concentration of total particulate (TP) and fine particulate (FP), including the mass fraction in six particle size ranges, was determined with a Hi-Vol on which was installed a Sierra Model 230-CP cyclone preseparator and Model 230 five-stage cascade impactor. All three samplers were located at a sampling height of 2 m above the ground.

A second array of equipment similar to that mentioned above was used to characterize the particulate concentrations downwind of the storage silos during product loading. This array of equipment consisted of one standard Hi-Vol, two Hi-Vols with SSIs, and two Hi-Vols with cyclones and impactors. These instruments were mounted on the back of a pickup truck in the configuration shown in Figure 2-17 with a Hi-Vol, Hi-Vol with SSI, and Hi-Vol with cyclone/impactor located at a sampling height of 2.5 m and a Hi-Vol with SSI, and a Hi-Vol with cyclone/impactor at a height of 4 m. A photo of the sampling vehicle itself is shown in Figure 2-18.



a Impingers 1, 3, and 4 are of the modified Greenburg-Smith design.
Impinger 2 is of the Greenburg-Smith design.
Impingers 1 and 2 contain 100 ml water.
Impinger 3 is empty.
Impinger 4 contains 200 to 300 g silica gel.

Figure 2-14. EPA Method 5 sampling train.

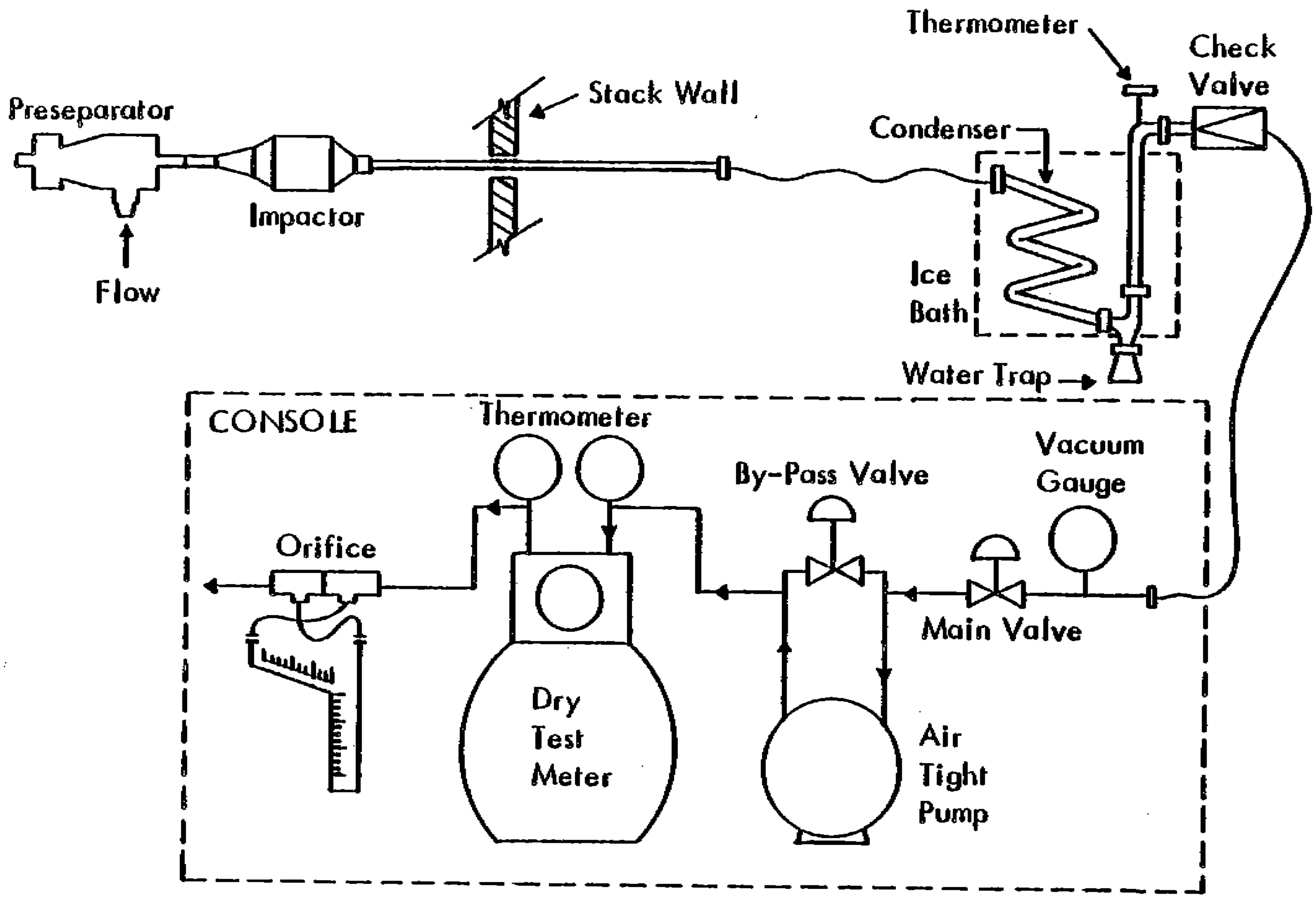


Figure 2-15. Andersen Mark III impactor with 15-μm preseparator sampling train.

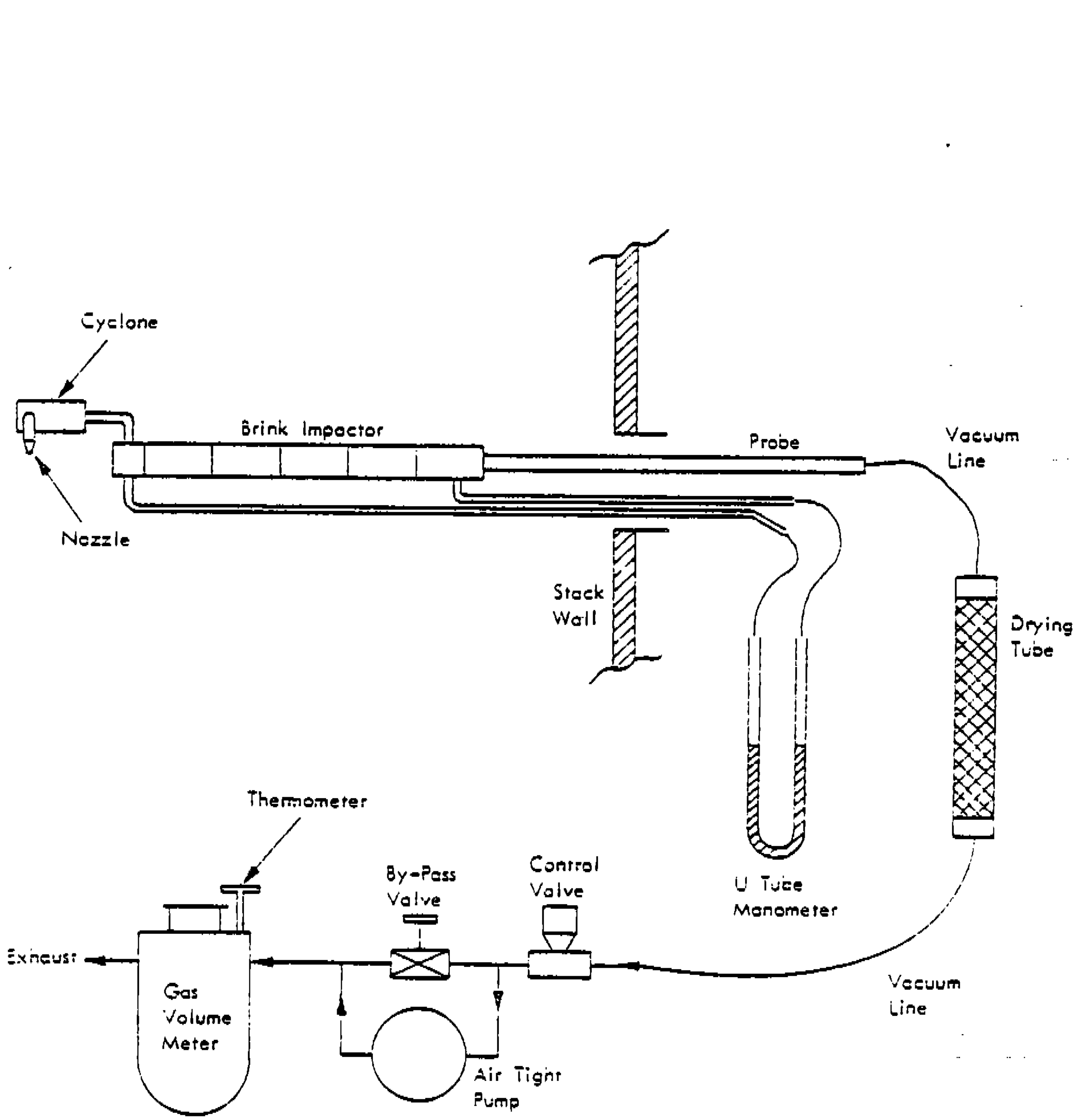


Figure 2-16. Brink impactor sampling train.

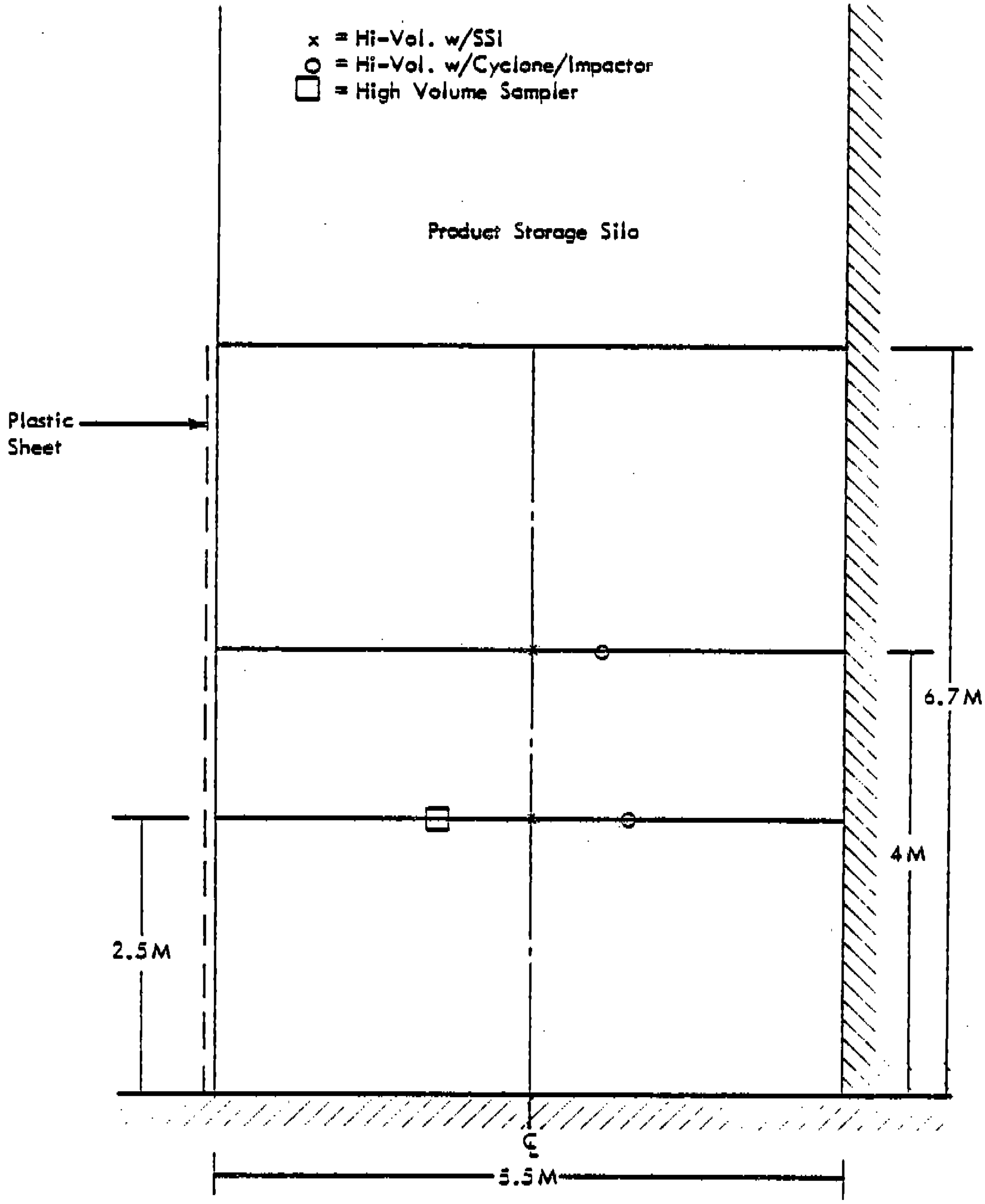


Figure 2-17. Location of sampling equipment for product loading/tests.

Figure 18. Sampling array used to sample the product loading area.

For identification purposes, each of the above samplers was designated according to the type of instrument and the type of sample being collected. According to this classification, an instrument which collected a background sample (no truck loading) was designated as an upwind unit, whereas an instrument collecting a source sample (during truck loading) was designated as a downwind unit even though this nomenclature was not entirely correct. This classification scheme was used, however, to ensure compatibility with the computer program used to reduce the data as described later in this report. Table 2-1 provides the classification for each piece of sampling equipment outlined above.

2.3 SAMPLING, RECOVERY, AND ANALYSIS PROCEDURES

2.3.1 Sampling Procedures

2.3.1.1 Ducted Sources--

EPA Methods 1, 2, and 3 (Federal Register, Vol. 42, No. 160, August 18, 1977) were followed in obtaining preliminary data for the mass trains. Preliminary data for the particle sizing tests were taken from previous mass train runs. The dust collector was tested at ambient conditions.

The "Procedure Manual for Inhalable Particulate Sampler Operation" (Southern Research Institute, November 30, 1979) was used to determine most of the sampling criteria for the particle sizing and mass. Using this manual, four sampling points were determined using Figure 2-19. A run was done at each sampling point, and these four runs constituted a test. There were four tests for a total of 16 runs each of mass and particle sizing.

A system of identification was developed for the Pfizer tests. A typical test number, ESP-I-1-4(2), was derived as follows.

The first designation indicates the sampling location: ESP, electrostatic precipitator; Bag, baghouse; and DC, dust collector. After the sampling location, the next designation indicates the inlet (I) or outlet (O) location of the control device being tested. The dust collector does not have a number designated because it has only one sampling site. The next part ("1" designation) is the test number. The number of the quadrant being tested is next given, and the final number, shown in parentheses, indicates the particular run in that quadrant.

The mass trains were operated according to EPA Method 5 guidelines, with the following changes. As stated earlier, four individual sampling points were used rather than a standard traverse. The criterion for isokinetic sampling was expanded to ± 20% rather than ± 10%. Mass trains were used at all of the sampling sites.

An Andersen impactor with a 15-µm preseparator was used at both outlets and the dust collector due to light loading at these sites. Preliminary and isokinetic sample calculations are shown in Appendix B. A sample was drawn from the stack at a constant velocity through the nozzle. This flow rate allowed for a 15-µm cutoff in the preseparator while remaining within the ± 20% isokinetic range.

TABLE 2-1. CLASSIFICATION OF PARTICULATE SAMPLING EQUIPMENT USED FOR FUGITIVE EMISSIONS TESTING

Sampler ID No.	Type of instrument	Type of sample collected: Background-oriented	Type of sample collected: Source-oriented	Computer input designation: Upwind	Computer input designation: Downwind	Sampling height (m)	Type of data collected by instrument: Total particulate[a]	Total suspended particulate[b]	Inhalable particulate[c]	Fine particulate[d]	Particle size distribution[e]
TSP-1	Standard Hi-Vol	X		X		2		X			
TSP-2	Standard Hi-Vol		X		X	2.5		X			
IP-3	Hi-Vol with SSI	X		X		2			X		
IP-4	Hi-Vol with SSI		X		X	2.5			X		
IP-5	Hi-Vol with SSI		X		X	4			X		
CI-1	Hi-Vol with cyclone/impactor	X		X		2	X		f	g	X
CI-2	Hi-Vol with cyclone/impactor		X		X	2.5	X		f	g	X
CI-3	Hi-Vol with cyclone/impactor		X		X	4	X		f	g	X

[a] Particles < ~ 300 μm in size.

[b] Particles < 30 μm in size.

[c] Particles < 15 μm in size.

[d] Particles < 2.5 μm in size.

[e] Particles 11.4 to 0.74 μm in size.

[f] By extrapolation of particle size distribution curve.

[g] By interpolation of particle size distribution curve.

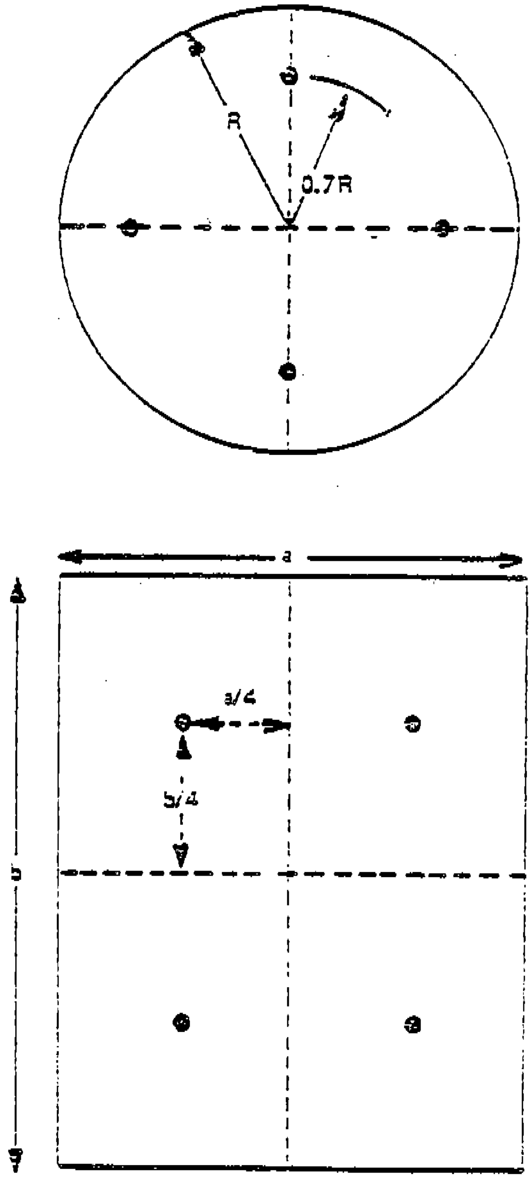


Figure 2-19. Recommended IP sampling points for circular and square or rectangular ducts.

The Brink impactor was run at the inlet of each emission control unit. The cyclone of the Brink allowed for a 7-μm cutoff. The Brink was run in the same manner as the Andersen. Appendix B contains sample calculations for the Brink.

2.3.1.2 Unducted Sources--

The first step taken prior to sampling was to install sheets of plastic along the exterior support members of each truck loading bay. These sheets provided a temporary wall which, along with an existing building, enclosed the loading area on two sides. This tunnel-like enclosure channeled the ambient wind through the bay toward the sampling equipment located at the downwind end of the enclosure. The location of the plastic sheets have been shown previously in Figure 2-12.

As stated above, the background concentrations of particulate matter in various particle size ranges were determined approximately 5 m downwind of each truck bay tested during a period when loading was not actually taking place. One background test of 1-hr duration was conducted at the completion of Run S-4 and a second 1-hr test following Run S-5. In both cases, the background concentrations were determined to be negligible compared to the values obtained during source sampling, as will be shown later during the discussion on data analysis.

Measurements of wind velocity through the loading area were made prior to source sampling using hot wire anemometers at 2- and 4-m heights along a horizontal traverse approximately 5 m downwind of the source. The approximate location of each velocity traverse point is shown in Figure 2-20. A velocity traverse was conducted during actual loading prior to Runs S-1, S-3, and S-5.

The accuracy of the velocity measurements should be considered within only ± 50%. This is a result of the turbulent conditions within the loading area caused by the irregular shape of the tunnel and blockage of air flow by the truck. In addition, heavy particulate loading concentrations observed during truck loadings made the operation of hot wire anemometers difficult. Furthermore, the shortness of the loading period (~ 5 min) did not provide sufficient time to properly perform an accurate velocity determination.

For each source test run, the sampling vehicle was moved into position approximately 5 m downwind of the loading bay enclosure immediately after the truck which was to be loaded entered the area beneath the silos. Upon initiation of the loading process, all instruments were activated and samples collected until the truck was fully loaded (5 min) at which time the instruments were shut off and the sampling vehicle moved out of position to make way for the exiting truck. After loading was completed, each truck was cleaned with compressed air prior to leaving the plant. This phase of the operation was not included in the samples collected. The loading of one truck was tested during each run.

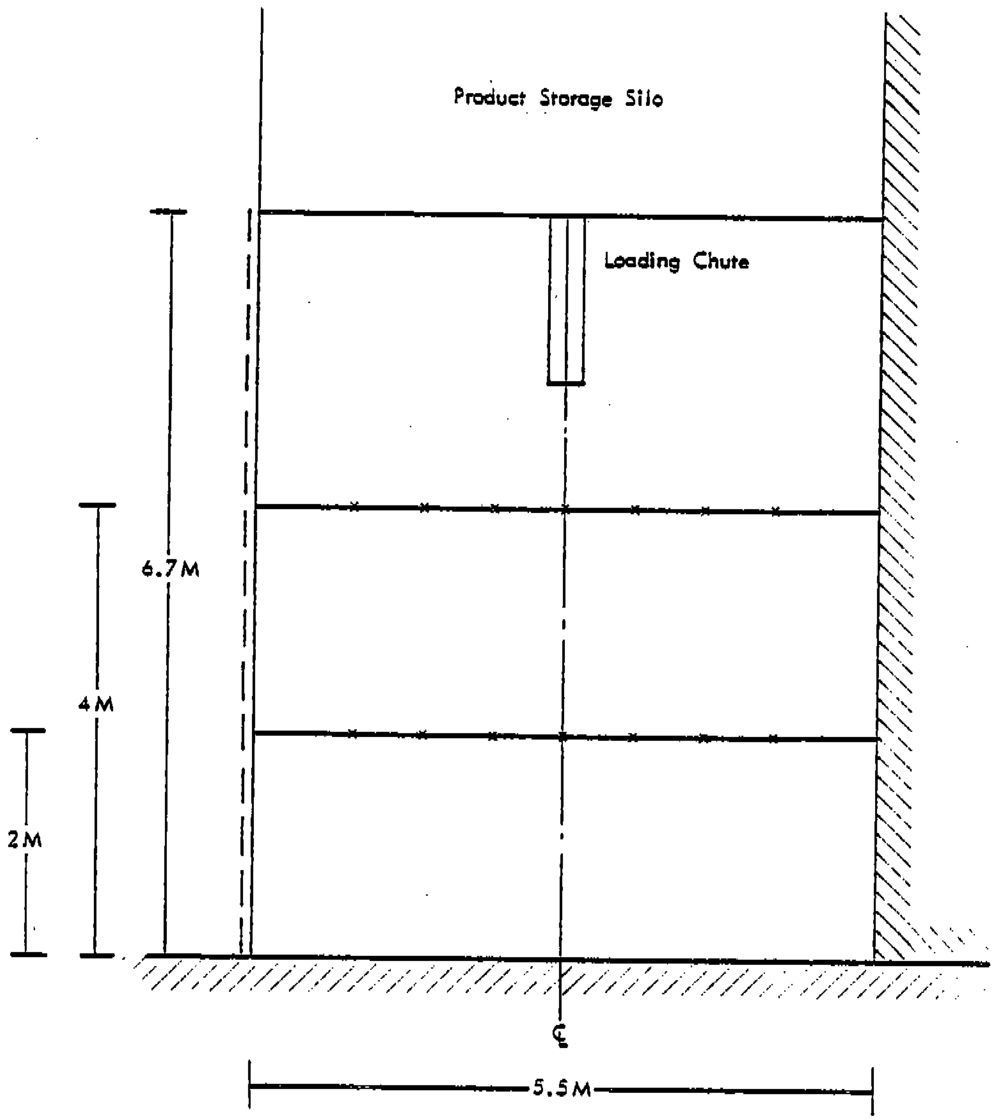


Figure 2-20. Wind velocity traverse point locations.

For the purpose of this program, the definition of product loading is:

1. Testing was conducted only during the actual physical loading of material into a truck.

2. The entrance and exiting of the trucks from the loading area was not considered as part of the truck loading process. This could not be tested, since the sampling equipment had to be moved prior to the entrance of each truck to the loading area.

3. Movement of trucks during loading was considered part of the process.

4. Cleaning of the trucks after each test with pressurized air was not tested, since this was immediately followed by truck exiting.

5. Results are reported for open-bed and closed trucks. The choice of lime or limestone tested, as well as the type of truck associated with each, was based on plant activity during the test period.

All of the Hi-Vols mentioned above were operated at a constant air flow rate of 45 scfm, those fitted with SSIs at 40 scfm, and those with impactors and cyclones at 20 scfm. Calibration of the Hi-Vols was conducted prior to testing by measuring the ΔP across a standardized calibration orifice. Flows were kept constant within ± 5% by using a Sierra Hi-Vol flow controller. Duplicate field blanks were obtained for each type of sampling instrument by preparing the equipment for testing, transporting it to the test site, and immediately performing a routine sample recovery. The blank values were averaged and subsequently used during data analysis to obtain a net catch for each sample collected.

The sampling equipment used during these tests were operated under conditions for which they have neither been designed nor tested. Ambient-type samplers were used in areas where particulate concentrations exceeded 500,000 $\mu g/m^3$, which may have caused a potential undefined error in all measurements made. In addition, test site conditions were not optimum for sample collection. Plume boundaries could not accurately be defined due to irregularities in the walls of the truck loading area, the turbulent wind conditions in the tunnel, and zero visibility during testing. The test sites were heavily contaminated with lime and limestone residuals from previous loadings, which ranged from 15 to 60 cm (6 in. to 2 ft) deep throughout the tunnel floor. This may have caused some reentrainment of residual material. A matrix of the overall fugitive sampling program showing the types of measurements made during each test run is provided in Table 2-2.

2.3.2 Recovery Procedures for Ducted Sources

Mass train sample recovery was performed using EPA Method 5 guidelines. For each Andersen Mark III test there were 10, 76 mm (3-in.) square aluminum foil liners labeled PRES (preseparator), 0 to 7, and F (final). Samples were placed in the foil as follows:

TABLE 2-2. SAMPLE MATRIX FOR FUGITIVE EMISSION TESTING

Run No.	Type of material loaded: Agricultural limestone	Type of material loaded: Glass lime	Bulk material sampled	Type of truck tested: Open-bed	Type of truck tested: Closed (tanker-type)	Background samples taken following run	Preliminary velocity traverse performed prior to run	No. of individual source (downwind) samples collected[a]: TP	TSP	IP	FP[b]	PSD
S-1	X		X	X			X	2	1	2	2	2
S-2	X				X			2	1	2	2	2
S-3	X				X		X	2	1	2	2	2
S-4	X			X		X		2	1	2	2	2
S-5		X	X		X	X	X	2	1	2	2	2

a TP = Total particulate matter (< ~ 300 μm)
TSP = Total suspended particulate (< 30 μm)
IP = Inhalable particulate (< 15 μm)
FP = Fine particulate (< 2.5 μm)
PSD = Particle size distribution (11.4 to 0.74 μm)

b By interpolation of cyclone/impactor data.

PRES liner: Visible particulate was brushed from the nozzle, cyclone body, and cyclone catch cup onto the foil. This was followed by an acetone rinse which was collected on a 64 mm (2-1/2 in.) glass fiber filter and added to the foil.

No. 0 liner: Brushings from the cyclone outlet tube and the impactor inlet cone were placed in this foil along with the stage 0 impaction substrate.

Nos. 1 to 7 and F liners: Impaction substrate Nos. 1 through 7 and the final filter were placed in the appropriate foils.

For each Brink test seven tared 5-ml polystyrene microbeakers were labeled CYC (cyclone preseparator), 1 to 5, or F (final filter). Samples were placed in the beakers as follows:

CYC beaker: Particulate from the nozzle, cyclone body, cyclone catch cup, and nozzle connecting tubes were placed in this container.

Nos. 1 to 5 beaker: Particulate from the nozzle walls and spring were added to their respective beakers along with the aluminum foil impaction plates and retainer rings.

F beaker: The final filter was placed in this beaker.

2.3.3 Analysis Procedures

2.3.3.1 Ducted Sources--

Mass train sample analysis was performed using EPA Method 5 guidelines. A Sartorius Model 2404 electrobalance was used for tare and final weighing of sample filters.

The Andersen Mark III and Brink Model B aluminum foil liners and microbeakers containing the samples were vacuum desiccated approximately 71 to 74 cm (28 to 29 in.) of Hg for 1 hr and weighed to the nearest 0.01 mg on a Cahn/Ventron Model 27 electrobalance. The samples were then vacuum desiccated for 15 min and weighed again. If the two weighings did not agree within 0.05 mg, the process was repeated. This procedure was used for tare and final weighing of Andersen Mark III and Brink Model B filters and containers.

2.3.3.2 Unducted Sources--

Filters - Particulate samples were collected on 20 x 27 cm (8- x 10-in.) type AE glass fiber filters and 10 x 12.5 cm (4- x 5-in.) type AE glass fiber collection substrate. Wash samples were collected on 47-mm glass fiber filters. Glass fiber filters were numbered and examined for defects, then equilibrated for 24 hr at 21°C (70°F) and less than 50% relative humidity in a special weighing room maintained by MRI for this purpose. The filters were weighed to the nearest 0.1 mg. To assure accuracy, the balance was checked at frequent intervals with type S standard weights. The filters remained in the same controlled environment for another 24 hr after which a second analyst reweighed 100% of them as a precision check. The filters in all sets whose check weights varied by more than 3.0 mg from initial weights were reweighed. After weighing, the filters were packed in flat folders for shipment to the field.

When exposed filters were returned from the field, they were equilibrated under the same conditions as the initial weighing, i.e., they were weighed and checked in the same manner.

Field measurements of atmospheric aerosols using cascade impactors have shown that the nature of the impaction surface has a significant effect on the observed size distribution due to particles bouncing off dry impaction surfaces and being collected on either subsequent stages or the backup filter. To minimize the problem, MRI developed a treatment procedure for glass fiber filter cascade impactor substrates that produces a sticky impactor surface. A grease solution was prepared by dissolving 100 g of stopcock grease in 1 liter of reagent grade toluene. A low pressure paint-type spray gun was used to apply this solution only to the filter substrates impactor surface. The borders and back of the filters were covered, thereby preventing any grease from being applied there. These filters were then handled, stored, and transported by means of specially designed wood and cardboard frames that only touched the filter's back and border, thus preventing any inadvertent contact with the greased surface. After application of grease, the filters were equilibrated and weighed using standard MRI procedures.

Cyclone catches - Laboratory grade deionized distilled water was used in the field laboratory to recover samples from cyclone preseparators. Each unit was thoroughly washed five to eight times. A wash consisted of spraying 15 to 25 ml of water into the unit, swirling the unit around, and then quantitatively transferring the wash water into a sample jar. After the last wash, the sample jar (holding 300 ± 100 ml of wash water) was sealed and packed for shipping to MRI for sample recovery.

At the MRI laboratory, the entire wash solution was passed through a 47-mm Buchner-type funnel holding a type AP glass fiber filter under suction. The sample jar was then rinsed twice with 10 to 20 ml of deionized water. This water was passed through the Buchner funnel ensuring collection of all suspended material on the 47-mm filter. The tared filter was then dried in an oven at 100°C for 24 hr. After drying, the filters were conditioned in a controlled temperature (24 ± 2°C) and humidity (45 ± 5%) environment for 24 hr.

All filters, both tared and exposed, were weighed to 1 μg with a 100% audit of tared and 10% audit of exposed filters. Blank values were determined by washing "clean" (no sample collected) cyclones in the field and following the above procedures.

Aggregate samples - Samples of aggregate materials were collected in 2- to 2.5-kg quantities for analysis of moisture and silt content. The samples were stored briefly in airtight plastic bags, then reduced with a sample splitter (riffle) to about 1 kg (800 to 1,600 g).

Samples were placed in plastic containers and sealed for shipment to MRI laboratories for determination of silt contents. This was done by mechanical dry sieving using ASTM Method C-429-65, with the portion passing a 200-mesh screen constituting the silt portion. The nest of sieves was placed on a conventional shaker for 30 to 55 min until a constant weight was obtained. The material passing the 200-mesh screen was also analyzed to determine the density of potentially suspendable particles.

SECTION 3.0

SUMMARY OF RESULTS

3.1 DUCTED SOURCES

In this section, test results are summarized in both tabular and graphic forms. The computer printouts of the mass and particle sizing from which the results have been summarized are presented in Appendices A and J.

3.1.1 Acceptance Criteria

Only data that have met specific acceptance criteria are summarized in this section for ducted sources. These criteria, as obtained from the "Procedures Manual for Inhalable Particulate Samples Operation" (SORI-EAS-79-761, 4181-37), prepared by Southern Research Institute for the EPA, are:

1. Each total mass and particle size run must be within ± 20% of isokinetic.

2. The particulate grain loading from the total mass train and the IP train must be within ± 50%.

Four total mass and four particle sizing tests consisting of four runs each (one run each per quadrant), were conducted at each test site. The average particulate grain loading for each set of four runs was determined to obtain an average for each of the four tests. Any measurement of the total mass which differs from the mean by more than 50% should be considered suspect. The suspect value should be compared with that found by the particle size train used at the same point. If these values disagree by less than 50%, the deviations probably indicate strong stratification of the particulate and all of the data should be retained.

Tables 3-1 through 3-3 summarize the data used for the acceptance criteria for the baghouse, ESP, and the dust collector, respectively.

3.1.2 Emission Factor

The emission factors for a typical ducted source were calculated for 15, 10, and 2.5 μm as follows:

1. An emission factor was calculated for each run of each test using the data collected with the modified Method 5 train and standard Method 5 calculations (Appendix B). IP emission factors were calculated using this factor rather than the particle sizing emission factor. The emission factor is presented in pounds per hour and pounds per ton of product. The product tonnage was provided by the plant.

TABLE 3-1. SUMMARY OF BAGHOUSE INLET AND OUTLET TEST ACCEPTANCE CRITERIA RESULTS

Test No.	Run no.	Test date	% Isokinetic	Particulate loading gr/dscf[a]	$\bar{x}$[b]	% From $\bar{x}$
Inlet mass train						
1	1	12-4-80	105.8	4.8426		
	2	12-3-80	104.0	4.7305		
	3	12-2-80	111.2	5.5895	4.9871	13
	4	12-3-80	108.8	4.7859		
2	1-(2)	1-9-81	107.0	3.6406		
	2	12-5-80	107.3	4.8117		
	3	12-5-80	107.5	4.8380	4.4047	0
	4	10-25-80	107.8	4.3286		
3	1	1-7-81	107.1	3.8216		
	2	12-6-80	106.4	5.4556		
	3	10-25-80	107.5	4.6595	4.3167	2
	4-(2)	1-8-81	116.4	3.3301		
4	1	1-9-81	104.5	3.4494		
	2	1-8-81	100.8	3.1045		
	3	1-7-81	105.7	4.1268	3.8971	11
	4	10-24-80	105.6	4.9077		
					$\bar{x}$ = 4.4014	
Outlet mass train						
1	1	12-4-80	103.6	0.0014		
	2	12-3-80	103.8	0.0056		
	3-(2)	1-9-81	102.1	0.0031	0.0042	27
	4	12-2-80	92.7	0.0066		
2	1	12-4-80	94.0	0.0026		
	2	12-5-80	102.0	0.0022		
	3	10-25-80	101.1	0.0029	0.0029	12
	4	12-5-80	100.7	0.0037		
3	1	1-7-81	102.7	0.0025		
	2	12-6-80	102.0	0.0049		
	3-(2)	1-8-81	103.6	0.0028	0.0032	3
	4	10-25-80	105.1	0.0026		
4	1	1-7-81	102.0	0.0016		
	2	1-8-81	100.8	0.0044		
	3	10-24-80	103.6	0.0019	0.0030	9
	4-(2)	1-9-81	102.2	0.0040		
					$\bar{x}$ = 0.0033	

Test no.	Run no.	Test date	% Isokinetic	Particulate loading gr/dscf	$\bar{x}$	% From $\bar{x}$
Inlet IP train (Brink cascade impactor with cyclone preseparator)						
1	1	12-4-80	119.5	4.20289		
	2	12-3-80	103.1	3.61812		
	3	12-2-80	101.9	5.05126	4.14643	2
	4	12-3-80	112.1	3.71344		
2	1	12-4-80	104.1	3.92627		
	2-(2)	1-9-81	98.1	4.02420		
	3-(2)	10-25-80	110.5	4.34651	4.38477	8
	4	12-5-80	98.2	5.24208		
3	1	1-7-81	119.8	2.30483		
	2	12-6-80	117.2	3.25152		
	3-(2)	1-7-81	92.1	4.63475	3.78436	7
	4	10-25-80	109.3	4.94635		
4	1	1-9-81	108.4	3.65110		
	2	1-8-81	105.2	3.68720		
	3	10-24-80	108.2	5.34420	3.95159	3
	4-(2)	1-8-81	116.0	3.12387		
					$\bar{x}$ = 4.06679	
Outlet IP train (Andersen Mark III impactor with 15-μ preseparator)						
1	1	12-2-80	118.4	0.00135		
	2	12-3-80	106.5	0.00037		
	3-(2)	1-9-81	109.7	0.00259	0.00125	42
	4	12-4-80	119.7	0.00068		
2	1	12-5-80	111.2	0.00128		
	2-(2)	10-25-80	98.7	0.00311		
	3	12-5-80	110.4	0.00463	0.00252	18
	4	12-4-80	118.4	0.00107		
3	1	10-25-80	103.7	0.00303		
	2-(2)	1-8-81	103.1	0.00166	0.00186	13
	3[c]	12-6-80	109.3	0.03655		
	4	1-7-81	115.9	0.00088		
4	1-(2)	1-8-81	111.2	0.00225		
	2	10-24-80	96.0	0.00413		
	3	1-7-81	106.2	0.00343	0.00292	36
	4	1-9-81	114.3	0.00187		
					$\bar{x}$ = 0.00214	

[a] gr/dscf = grains per dry standard cubic foot.

[b] $\bar{x}$ = mean.

[c] The particulate loading data from this run were considered suspect. The data were not used to compute an average particulate loading for this test.

TABLE 3-2. SUMMARY OF ESP INLET AND OUTLET TEST ACCEPTANCE CRITERIA RESULTS

Test No.	Run no.	Test date	% Isokinetic	Particulate loading gr/dscf[a]	$\bar{x}$[b]	% From $\bar{x}$
Inlet mass train						
1	1	10-30-80	104.6	15.4772		
	2	10-30-80	103.7	13.5695		
	3-(2)	10-28-80	98.7	19.9986	19.4710	10
	4-(2)	10-28-80	93.3	28.8387		
2	1	10-30-80	103.1	13.6711		
	2	10-31-80	98.8	15.8968		
	3	10-28-80	103.6	23.1656	17.1287	3
	4	10-29-80	106.1	15.7811		
3	1	10-31-80	105.9	13.6749		
	2	11-3-80	102.9	18.2835		
	3	10-29-80	102.3	21.7704	17.5775	1
	4	10-29-80	104.1	16.5811		
4	1-(2)	11-5-80	99.8	16.7962		
	2	11-4-80	104.6	16.6820		
	3	10-29-80	103.3	13.6188	16.7638	5
	4-(2)	12-8-80	102.8	19.9580		
					$\bar{x}$ = 17.7353	
Outlet mass train						
1	1-(2)	10-28-80	102.0	0.2483		
	2-(2)	10-28-80	105.6	0.2797		
	3	10-30-80	100.9	0.5761	0.3679	14
	4-(2)	12-8-80	102.9	0.3675		
2	1	10-28-80	103.1	0.2796		
	2	10-29-80	103.7	0.3718		
	3	10-30-80	107.2	0.4635	0.4734	11
	4	10-31-80	103.1	0.7786		
3	1	10-29-80	106.4	0.3868		
	2	10-29-80	103.2	0.3817		
	3	10-31-80	103.4	0.4167	0.4098	4
	4	11-3-80	105.3	0.4540		
4	1	10-29-80	105.5	0.4838		
	2	10-30-80	103.6	0.6120		
	3-(2)	11-5-80	104.5	0.4252	0.4623	8
	4	11-4-80	102.9	0.3281		
					$\bar{x}$ = 0.4282	

Test no.	Run no.	Test date	% Isokinetic	Particulate loading gr/dscf	$\bar{x}$	% From $\bar{x}$
Inlet IP train (Brink cascade impactor with cyclone preseparator)						
1	1	10-30-80	120.5	18.14265		
	2	10-30-80	112.3	15.75589		
	3-(2)	10-28-80	114.2	24.24172	21.86227	1
	4-(2)	10-28-80	90.4	29.30883		
2	1	10-31-80	109.5	12.63394		
	2	10-30-80	119.5	16.42790		
	3	10-29-80	108.4	20.90163	20.67356	6
	4	10-28-80	95.3	32.73077		
3	1	11-3-80	102.5	25.86079		
	2	10-31-80	113.7	17.95521		
	3	10-29-80	112.8	18.77378	22.46319	2
	4	10-29-80	110.9	27.26298		
4	1	11-4-80	100.2	21.06954		
	2-(2)	11-5-80	107.7	23.54905		
	3	10-30-80	113.5	21.25740	22.92122	4
	4	10-29-80	110.8	25.80887		
					$\bar{x}$ = 21.98006	
Outlet IP train (Andersen Mark III impactor with 15-μ preseparator)						
1	1-(2)	10-28-80	105.5	0.53276		
	2-(2)	10-28-80	100.6	0.42642		
	3	10-30-80	98.0	0.47715	0.42889	16
	4	10-30-80	95.6	0.27921		
2	1	10-29-80	101.3	0.51969		
	2	10-28-80	101.9	0.43747		
	3	10-31-80	104.8	1.18829	0.63548	25
	4	10-30-80	82.6	0.39646		
3	1	10-29-80	99.4	0.59221		
	2	10-29-80	98.2	0.36175		
	3	11-3-80	100.0	0.47769	0.44370	13
	4	10-31-80	103.5	0.34316		
4	1	10-30-80	94.2	0.71852		
	2	10-29-80	97.7	0.34191		
	3	11-4-80	98.0	0.74824	0.52945	4
	4-(2)	12-8-80	98.1	0.30911		
					$\bar{x}$ = 0.50938	

[a] gr/dscf = grains per dry standard cubic foot.

[b] $\bar{x}$ = mean.

TABLE 3-3. SUMMARY OF DUST COLLECTOR TEST ACCEPTANCE CRITERIA RESULTS

Test No.	Run no.	Test date	% Isokinetic	Particulate loading gr/dscf[a]	$\bar{x}$[b]	% From $\bar{x}$	Test no.	Run no.	Test date	% Isokinetic	Particulate loading gr/dscf	$\bar{x}$	% From $\bar{x}$
Mass train							IP train (Andersen Mark III impactor with 15-μ preseparator)						
1	1	12-3-80	102.1	1.0575			1	1	12-3-80	88.3	1.04607		
	2	12-2-80	104.4	0.6519				2	12-3-80	81.9	0.69250		
	3	12-3-80	100.0	0.5835	0.8035	17		3	12-3-80	98.9	0.22505	0.71798	7
	4-(2)	1-9-81	101.8	0.9211				4-(3)	1-9-81	105.1	0.90831		
2	1	12-5-80	102.1	1.3234			2	1	12-5-80	89.0	1.17279		
	2	12-5-80	102.8	0.9306				2	12-5-80	91.0	0.39786		
	3	12-5-80	102.1	1.0120	1.0199	5		3	12-5-80	84.7	0.90049	0.63629	18
	4	12-4-80	102.9	0.8134				4	12-4-80	81.7	0.07401		
3	1	12-6-80	102.0	1.5973			3	1	12-6-80	102.6	1.01447		
	2	1-6-81	100.2	0.9379				2	1-6-81	87.1	1.18657		
	3	12-6-80	100.8	1.8515	1.3379	38		3	12-6-80	105.7	0.70310	0.97140	25
	4	1-7-81	97.8	0.9647				4-(2)	1-7-81	85.0	0.98146		
4	1	1-9-81	104.5	0.8245			4	1	1-9-81	99.8	0.91699		
	2	1-7-81	101.3	0.9653				2	1-7-81	105.7	0.74601		
	3	1-8-81	101.7	0.3364	0.7114	27		3	1-8-81	89.6	0.69231	0.77573	0
	4	1-8-81	100.5	0.7194				4	1-8-81	81.9	0.74761		
					$\bar{x}$ = 0.9682							$\bar{x}$ = 0.77535	

[a] gr/dscf = grains per dry standard cubic foot

[b] $\bar{x}$ = mean.

The calculation for a single run is based on the assumption that the average stack velocity during the run is the same as the stack velocity measured at the sampling point of the quadrant being sampled. Also, since the series of runs required for a test were collected over more than 1 day, it was assumed that operating conditions did not vary appreciably over the sample periods.

2. The mass collected on each stage of the particle size trains was determined, and the cumulative percentage of the total mass for each stage was calculated. The effective cut size (D_{50}) for each stage was determined. D_{50} is the characteristic particle size which theoretically has a 50% probability of striking the collection surface. The computer printouts in Appendix J indicate cumulative percent greater than the stated D_{50}, whereas the graphs and tables indicate D_{50} as cumulative percent less than stated size. The equations for the Anderson and Brink calculations are given in Appendix B.

It should be noted that, under certain conditions, loading on some stages may be quite low. In a few cases, application of the blank correction factor led to negative weights. These were recorded as zero in the computer. In addition, certain flow conditions caused the D_{50} cutpoint of the cyclone preseparator to have a smaller value than the D_{50} for the zero stage of the Andersen Mark III impactor. Whenever this condition occurred, the mass from the zero stage was added to the mass on stage one of the impactor, and the zero stage was eliminated from the calculation.

3. The cumulative percentages for each stage were then applied to the total mass emission factor (calculated from the modified Method 5 train) to obtain an emission factor for each stage of the particle size device.

4. A spline equation was used to fit the data and to extrapolate, where required, to the desired cutpoints. A program for handling impactor data using a spline fit has been developed by J. W. Johnson et al., ("A Computer Based Cascade Impactor Data Reduction System," EPA-600/7-78-042, March 1978). An improvement to the above program has been recently completed and was used to determine emission factors. Emission factors were calculated for 2.5, 10, and 15 μm. The upper limit of particle diameter was set at 50 μm for the calculation using the spline fit.

5. Graphs indicating the computer generated lines and calculated cutpoints were constructed from the averages of the four runs from each test. A graph of the average of the four tests from each test location was also constructed. Also shown on the graph is the D_{50} versus cumulative percent less than the stated size.

Extrapolations are denoted on the graph by a broken line. It should be noted that the Brink impactor results have been extrapolated from a maximum cyclone cutpoint of 7 to 15 μm, a process which has the potential of leading to substantial errors.

3.1.3 Presentation of Data

Summary tables have been presented for each emission source as follows:

1. Impactor Particle Size Test Sampling Data--Mass (mg) weights, D_{50} (effective cut size), and the cumulative percent less than the stated size for each stage are presented in this table.

2. Emission Factors Based on Total Mass and Impactor Size Distribution--This table presents the total emission factor, a ratio of total mass concentration to total particle size concentration based on grains per dry standard cubic foot, and the emission factors for 15, 10, and 2.5 µm.

A listing of tables for each source is noted in the next section.

Graphs for each source have been included. These graphs include particle size (D_{50}) versus cumulative percent less than, and emission factors for the static sizes. Each test and an average of the tests for each sampling site are represented. A list of graphs for each duct is presented in Subsection 3.1.4.

3.1.4 Calculation Procedures for each Ducted Source

Several differences in the calculation procedures were used for each of the ducted sources since each was a unique source.

3.1.4.1 Baghouse--

The baghouse as shown in Figures 2-2, 2-3, 2-4, and 2-5 has five outlets of which only one was tested. All five cells were assumed to have equivalent flow rates and particle size distribution. The results of the single runs were multiplied by a factor of 5 to obtain the total emissions for the entire baghouse as indicated in Table 3-5.

Emissions factors from the inlet are less than would be expected due to the cyclone preceding the sampling duct. The cyclone is shown in Figures 2-2 and 2-3.

Stage loading in some cases were quite low for the outlet. In many cases, negative weights were found. Also, the situation where the zero stage had a larger cutpoint than the preseparator was encountered. These two problems were addressed in Subsection 3.1.2.

Tables 3-4, and 3-5 summarize the baghouse data and Figures 3-1 through 3-10 show graphically the results.

3.1.4.2 Electrostatic Preseparator--

The ESP tested was only one of three servicing the second kiln (see Figures 2-6, 2-7, and 2-8). An emission factor for the kiln was calculated assuming particle size and distribution were equivalent in all three ESP's. A velocity traverse was performed at the inlet of each ESP and the common outlet stack of all three (Appendix I). The ESP being sampled handled 26% of the total flow from the kiln; therefore, a multiplication factor of 3.85 was used to adjust the emission factors for total emissions from the kiln.

TABLE 3-4. IMPACTOR PARTICLE SIZE TEST SAMPLING DATA BAGHOUSE INLET AND OUTLET

Run No.	7 µm cyclone Mass (mg)[a]	D_{50} size (µm)[b]	Cum. % less than[c]	Stage 1 Mass (mg)	D_{50} size (µm)	Cum. % less than	Stage 2 Mass (mg)	D_{50} size (µm)	Cum. % less than	Stage 3 Mass (mg)	D_{50} size (µm)	Cum. % less than	Stage 4 Mass (mg)	D size (µm)	Cum. % less than
Bag-1-1-1	58.77	7.00	28.56	1.06	3.33	27.28	11.06	1.95	13.83	6.92	1.31	5.42	1.44	0.67	3.67
Bag-1-1-2	28.40	7.00	34.00	2.16	4.38	28.51	8.45	2.58	8.80	2.35	1.76	3.42	1.03	0.92	1.02
Bag-1-1-3	49.30	7.00	31.52	3.16	3.81	27.13	15.60	2.23	5.46	2.77	1.51	1.61	1.16	0.77	0.00
Bag-1-1-4	34.32	7.00	25.34	6.59	4.20	11.01	4.16	2.47	1.96	0.90	1.68	0.00	0.00	0.87	0.00
Bag-1-2-1	46.40	7.00	34.19	3.48	3.51	29.26	15.97	2.05	6.61	3.43	1.39	1.74	0.71	0.71	0.74
Bag-1-2-2(2)[d]	0.00	7.00	100.00	3.27	4.47	92.82	4.71	2.64	82.47	4.37	1.80	72.88	1.31	0.94	70.00
Bag-1-2-3(2)	50.57	7.00	29.81	11.28	3.57	14.15	6.47	2.09	5.17	1.98	1.41	2.41	0.90	0.72	1.16
Bag-1-2-4	38.16	7.00	33.41	2.39	4.48	29.24	8.35	2.64	14.67	7.44	1.80	1.69	0.67	0.94	0.52
Bag-1-3-1	33.47	7.00	33.93	7.99	3.16	18.15	5.82	1.85	6.66	1.91	1.25	2.88	0.83	0.63	1.23
Bag-1-3-2	25.70	7.00	43.17	1.81	3.93	39.16	9.04	2.31	19.17	7.28	1.56	3.07	0.88	0.81	1.13
Bag-1-3-3(2)	40.30	7.00	34.78	3.57	4.03	28.99	13.53	2.37	7.09	2.61	1.61	2.86	0.90	0.83	1.40
Bag-1-3-4	42.57	7.00	28.10	7.25	4.25	15.85	5.87	2.50	5.93	2.10	1.70	2.38	0.47	0.88	1.58
Bag-1-4-1	50.00	7.00	25.88	8.50	3.45	13.28	5.15	2.02	5.64	2.00	1.37	2.67	0.77	0.70	1.52
Bag-1-4-2	30.67	7.00	35.03	2.20	4.24	30.36	9.19	2.49	10.89	2.66	1.69	5.25	1.67	0.88	1.70
Bag-1-4-3	70.11	7.00	28.81	12.41	3.61	16.20	11.18	2.11	4.85	2.92	1.43	1.88	0.94	0.73	0.92
Bag-1-4-4(2)	23.10	7.00	33.35	4.39	4.35	20.67	4.60	2.56	7.39	1.98	1.74	1.67	0.50	0.91	0.21

Run No.	Stage 4 Mass (mg)	D_{50} size (µm)	Cum. % less than	Stage 5 Mass (mg)	D_{50} size (µm)	Cum. % less than	Filter Mass (mg)	D_{50} size (µm)	Total mass (mg)
Bag-1-1-1	1.44	0.67	3.67	3.02	0.40	0.00	0.00	< 0.40	82.27
Bag-1-1-2	1.03	0.92	1.02	0.44	0.58	0.00	0.00	< 0.58	
Bag-1-1-3	1.16	0.77	0.00	0.00	0.47	0.00	0.00	< 0.47	
Bag-1-1-4	0.00	0.87	0.00	0.00	0.54	0.00	0.00	< 0.54	
Bag-1-2-1	0.71	0.71	0.74	0.52	0.42	0.00	0.00	< 0.42	
Bag-1-1-2(2)[d]	1.31	0.94	70.00	0.42	0.60	69.07	31.48	< 0.60	
Bag-1-2-3(2)	0.90	0.72	1.16	0.13	0.44	0.98	0.71	< 0.44	
Bag-1-2-4	0.67	0.94	0.52	0.29	0.59	0.02	0.01	< 0.59	
Bag-1-3-1	0.83	0.63	1.23	0.62	0.38	0.00	0.00	< 0.38	
Bag-1-3-2	0.88	0.81	1.13	0.45	0.50	0.13	0.06	< 0.50	
Bag-1-3-3(2)	0.90	0.83	1.40	0.86	0.52	0.00	0.00	< 0.52	
Bag-1-3-4	0.47	0.88	1.58	0.19	0.55	1.26	0.75	< 0.55	
Bag-1-4-1	0.77	0.70	1.52	0.61	0.42	0.61	0.41	< 0.42	
Bag-1-4-2	1.67	0.88	1.70	0.51	0.55	0.61	0.29	< 0.55	
Bag-1-4-3	0.94	0.73	0.92	0.09	0.45	0.83	0.82	< 0.45	
Bag-1-4-4(2)	0.50	0.91	0.21	0.07	0.57	0.00	0.00	< 0.57	

(continued)

TABLE 3-4. (continued)

Run No.	15 µm cyclone Mass (mg)[a]	15 µm cyclone D_{50} size (µm)[b]	15 µm cyclone Cum. % less than[c]	Stage 0 Mass (mg)	Stage 0 D_{50} size (µm)	Stage 0 Cum. % less than	Stage 1 Mass (mg)	Stage 1 D_{50} size (µm)	Stage 1 Cum. % less than	Stage 2 Mass (mg)	Stage 2 D_{50} size (µm)	Stage 2 Cum. % less than	Stage 3 Mass (mg)	Stage 3 D_{50} size (µm)	Stage 3 Cum. % less than
Bag-0-1-1	4.47	15.16	20.29	0.00	15.16	20.29	0.06	9.45	19.15	0.00	6.40	19.15	0.12	4.35	16.95
Bag-0-1-2	0.19	16.06	86.08	0.20	15.94	71.45	0.00	9.94	71.45	0.00	6.73	71.45	0.23	4.57	54.66
Bag-0-1-3(2)	4.44	15.80	55.36	0.21	15.80	53.24	0.98	9.85	43.37	0.88	6.67	34.51	0.87	4.54	25.75
Bag-0-1-4	0.00	15.33	100.00	0.32	15.33	88.23	0.35	9.56	75.36	0.38	6.47	61.41	0.33	4.40	49.27
Bag-0-2-1	1.07	15.65	78.53	0.52	15.65	68.05	0.25	9.76	62.98	0.39	6.61	55.10	0.38	4.49	47.43
Bag-0-2-2(2)	0.00	16.34	100.00	1.28	16.24	88.28	1.13	10.13	77.94	1.15	6.86	67.41	1.31	4.66	55.42
Bag-0-2-3	14.89	15.31	20.07	0.50	15.31	17.37	0.41	9.55	15.15	0.43	6.46	12.82	0.53	4.39	9.96
Bag-0-2-4	0.00	15.25	100.00	0.71	15.25	83.59	0.50	9.50	72.01	0.38	6.43	63.19	0.49	4.37	51.84
Bag-0-3-1	0.38	16.13	96.54	1.15	16.08	85.94	0.87	10.03	77.93	1.33	6.79	65.67	1.25	4.61	54.15
Bag-0-3-2(2)	0.05	16.18	99.19	0.00	16.18	99.19	0.00	10.09	99.19	0.00	6.84	99.19	1.05	4.65	82.05
Bag-0-3-3	126.01	15.49	12.02	0.00	15.49	12.02	0.00	9.66	12.02	0.00	6.54	12.02	2.03	4.44	10.60
Bag-0-3-4	0.96	15.49	72.14	0.00	15.49	72.14	0.00	9.65	72.14	0.13	6.53	68.33	0.42	4.44	56.11
Bag-0-4-1(2)	1.33	15.59	84.95	0.40	15.59	80.41	0.27	9.72	77.34	0.69	6.58	69.52	0.99	4.47	58.30
Bag-0-4-2	0.08	16.87	99.39	2.13	16.61	84.08	1.65	10.36	72.21	1.46	7.01	61.72	1.55	4.77	50.50
Bag-0-4-3	1.65	15.54	87.68	1.02	15.54	80.05	0.76	9.69	74.37	1.14	6.56	65.84	1.01	4.46	58.29
Bag-0-4-4	1.65	15.84	76.82	0.66	15.84	67.54	0.20	9.88	64.71	0.55	6.69	56.97	0.93	4.55	43.89

Run No.	Stage 4 Mass (mg)	Stage 4 D_{50} size (µm)	Stage 4 Cum. % less than	Stage 5 Mass (mg)	Stage 5 D_{50} size (µm)	Stage 5 Cum. % less than	Stage 6 Mass (mg)	Stage 6 D_{50} size (µm)	Stage 6 Cum. % less than	Stage 7 Mass (mg)	Stage 7 D_{50} size (µm)	Stage 7 Cum. % less than	Filter Mass (mg)	Filter D_{50} size (µm)
Bag-0-1-1	0.36	2.78	10.47	0.44	1.37	2.56	0.14	0.83	0.00	0.00	0.55	0.00	0.00	< 0.55
Bag-0-1-2	0.20	2.93	40.04	0.47	1.45	6.01	0.08	0.88	0.00	0.00	0.59	0.00	0.00	< 0.59
Bag-0-1-3(2)	0.87	2.90	16.99	1.23	1.44	4.62	0.27	0.87	1.89	0.04	0.58	1.47	0.15	< 0.58
Bag-0-1-4	0.37	2.81	35.68	0.68	1.39	10.82	0.18	0.84	4.14	0.11	0.56	0.00	0.00	< 0.56
Bag-0-2-1	0.72	2.87	32.95	0.83	1.42	16.28	0.49	0.86	6.40	0.10	0.57	4.33	0.22	< 0.57
Bag-0-2-2(2)	1.75	2.98	39.41	1.76	1.48	23.30	1.23	0.90	12.04	0.90	0.60	3.80	0.42	< 0.60
Bag-0-2-3	0.53	2.81	7.09	0.74	1.39	3.10	0.35	0.84	1.20	0.22	0.56	0.00	0.00	< 0.56
Bag-0-2-4	0.68	2.79	36.12	0.74	1.38	19.02	0.47	0.83	8.13	0.35	0.55	0.00	0.00	< 0.55
Bag-0-3-1	1.71	2.95	38.39	1.68	1.46	22.90	1.12	0.89	12.58	0.91	0.59	4.19	0.45	< 0.59
Bag-0-3-2(2)	1.92	2.98	50.74	2.22	1.48	14.54	0.57	0.90	5.23	0.32	0.61	0.00	0.00	< 0.61
Bag-0-3-3	3.99	2.84	7.81	7.71	1.40	2.43	3.14	0.85	0.23	0.33	0.57	0.00	0.00	< 0.57
Bag-0-3-4	0.65	2.84	37.21	1.16	1.40	3.52	0.12	0.85	0.00	0.00	0.56	0.00	0.00	< 0.56
Bag-0-4-1(2)	1.34	2.86	43.12	1.67	1.41	24.21	0.49	0.86	18.65	0.15	0.57	16.94	1.50	< 0.57
Bag-0-4-2	1.89	3.05	36.99	1.85	1.51	23.69	1.48	0.92	13.05	1.09	0.61	5.21	0.73	< 0.61
Bag-0-4-3	1.57	2.85	46.56	2.57	1.41	27.35	2.00	0.85	12.41	1.66	0.57	0.00	0.00	< 0.57
Bag-0-4-4	1.18	2.91	27.30	1.46	1.44	6.78	0.41	0.88	1.00	0.07	0.59	0.00	0.00	< 0.59

[a] mg = milligrams

[b] µm = micrometers

[c] Cum. % = cumulative percent less than stated D_{50} size

[d] Not used in calculations due to suspect stage loading

TABLE 3-5. EMISSION FACTORS BASED ON TOTAL MASS AND IMPACTOR SIZE DISTRIBUTION BAGHOUSE INLET AND OUTLET

Run No.	Total mass emission rate (lb/hr)[a]	Production rate (tons/day)	Total mass emission factor (lb/ton)	Ratio of total mass conc. to particle size train conc.	Emission factors 15 μm (lb/ton)[b]	Emission factors 10 μm (lb/ton)[b]	Emission factors 2.5 μm (lb/ton)[b]
Bag-I-1-1	1,842	276 → 11.5 ton/hr	160.2		82.0	56.1	32.7
Bag-I-1-2	1,271	276	110.5		64.8	46.9	9.2
Bag-I-1-3	1,816	276	157.9		87.6	61.7	13.2
Bag-I-1-4	1,227	276	106.7		64.8	43.1	1.9
Average	1,539	276	133.8	0.83	74.8	52.0	14.2
Bag-I-2-1	1,473	276	128.1		73.5	53.3	16.6
~~Bag-I-2-2(2)~~[c]	~~1,336~~	~~276~~	~~116.1~~		116.5	117.1	94.1
Bag-I-2-3(2)	1,548	276	134.6		82.3	57.4	10.0
Bag-I-2-4	1,129	276	98.1		56.7	40.8	11.0
Average	1,383	276	120.3	1.00	70.8	50.5	12.5
Bag-I-3-1	1,634	276	142.1		88.3	64.1	17.5
Bag-I-3-2	1,503	276	130.7		83.3	65.3	29.5
Bag-I-3-3	1,539	276	133.8		78.6	57.3	11.3
Bag-I-3-4	779	276	67.7		40.7	27.8	4.1
Average	1,364	276	118.9	0.88	72.7	53.6	15.6
Bag-I-4-1	1,369	276	119.1		67.0	44.6	9.8
Bag-I-4-2	881	276	76.6		44.9	32.8	8.6
Bag-I-4-3	1,392	276	121.1		70.6	48.6	9.1
Bag-I-4-4	1,341	276	116.6		74.6	53.9	7.9
Average	1,246	276	108.4	1.01	64.3	45.0	8.9
Total average	1,383	276	120.4	0.92	70.7	50.3	12.8

(continued)

TABLE 3-5. (continued)

Run No.	Total mass emission rate (lb/hr)[a]	Production rate (tons/day)	Total mass emission factor (lb/ton)	Ratio of total mass conc. to particle size train conc.	Emission factors 15 µm (lb/ton)[b]	Emission factors 10 µm (lb/ton)[b]	Emission factors 2.5 µm (lb/ton)[b]
~~Bag-0-1-1~~[c]	~~0.45~~	~~276~~	~~0.04~~		0.08	0.07	0.003
~~Bag-0-1-2~~[c]	~~2.0~~	~~276~~	~~0.18~~		0.15	0.13	0.05
~~Bag-0-1-3(2)~~[c]	~~1.25~~	~~276~~	~~0.11~~		0.06	0.05	0.01
~~Bag-0-1-4~~[c]	~~2.30~~	~~276~~	~~0.20~~		0.18	0.15	0.06
Average	1.50	276	~~0.13~~	0.30	0.09	0.08	0.03
Bag-0-2-1	0.85	276	0.08		0.06	0.05	0.02
Bag-0-2-2	0.75	276	0.07		0.06	0.05	0.02
Bag-0-2-3	1.05	276	0.09		0.02	0.01	0.006
Bag-0-2-4	1.50	276	0.13		0.11	0.09	0.04
Average	1.05	276	0.09	0.87	0.06	0.05	0.02
Bag-0-3-1	1.05	276	0.09		0.09	0.07	0.03
Bag-0-3-2	1.65	276	0.15		0.14	0.14	0.05
Bag-0-3-3	1.05	276	0.09		0.01	0.01	0.006
Bag-0-3-4	1.00	276	0.09		0.06	0.06	0.03
Average	1.20	276	0.10	0.58	0.08	0.07	0.03
Bag-0-4-1	0.60	276	0.05		0.04	0.04	0.02
Bag-0-4-2	1.55	276	0.14		0.13	0.10	0.04
Bag-0-4-3	0.75	276	0.07		0.06	0.05	0.03
Bag-0-4-4	1.60	276	0.14		0.11	0.09	0.03
Average	1.15	276	0.10	0.97	0.09	0.07	0.03
Total average	1.25	276	0.11	0.65	0.08	0.06	0.03

[a] lb/hr = emission rate of entire baghouse, pounds per hour.

[b] lb/ton = pounds per ton of product.

[c] Not used in calculations due to suspect loading of the Brink Stages.

LR489E(P)

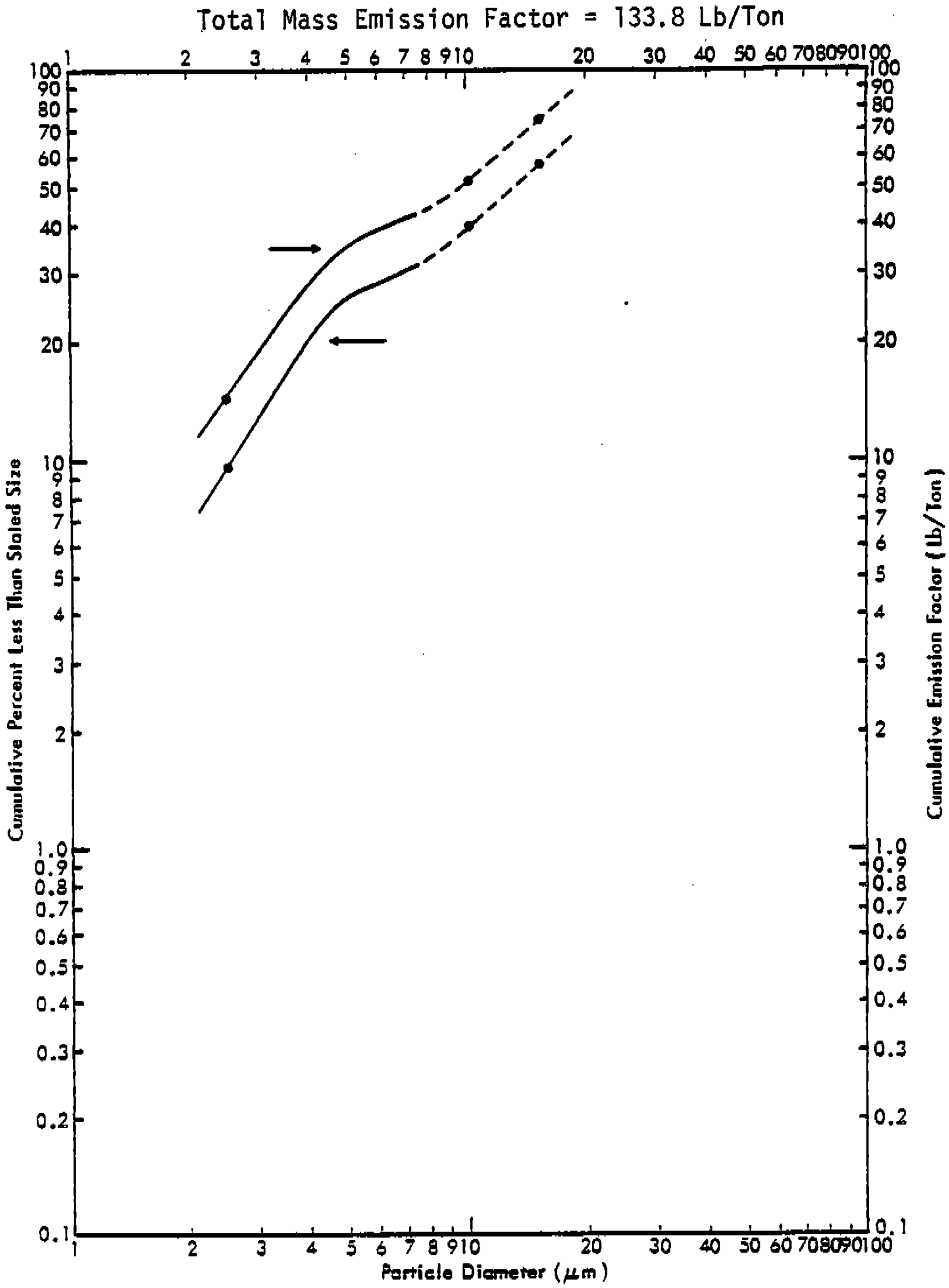


Figure 3-1. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--baghouse inlet--test one.

Total Mass Emission Factor = 120.3 Lb/Ton

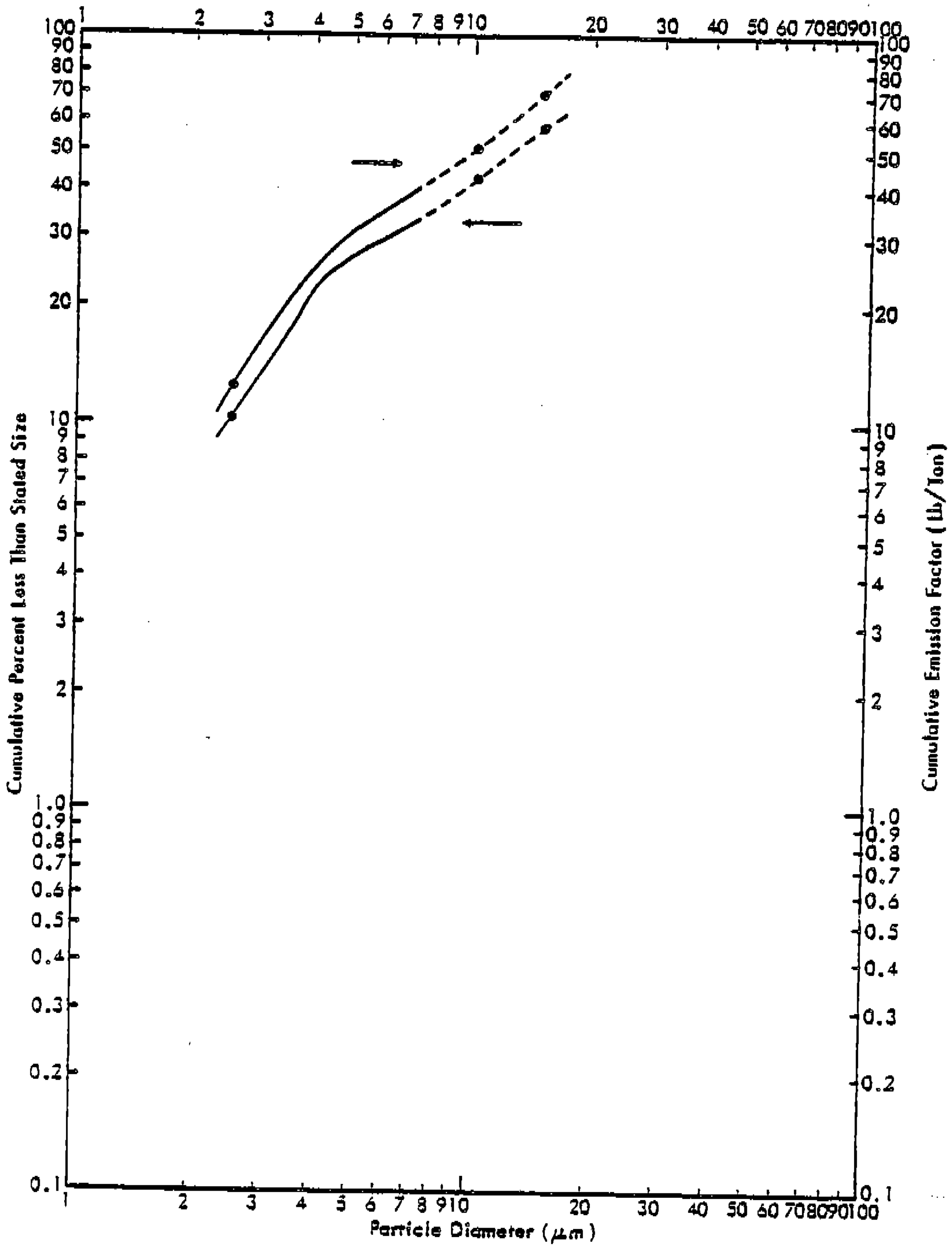


Figure 3-2. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--baghouse inlet--test two.

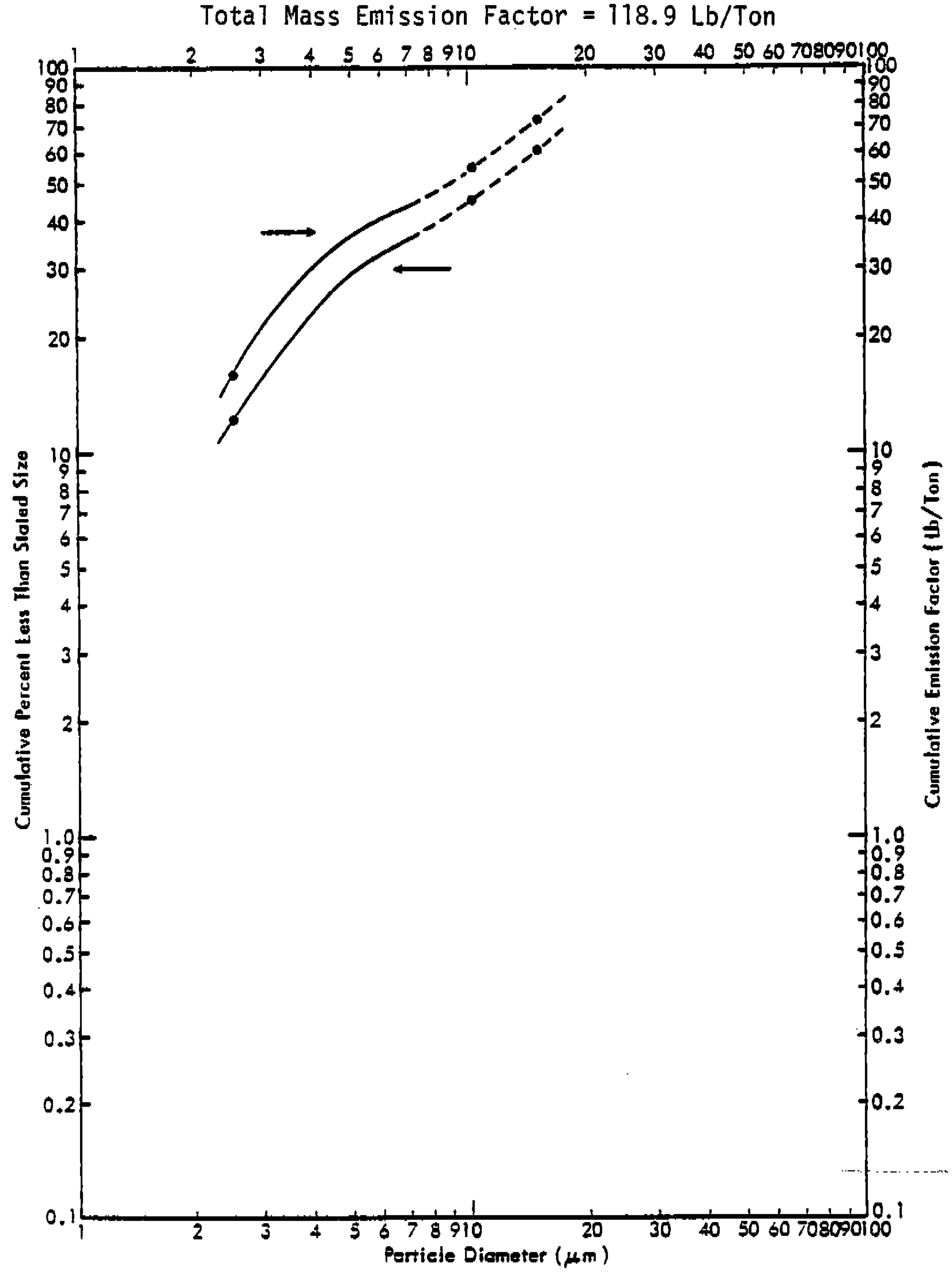


Figure 3-3. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--baghouse inlet--run three.

Total Mass Emission Factor = 108.4 Lb/Ton

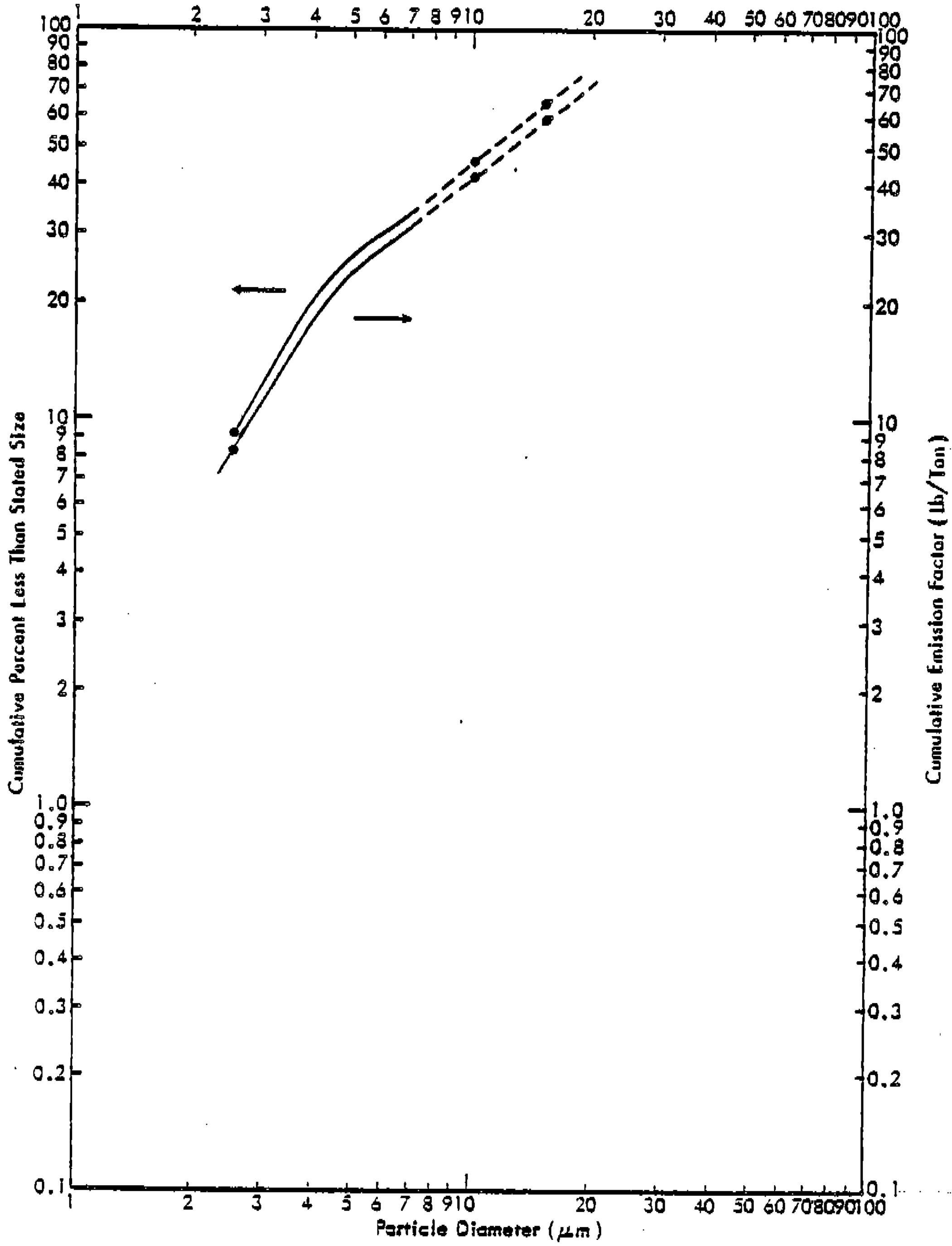


Figure 3-4. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--baghouse inlet--test four.

Total Mass Emission Factor = 120.4 Lb/Ton

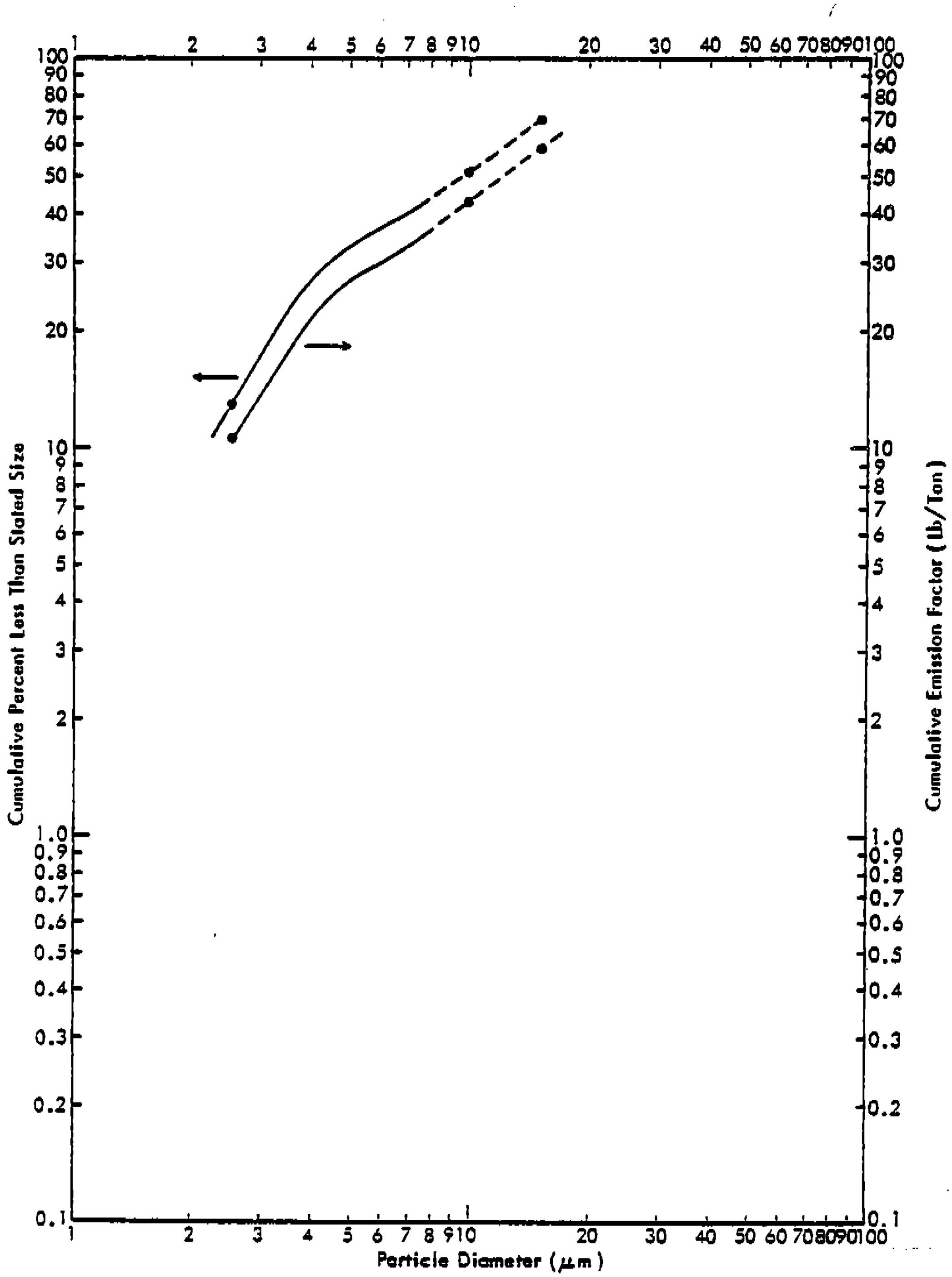


Figure 3-5. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--baghouse inlet--total average.

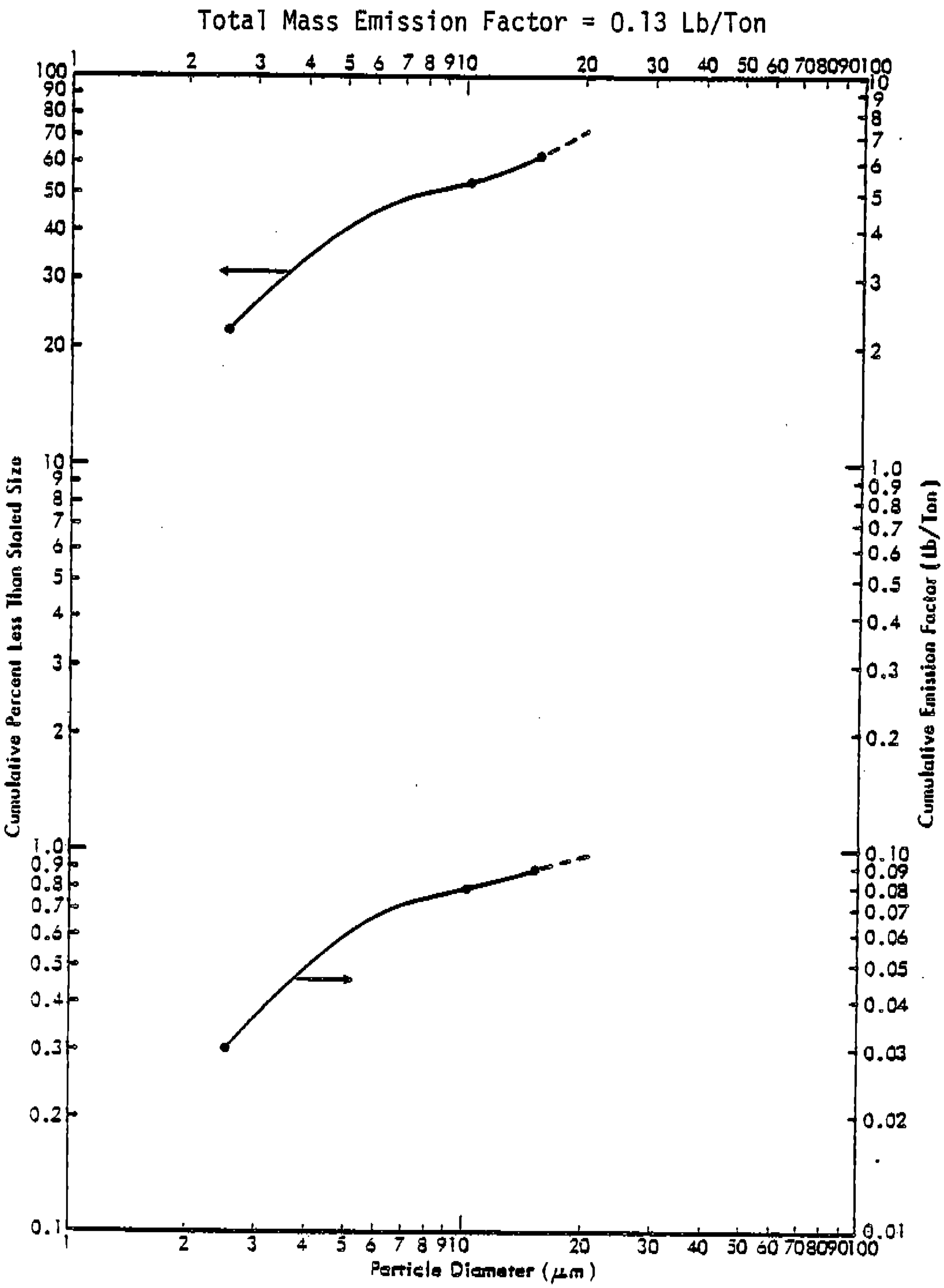


Figure 3-6. Cumulative percent less than stated size and cumulative emission factor versus particle diameter—baghouse outlet—test one.

Total Mass Emission Factor = 0.09 Lb/Ton

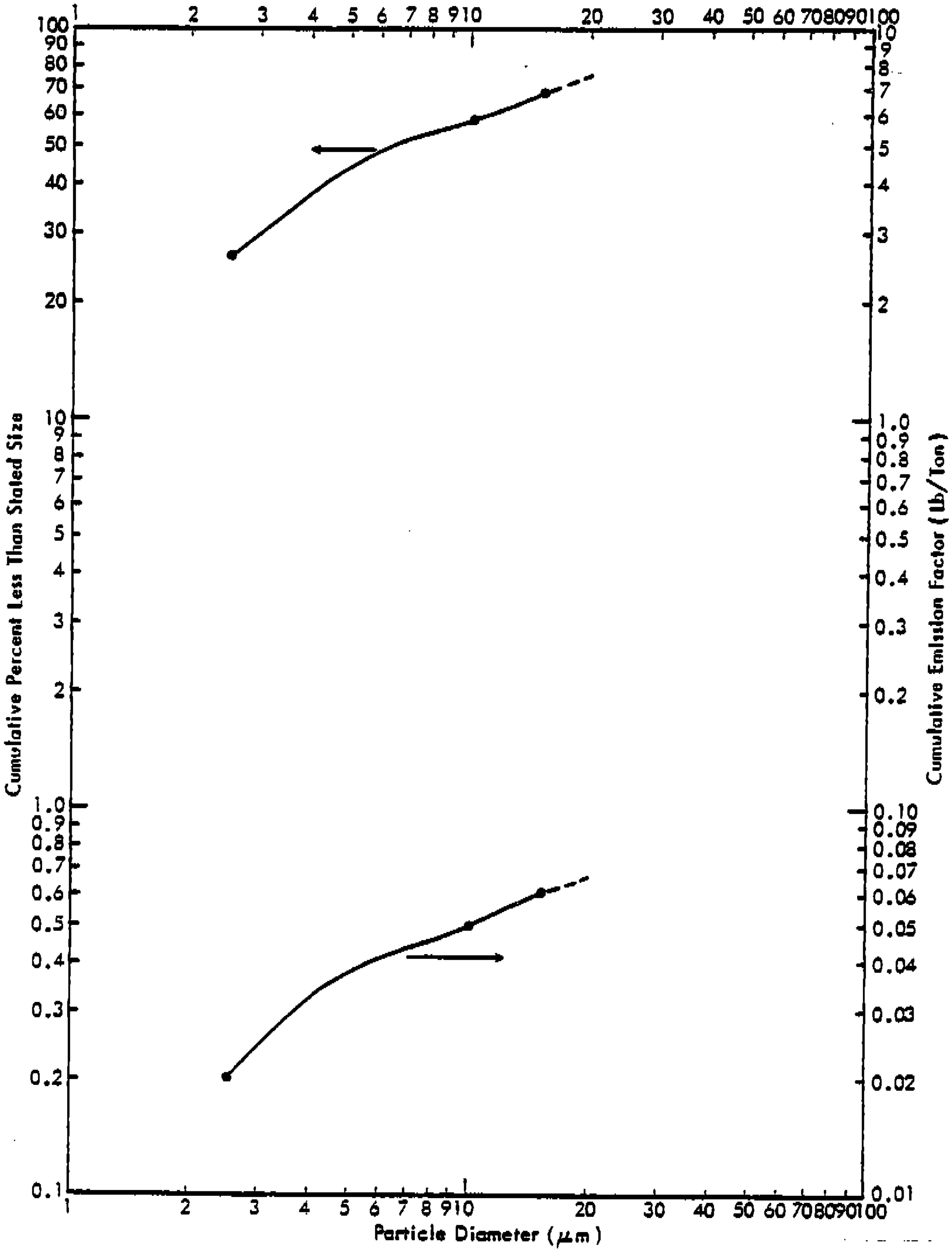


Figure 3-7. Cumulative percent less than stated size and cumulative emission factor versus particle diameter—baghouse outlet—test two.

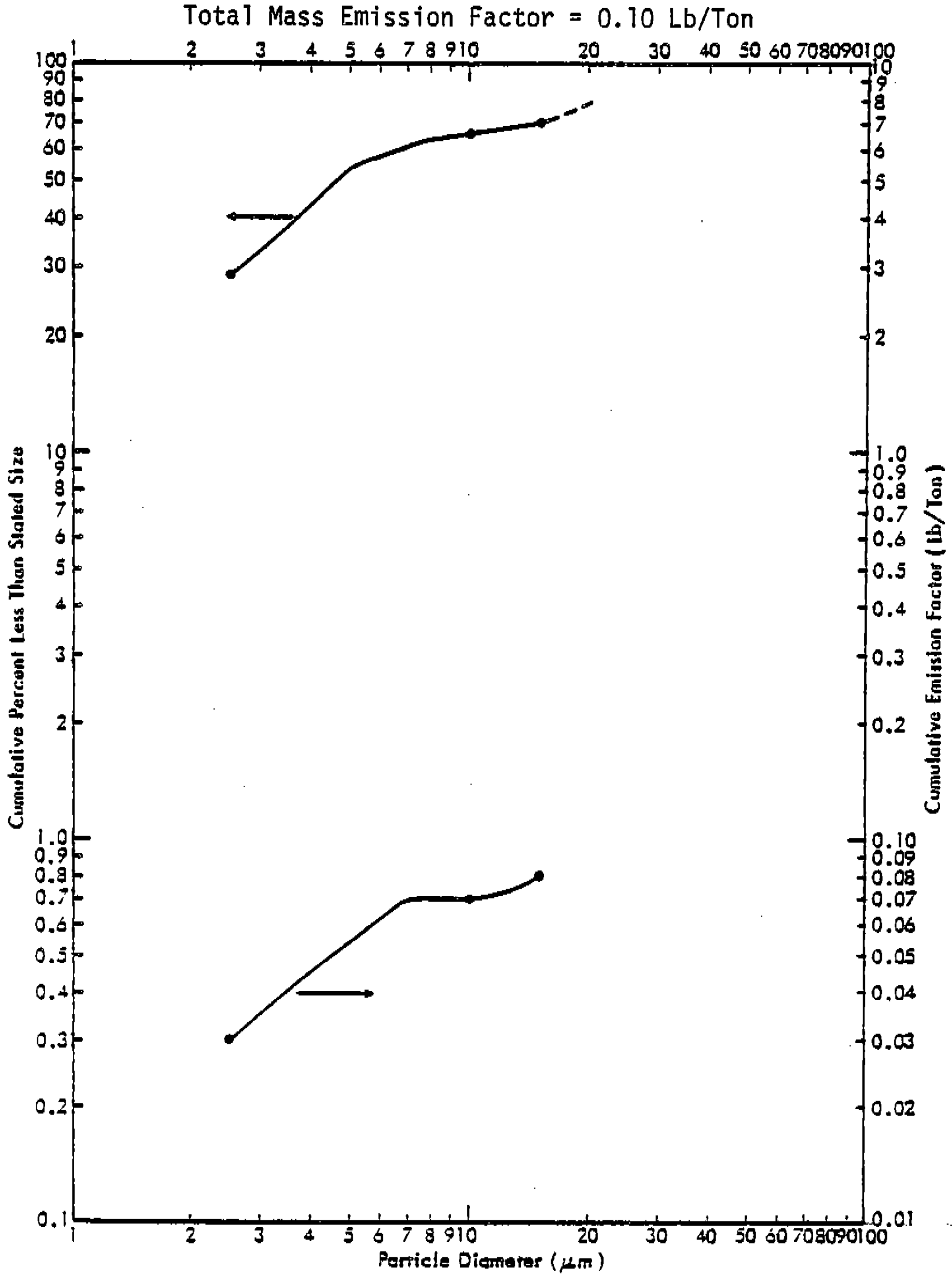


Figure 3-8. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--baghouse outlet--test three.

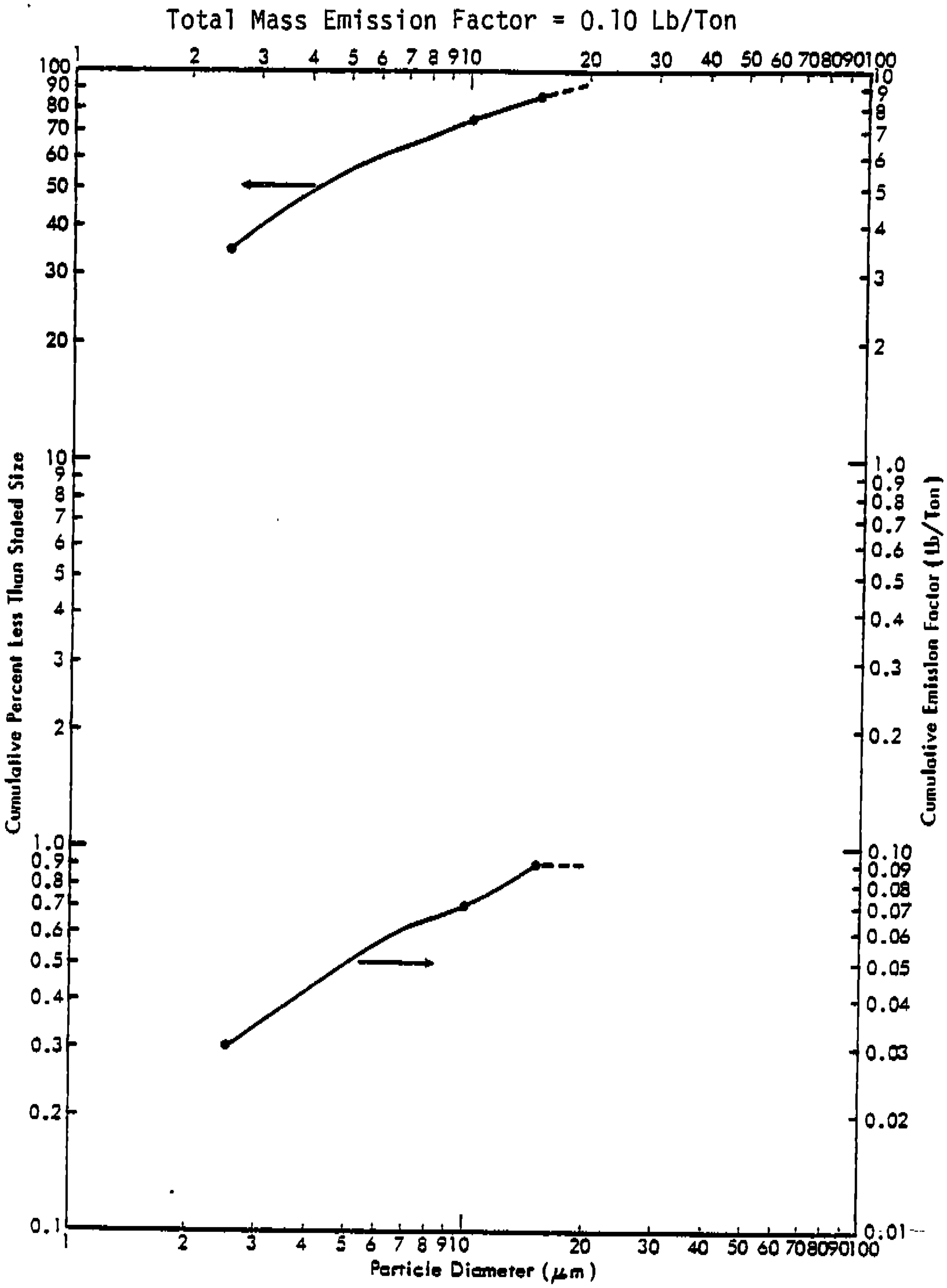


Figure 3-9. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--bag outlet--test four.

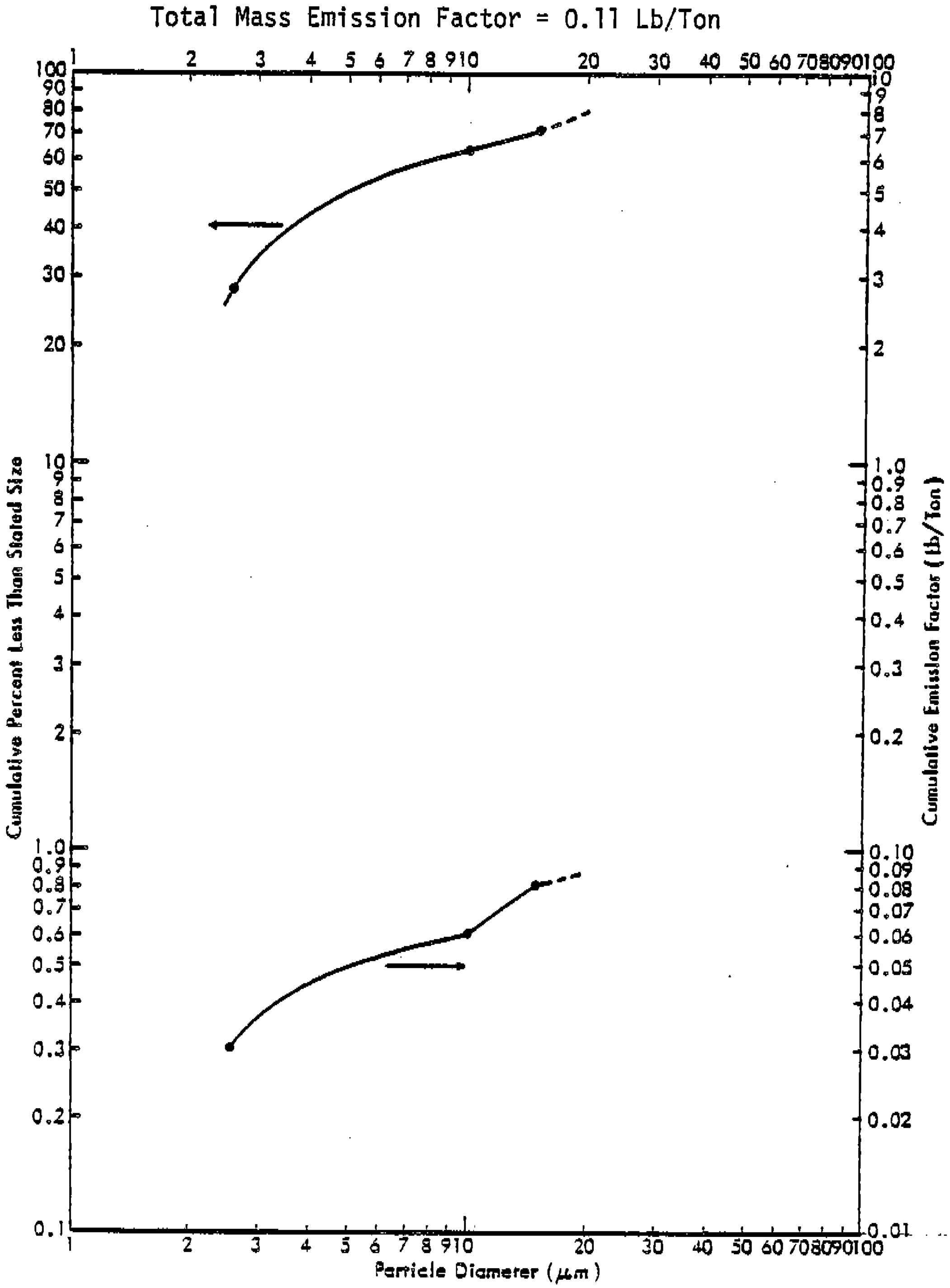


Figure 3-10. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--bag outlet--total average.

Summary of the ESP results are tabulated in Tables 3-6 and 3-7 and graphically in Figures 3-11 through 3-20.

3.1.4.3 Dust Collector--

The dust collector production rate varied for each run depending on whether one kiln or both kilns were running. As stated earlier, the process was intermittant which also may introduce error. Problems with negative weights and larger D_{50} on stage 0 than the preseparator were encountered with the dust collector. The problems were discussed in Subsection 3.1.2.

Tables 3-8 and 3-9 present the summary data for the dust collector. Figures 3-21 through 3-25 graphically demonstrate the data.

3.1.5 Summary of Results

The inhalable emission factors for the various sources were calculated for 15 and 10 µm. Fine particulates (< 2.5 µm) were also determined.

Limited sampling was done on the inlet and outlet of the baghouse for kiln No. 6. The inlet averaged 70.7 lb/ton (pounds per ton of product) at 15 µm and 50.3 lb/ton at 10 µm. The fines were 12.8 lb/ton. The outlet emissions for 15 and 10 µm were 0.08 and 0.06 lb/ton, respectively, with 0.03 lb/ton of fines.

Assuming certain factors, emissions for the electrostatic precipitators of the No. 7 kiln were measured. The inlets were 159.5 lb/ton for 15 µm, 58.2 lb/ton for the 10 µm, and 3.3 lb/ton were for fine particulates. The outlet emitted 5.8 lb/ton for 15 µm and 4.6 lb/ton for the 10 µm with 1.3 lb/ton of fine particulates.

The dust collector emission factors were 0.22 lb/ton at 15 µm and at 10 µm 0.19 lb/ton. The fine particulates were 0.08 lb/ton.

Table 3-10 indicates emission factors for each test and the average.

The situation for kiln no. 7 is less straight-forward since a cyclone separator was located between the kiln exit and sampling location. Plant officials felt that most of the coal ash was removed in this cyclone and consequently the material from the cyclone was discarded after collection. Since the amount of material collected is not known, it is not possible to estimate the coal ash contribution to the inlet.

The emission factors calculated for kilns 6 and 7 include contributions from both lime and coal ash from the kiln burner. From data provided by Pfizer, it is possible to calculate the mass of coal ash produced in each kiln per ton of lime produced. The coal used had a Btu content of 24.5M Btu per ton and an ash content of 8 percent. Since kiln no. 6 required 6.8M Btu per ton of lime and kiln no. 7 required 8M Btu per ton of lime, kiln no. 6 produced 44.4 lbs of coal ash per ton of lime and kiln no. 7 produced 52.5 lbs per ton of lime.

TABLE 3-6. IMPACTOR PARTICLE SIZE TEST SAMPLING DATA ELECTROSTATIC PRECIPITATOR INLET AND OUTLET

Run No.	7 µm cyclone Mass (mg)[a]	7 µm cyclone D_{50} size (µm)[b]	7 µm cyclone Cum. % less than[c]	Stage 1 Mass (mg)	Stage 1 D_{50} size (µm)	Stage 1 Cum. % less than	Stage 2 Mass (mg)	Stage 2 D_{50} size (µm)	Stage 2 Cum. % less than	Stage 3 Mass (mg)	Stage 3 D_{50} size (µm)	Stage 3 Cum. % less than
ESP-1-1-1	244.42	7.00	5.80	9.31	3.93	2.21	2.80	2.29	1.13	0.94	1.55	0.77
ESP-1-1-2	205.03	7.00	5.49	6.52	4.00	2.48	3.24	2.34	0.99	0.58	1.58	0.72
ESP-1-1-3(2)	284.14	7.00	5.64	9.83	4.14	2.37	3.51	2.41	1.21	1.10	1.63	0.84
ESP-1-1-4(2)	295.16	7.00	4.89	8.21	4.56	2.24	4.29	2.67	0.86	1.19	1.81	0.48
ESP-1-2-1	144.85	7.00	11.21	12.61	4.16	3.48	4.27	2.43	0.86	0.74	1.64	0.40
ESP-1-2-2	212.54	7.00	6.93	9.82	4.00	2.63	3.17	2.36	1.24	0.82	1.58	0.88
ESP-1-2-3	237.04	7.00	5.68	8.59	4.26	2.27	2.94	2.49	1.19	0.77	1.68	0.79
ESP-1-2-4	392.14	7.00	8.05	25.03	4.11	2.18	6.06	2.40	0.75	1.48	1.62	0.41
ESP-1-3-1	297.77	7.00	5.47	11.38	4.23	1.85	3.39	2.47	0.77	0.76	1.67	0.53
ESP-1-3-2	221.67	7.00	6.69	10.14	4.09	2.42	4.14	2.39	0.67	0.88	1.62	0.30
ESP-1-3-3	231.96	7.00	5.25	8.62	4.11	1.73	3.12	2.40	0.46	0.50	1.62	0.25
ESP-1-3-4	383.07	7.00	5.02	14.67	3.84	1.39	3.48	2.24	0.52	0.90	1.51	0.30
ESP-1-4-1	236.77	7.00	6.07	9.64	4.24	2.24	3.21	2.48	0.97	0.87	1.67	0.62
ESP-1-4-2(2)	281.92	7.00	5.61	4.65	4.19	4.06	16.77	2.45	0.45	0.68	1.66	0.22
ESP-1-4-3	252.63	7.00	5.99	10.60	4.16	2.04	3.96	2.43	0.57	0.90	1.64	0.23
ESP-1-4-4	352.38	7.00	6.39	14.92	3.88	2.42	6.00	2.26	0.83	1.15	1.52	0.52

Run No.	Stage 4 Mass (mg)	Stage 4 D_{50} size (µm)	Stage 4 Cum. % less than	Stage 5 Mass (mg)	Stage 5 D_{50} size (µm)	Stage 5 Cum. % less than	Filter Mass (mg)	Filter D_{50} size (µm)
ESP-1-1-1	0.47	0.78	0.59	0.31	0.47	0.47	1.21	< 0.47
ESP-1-1-2	0.20	0.81	0.63	0.27	0.49	0.50	1.08	< 0.49
ESP-1-1-3(2)	0.73	0.83	0.60	0.47	0.50	0.44	1.32	< 0.50
ESP-1-1-4(2)	0.57	0.93	0.29	0.75	0.57	0.05	0.15	< 0.57
ESP-1-2-1	0.36	0.84	0.18	0.13	0.51	0.10	0.16	< 0.51
ESP-1-2-2	0.26	0.80	0.77	0.65	0.49	0.48	1.10	< 0.49
ESP-1-2-3	0.19	0.86	0.71	0.67	0.52	0.44	1.11	< 0.52
ESP-1-2-4	0.80	0.82	0.22	0.93	0.49	0.00	0.00	< 0.49
ESP-1-3-1	0.27	0.85	0.45	0.34	0.52	0.34	1.07	< 0.52
ESP-1-3-2	0.28	0.83	0.18	0.08	0.50	0.15	0.36	< 0.50
ESP-1-3-3	0.14	0.82	0.19	0.36	0.50	0.05	0.11	< 0.50
ESP-1-3-4	0.31	0.76	0.22	0.30	0.45	0.15	0.59	< 0.45
ESP-1-4-1	0.41	0.85	0.46	0.30	0.52	0.34	0.85	< 0.52
ESP-1-4-2(2)	0.21	0.85	0.15	0.12	0.52	0.11	0.33	< 0.52
ESP-1-4-3	0.47	0.84	0.05	0.00	0.51	0.05	0.14	< 0.51
ESP-1-4-4	0.57	0.76	0.37	0.90	0.45	0.13	0.50	< 0.45

(continued)

TABLE 3-6. (continued)

Run No.	15 μm cyclone Mass (mg)[a]	15 μm cyclone D_{50} size (μm)[b]	15 μm cyclone Cum. % less than[c]	Stage 0 Mass (mg)	Stage 0 D_{50} size (μm)	Stage 0 Cum. % less than	Stage 1 Mass (mg)	Stage 1 D_{50} size (μm)	Stage 1 Cum. % less than	Stage 2 Mass (mg)	Stage 2 D_{50} size (μm)	Stage 2 Cum. % less than
ESP-0-1-1(2)	64.13	12.97	33.47	1.67	12.64	31.73	1.94	7.86	29.72	8.34	5.30	21.07
ESP-0-1-2(2)	25.14	13.40	96.20	5.28	12.98	59.06	1.94	8.07	56.45	6.79	5.45	47.31
ESP-0-1-3	47.63	12.61	49.35	1.43	12.36	47.83	3.10	7.68	44.53	13.85	5.18	29.80
ESP-0-1-4	17.67	12.75	67.49	1.53	12.45	64.68	2.17	7.74	60.68	8.95	5.22	44.21
ESP-0-2-1	56.27	13.11	41.51	4.94	12.70	36.38	2.36	7.90	33.92	8.31	5.33	25.29
ESP-0-2-2	23.58	15.32	61.93	6.73	14.45	51.06	3.62	9.00	45.21	7.73	6.08	32.73
ESP-0-2-3	114.26	14.95	34.76	2.12	14.14	33.55	2.17	8.80	32.31	13.62	5.94	24.53
ESP-0-2-4	29.84	13.53	55.74	1.36	13.13	53.72	1.99	8.17	50.77	9.74	5.51	36.32
ESP-0-3-1	44.65	13.13	59.58	5.38	12.72	54.70	4.68	7.91	50.47	12.88	5.34	38.80
ESP-0-3-2	22.21	14.04	62.28	0.84	13.48	60.85	1.60	8.39	58.14	7.06	5.66	46.14
ESP-0-3-3	34.02	15.30	49.00	2.66	14.44	45.02	1.36	8.99	42.98	6.92	6.07	32.60
ESP-0-3-4	17.02	15.02	65.98	1.85	14.22	62.29	1.12	8.85	60.05	5.27	5.98	49.53
ESP-0-4-1	64.23	13.43	49.67	3.67	12.90	46.79	6.18	8.02	41.95	17.47	5.41	28.26
ESP-0-4-2	14.33	14.01	74.49	1.92	13.40	71.07	2.95	8.34	65.81	10.58	5.63	46.97
ESP-0-4-3	67.35	16.74	27.28	0.91	15.43	86.30	1.20	9.60	25.00	4.98	6.49	19.63
ESP-0-4-4(2)	18.96	15.81	54.31	0.43	14.82	53.27	0.38	9.23	52.36	3.55	6.23	43.80

(continued)

TABLE 3-6. (continued)

Run No.	Stage 3 Mass (mg)[a]	Stage 3 D_{50} size (μm)[b]	Stage 3 Cum. % less than[c]	Stage 4 Mass (mg)	Stage 4 D_{50} size (μm)	Stage 4 Cum. % less than	Stage 5 Mass (mg)	Stage 5 D_{50} size (μm)	Stage 5 Cum. % less than	Stage 6 Mass (mg)	Stage 6 D_{50} size (μm)	Stage 6 Cum. % less than
ESP-0-1-1(2)	7.16	3.59	13.64	6.21	2.28	7.20	3.97	1.10	3.08	1.22	0.65	1.81
ESP-0-1-2(2)	15.78	3.69	26.07	5.46	2.34	18.72	4.20	1.13	13.06	3.31	0.67	8.61
ESP-0-1-3	10.88	3.51	18.23	8.03	2.22	9.69	4.61	1.07	4.79	1.32	0.63	3.39
ESP-0-1-4	8.96	3.53	27.72	6.88	2.24	15.06	3.80	1.08	8.07	1.10	0.64	6.05
ESP-0-2-1	8.29	3.61	16.67	6.48	2.29	9.93	3.41	1.11	6.39	1.35	0.65	4.98
ESP-0-2-2	6.92	4.12	21.55	6.51	2.62	11.04	3.99	1.28	4.59	1.61	0.76	1.99
ESP-0-2-3	11.26	4.03	18.10	15.03	2.56	9.52	10.06	1.25	3.78	2.21	0.74	2.52
ESP-0-2-4	9.53	3.73	22.19	8.24	2.37	9.96	4.43	1.15	3.39	0.86	0.68	2.11
ESP-0-3-1	12.89	3.61	27.13	10.90	2.29	17.26	9.53	1.11	8.63	2.59	0.65	6.29
ESP-0-3-2	7.72	3.83	33.03	8.64	2.44	18.35	6.12	1.18	7.96	1.51	0.70	5.39
ESP-0-3-3	6.90	4.11	22.26	6.39	2.62	12.68	5.10	1.27	5.03	1.19	0.76	3.25
ESP-0-3-4	7.06	4.05	35.40	6.82	2.58	21.76	5.57	1.25	10.63	2.03	0.75	6.57
ESP-0-4-1	12.99	3.66	18.08	12.54	2.32	8.26	5.51	1.12	3.94	1.50	0.66	2.76
ESP-0-4-2	8.92	3.81	31.09	7.70	2.42	17.37	4.95	1.17	8.56	1.39	0.69	6.08
ESP-0-4-3	5.21	4.40	14.00	5.25	2.80	8.33	4.06	1.37	3.95	1.03	0.82	2.83
ESP-0-4-4(2)	4.71	4.23	32.45	6.85	2.69	15.94	5.06	1.31	3.74	1.40	0.78	0.36

Run No.	Stage 7 Mass (mg)	Stage 7 D_{50} size (μm)	Stage 7 Cum. % less than	Filter Mass (mg)	Filter D_{50} size (μm)
ESP-0-1-1(2)	0.83	0.41	0.95	0.92	< 0.41
ESP-0-1-2(2)	3.96	0.43	3.28	2.43	< 0.43
ESP-0-1-3	1.63	0.40	1.65	1.56	< 0.40
ESP-0-1-4	1.69	0.41	2.94	1.60	< 0.41
ESP-0-2-1	1.73	0.42	3.19	3.07	< 0.42
ESP-0-2-2	0.78	0.49	0.73	0.45	< 0.49
ESP-0-2-3	0.70	0.48	2.12	3.70	< 0.48
ESP-0-2-4	0.48	0.44	1.40	0.94	< 0.44
ESP-0-3-1	2.44	0.42	4.08	4.51	< 0.42
ESP-0-3-2	0.85	0.45	3.95	2.33	< 0.45
ESP-0-3-3	0.55	0.49	4.42	1.62	< 0.49
ESP-0-3-4	1.22	0.48	4.13	2.06	< 0.48
ESP-0-4-1	1.32	0.42	1.73	2.20	< 0.42
ESP-0-4-2	1.34	0.45	3.70	2.08	< 0.45
ESP-0-4-3	0.69	0.53	2.09	1.93	< 0.53
ESP-0-4-4(2)	0.15	0.51	0.00	0.00	< 0.51

[a] mg = net weight milligrams.

[b] D_{50} size = 50% effective cutoff diameter micrometers.

[c] Cum. % less than = cumulative percent less than stated size.

TABLE 3-7. EMISSION FACTORS BASED ON TOTAL MASS AND IMPACTOR DISTRIBUTION ELECTROSTATIC PRECIPITATOR INLET AND OUTLET

Run No.	Total mass emission rate (lb/hr)[a]	Production rate (tons/day)	Total mass emission factor (lb/ton)[b]	Ratio of total mass conc. to particle size train conc.	Emission factors for: 15 μm (lb/ton)[b]	10 μm (lb/ton)[b]	2.5 μm (lb/ton)[b]
ESP-1-1-1	2,687.0	300 = 12.5 ton/hr	215.0		82.7	32.1	2.7
ESP-1-1-2	3,677.5	300	294.2		110.4	41.5	3.3
ESP-1-1-3	3,962.7	300	317.0		121.1	46.4	4.0
ESP-1-1-4	7,391.7	300	591.4		222.0	80.1	4.5
Average	4,429.7	300	354.4	1.12	134.0	50.0	3.6
ESP-1-2-1	3,853.3	300	308.3		144.5	73.2	2.9
ESP-1-2-2	4,491.3	300	359.3		359.3	59.7	4.8
ESP-1-2-3	5,875.9	300	470.1		181.7	70.0	5.1
ESP-1-2-4	4,697.3	300	375.8		162.6	73.3	3.0
Average	4,729.4	300	378.4	1.21	212.0	69.1	4.0
ESP-1-3-1	3,824.5	300	306.0		119.4	45.9	2.4
ESP-1-3-2	5,163.9	300	413.1		165.1	68.0	3.1
ESP-1-3-3	5,880.3	300	470.4		181.3	68.5	2.4
ESP-1-3-4	4,904.5	300	392.4		150.6	56.3	2.5
Average	4,943.3	300	395.5	1.28	154.1	59.7	2.6
ESP-1-4-1	4,670.0	300	373.6		147.4	58.6	3.7
ESP-1-4-2	4,688.6	300	375.1		134.2	49.0	1.9
ESP-1-4-3	3,711.7	300	296.9		117.2	46.5	1.8
ESP-1-4-4	4,903.4	300	392.3		153.2	61.6	4.0
Average	4,493.4	300	359.5	1.37	138.0	53.9	2.8
Total average	4,649.0	300	371.9	1.24	159.5	58.2	3.3

(continued)

TABLE 3-7. (continued)

Run No.	Total mass emission rate (lb/hr)[a]	Production rate (tons/day)	Total mass emission factor (lb/ton)[b]	Ratio of total mass conc. to particle size train conc.	Emission factors for: 15 μm (lb/ton)[b]	10 μm (lb/ton)[b]	2.5 μm (lb/ton)[b]
ESP-0-1-1(2)	58.6	300	4.7		2.1	1.5	0.4
ESP-0-1-2(2)	53.4	300	4.3		3.8	2.5	0.8
ESP-0-1-3	161.2	300	12.9		8.0	6.3	1.5
ESP-0-1-4	132.9	300	10.6		9.0	6.7	1.9
Average	101.5	300	8.1	1.17	5.7	4.3	1.1
ESP-0-2-1	73.1	300	5.9		3.8	2.1	0.6
ESP-0-2-2	87.2	300	7.0		4.0	3.3	0.7
ESP-0-2-3	87.2	300	10.8		3.8	3.6	1.0
ESP-0-2-4	135.3	300	18.2		11.4	9.6	2.0
Average	27.0	300	10.5	1.34	5.8	4.7	1.1
ESP-0-3-1	110.2	300	8.8		7.0	4.7	1.7
ESP-0-3-2	90.0	300	7.2		6.2	4.3	1.4
ESP-0-3-3	120.5	300	9.7		4.6	4.2	1.2
ESP-0-3-4	131.2	300	10.5		6.9	6.4	2.2
Average	113.0	300	9.1	1.08	6.2	4.9	1.6
ESP-0-4-1	125.6	300	10.0		5.8	4.5	1.0
ESP-0-4-2	143.0	300	11.5		9.1	7.8	2.1
ESP-0-4-3	117.6	300	9.4		2.5	2.4	0.7
ESP-0-4-4	86.8	300	6.9		3.7	3.7	1.0
Average	118.3	300	9.5	1.15	5.3	4.6	1.2
Total average	115.9	300	9.3	1.19	5.8	4.6	1.3

[a] lb/hr = emission rate of all ESPs, pounds per hour.

[b] lb/ton = pounds per ton of product.

Total Mass Emission Factor = 354.4 Lb/Ton

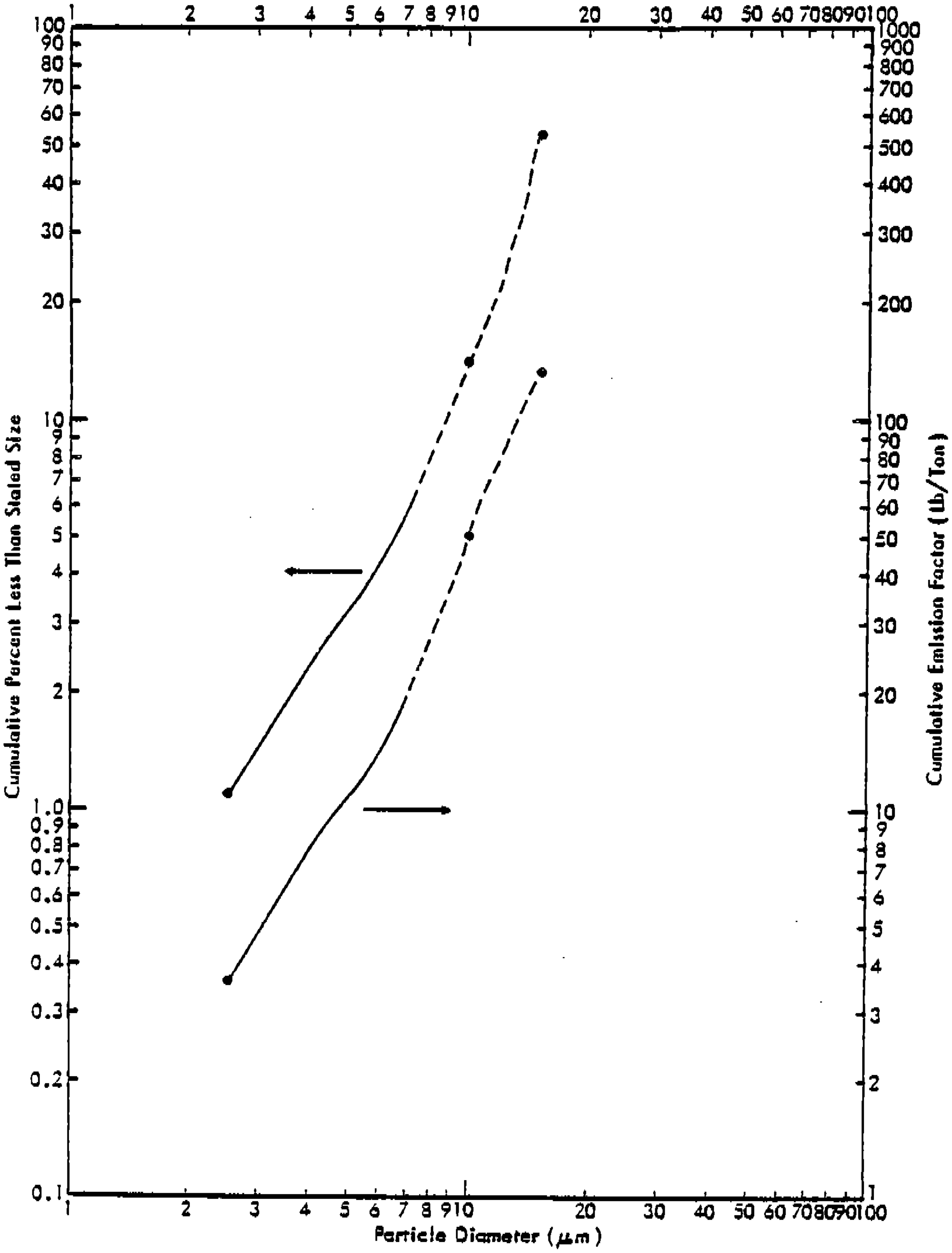


Figure 3-11. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--ESP inlet--test one.

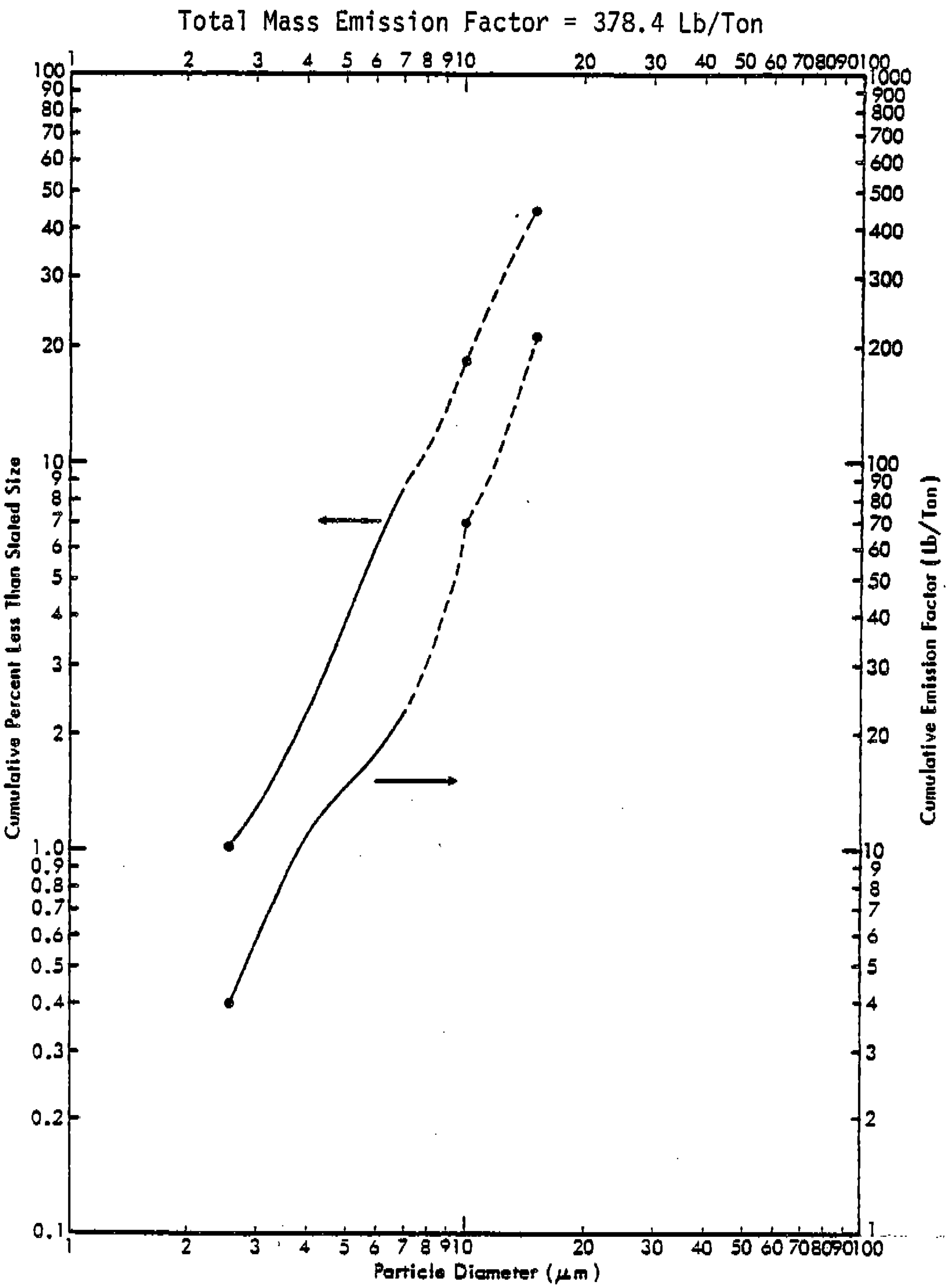


Figure 3-12. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--ESP inlet--test two.

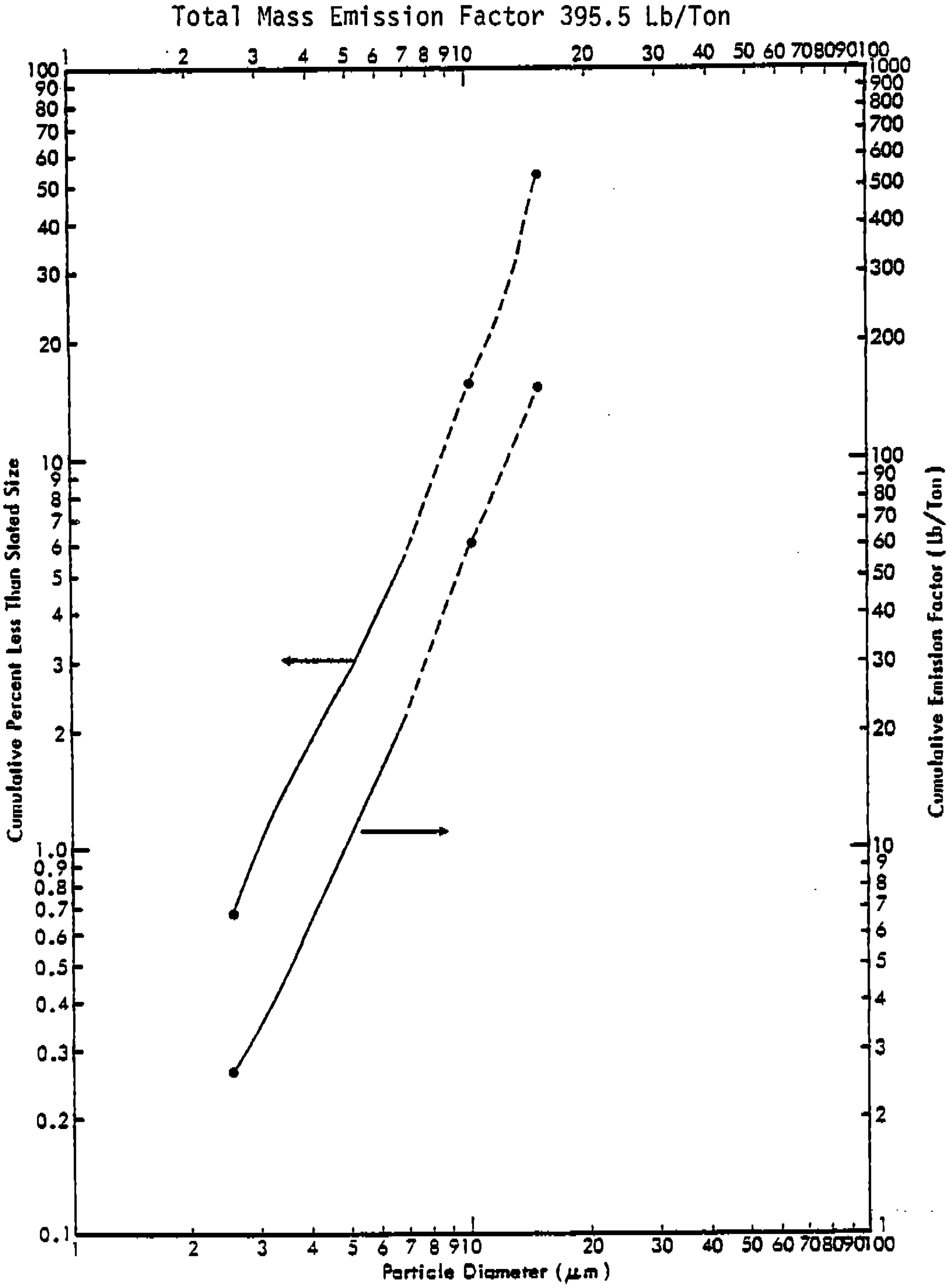


Figure 3-13. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--ESP inlet--test three.

Total Mass Emission Factor 359.5 Lb/Ton

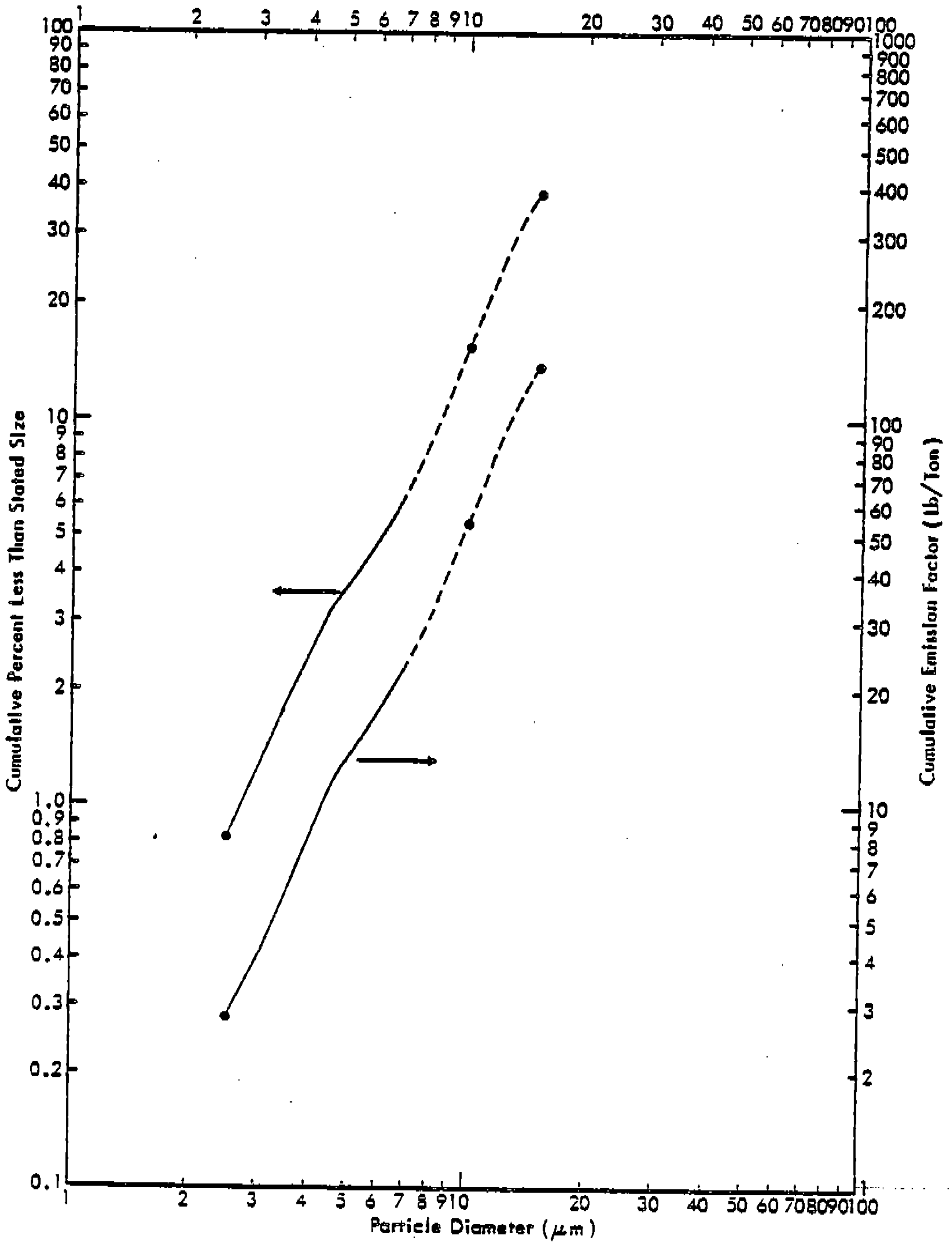


Figure 3-14. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--ESP inlet--test four.

Total Mass Emission Factor = 371.9 Lb/Ton

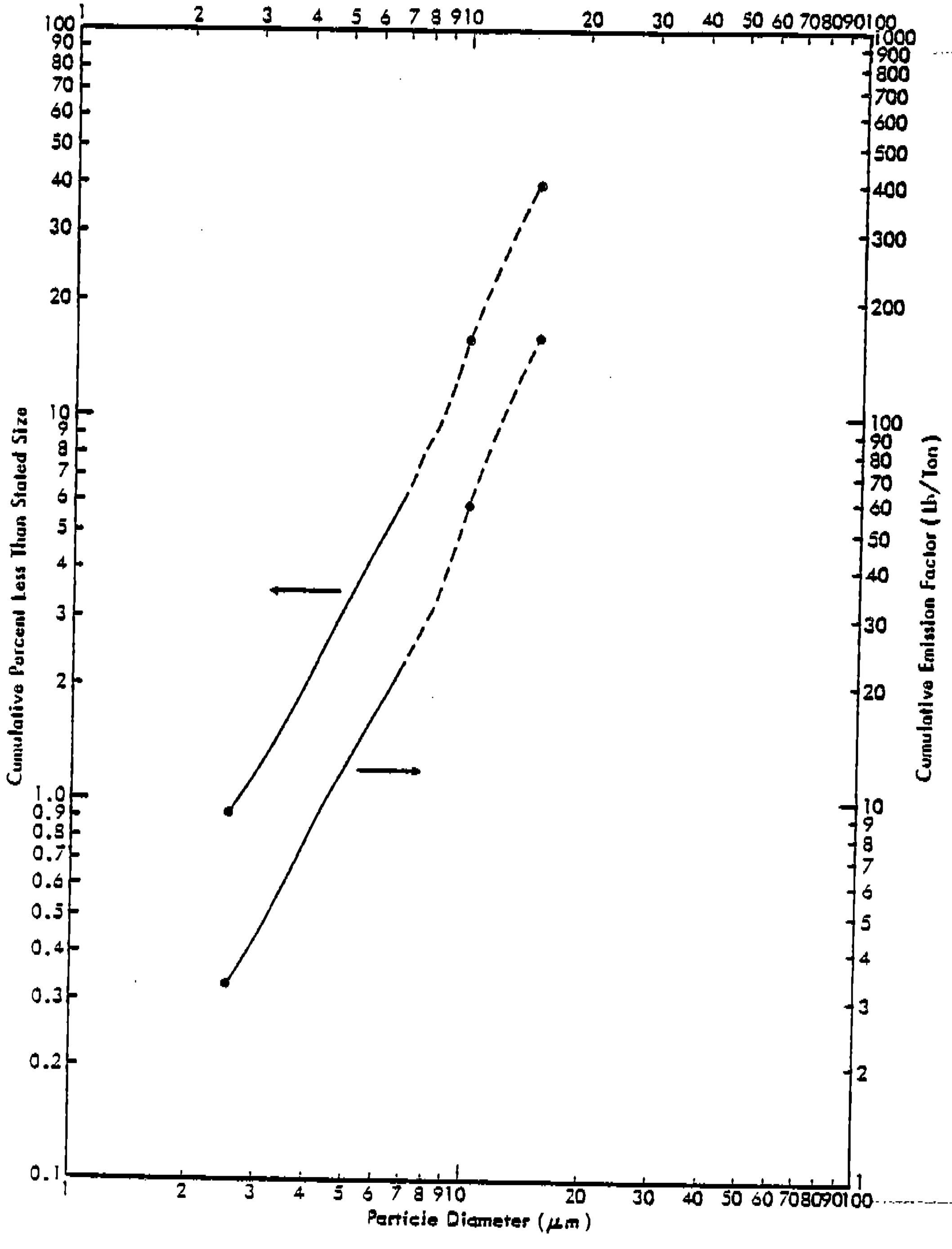


Figure 3-15. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--ESP inlet--total average.

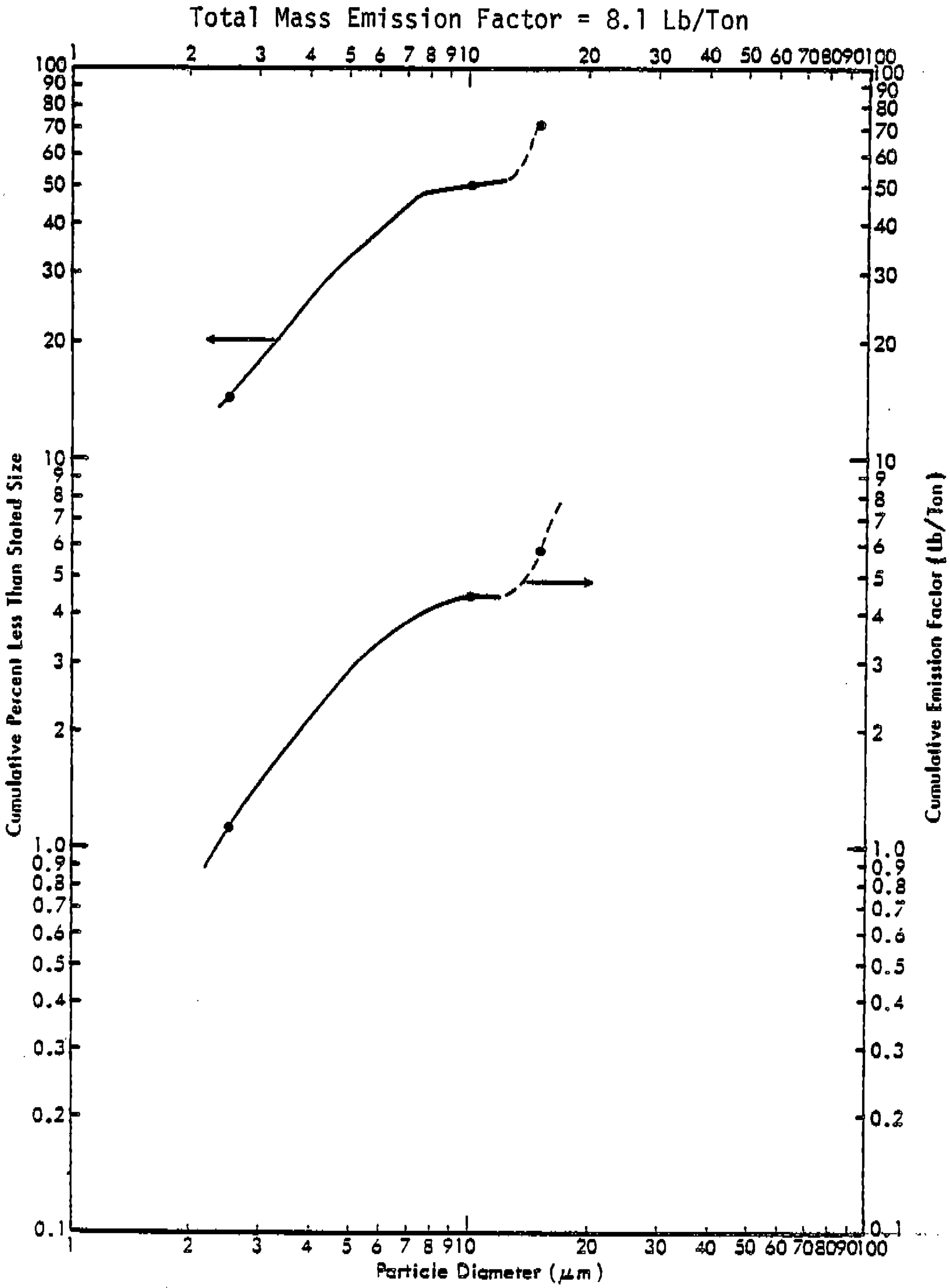


Figure 3-16. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--ESP outlet--test one.

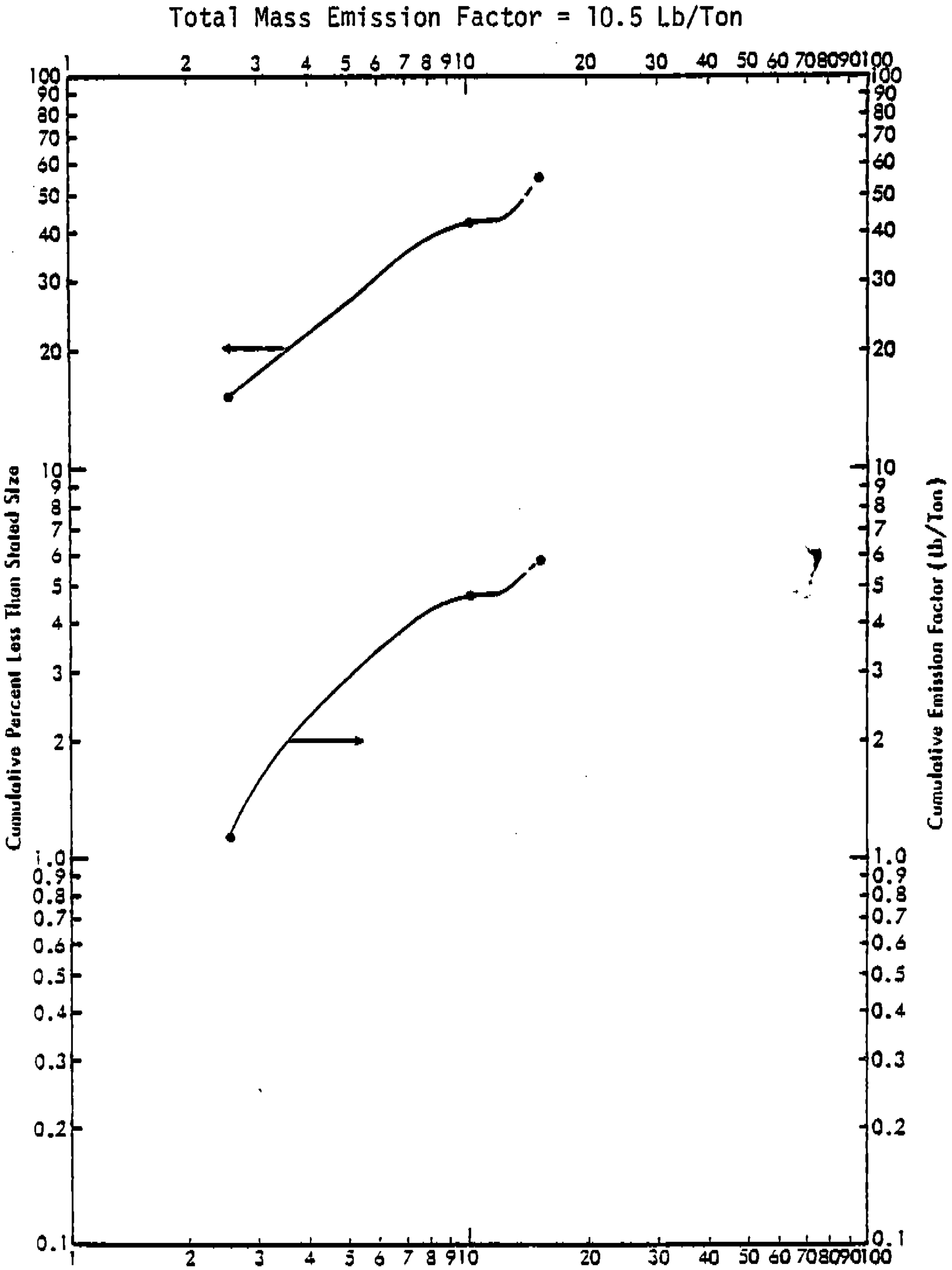


Figure 3-17. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--ESP outlet--test two.

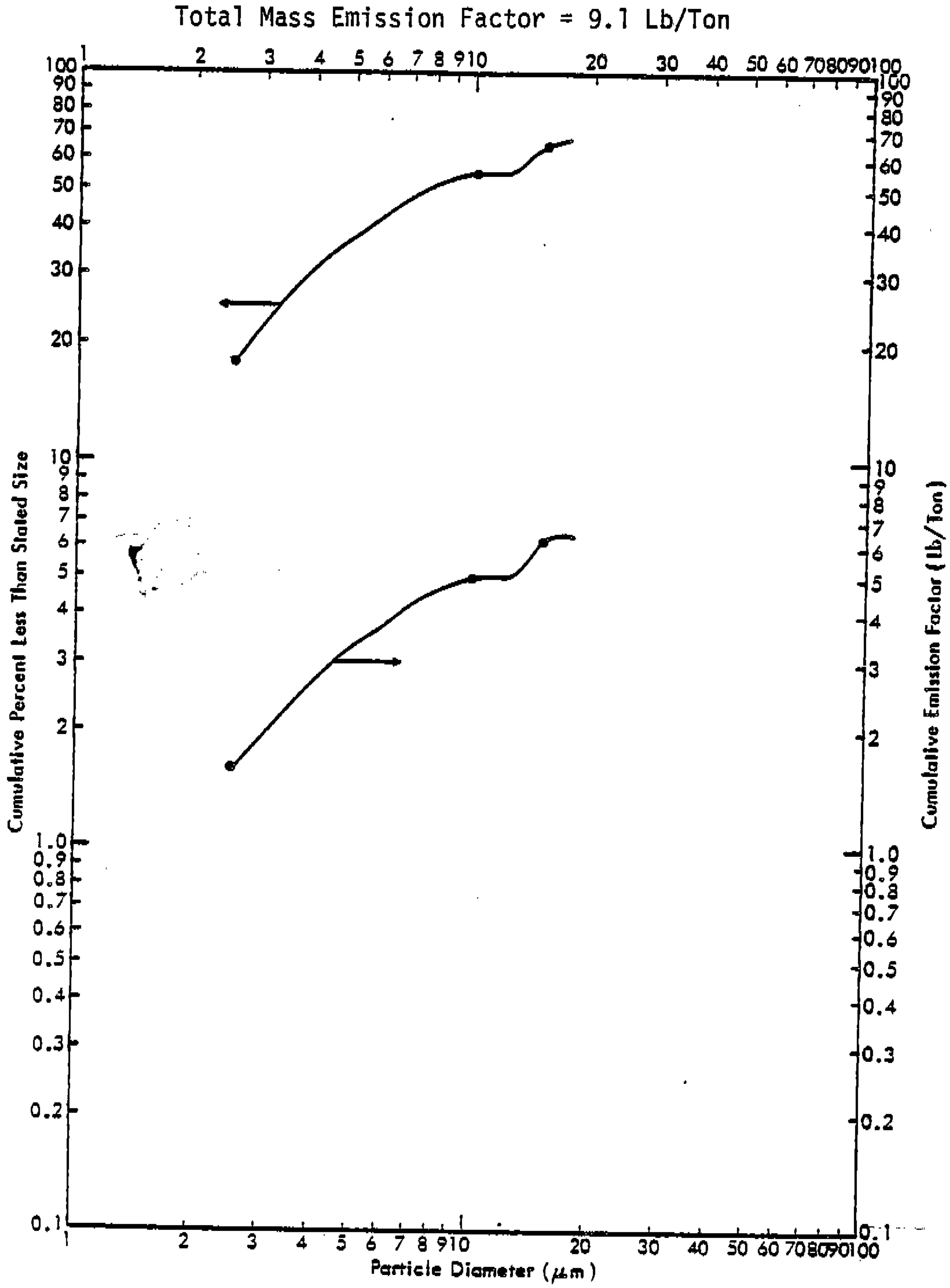


Figure 3-18. Cumulative percent less than stated size and cumulative emission factor versus particle diameter—ESP outlet—test three.

Total Mass Emission Factor = 9.5 Lb/Ton

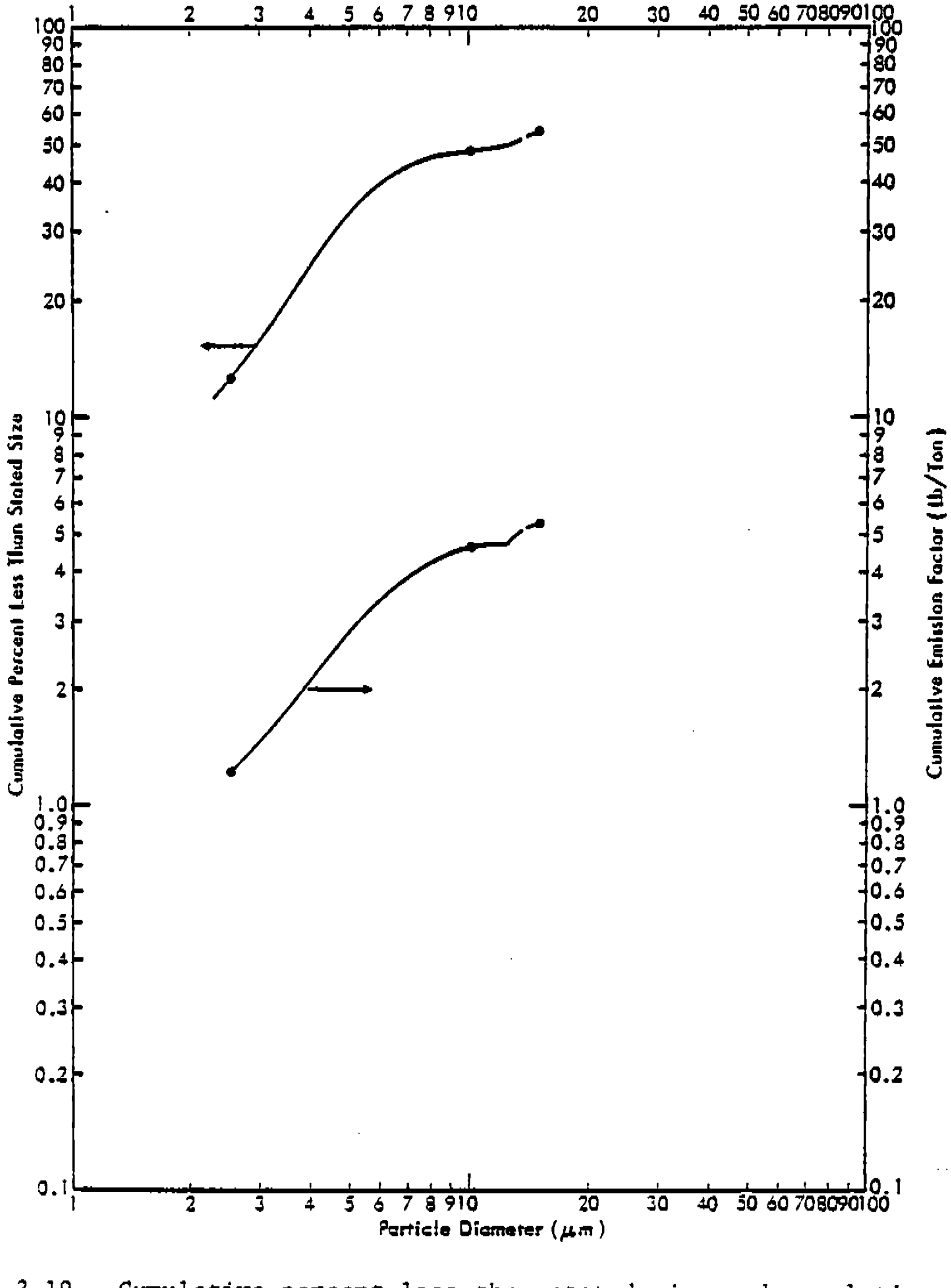


Figure 3-19. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--ESP outlet--test four.

Total Mass Emission Factor = 9.3 Lb/Ton

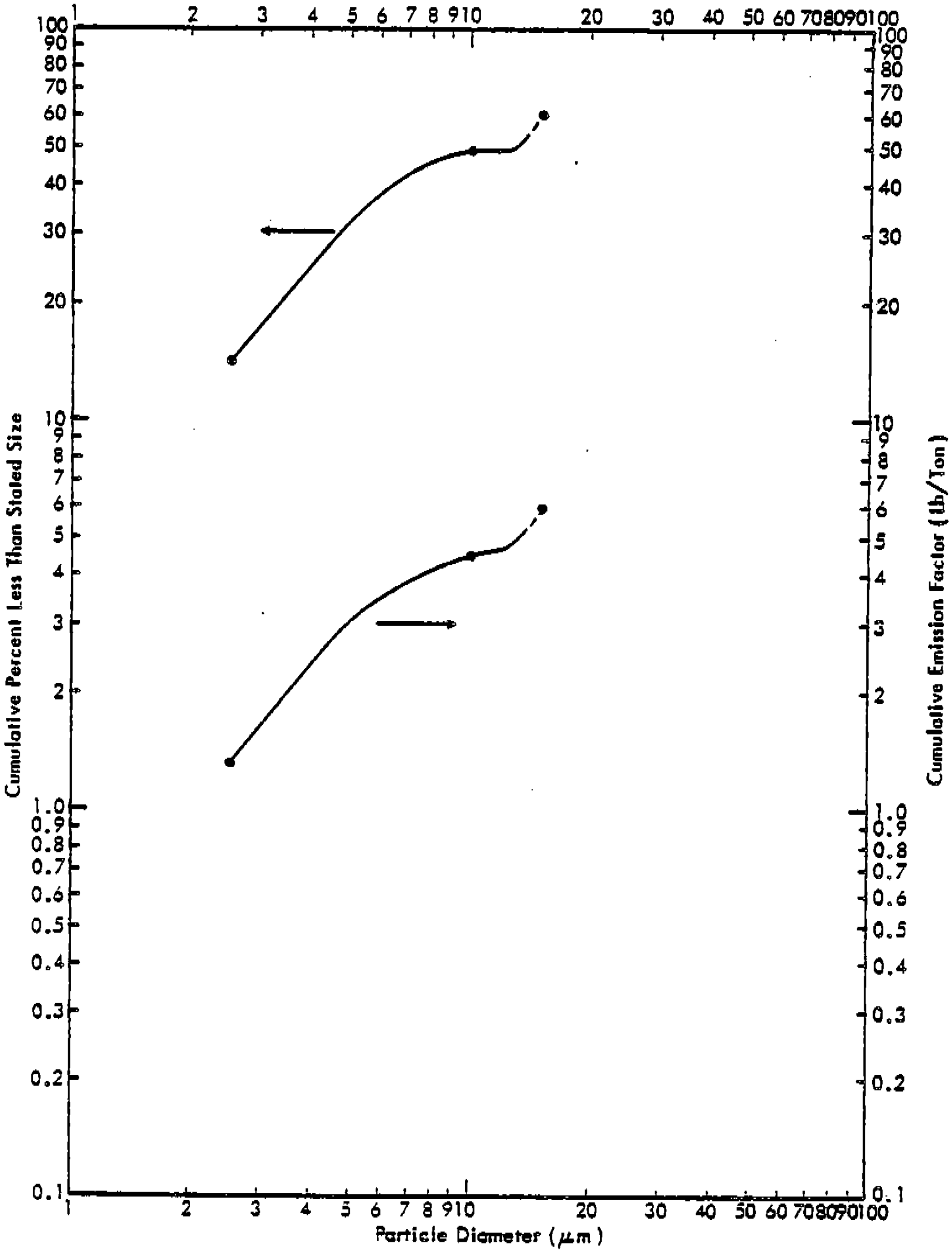


Figure 3-20. Cumulative percent less than stated size and cumulative emission factor versus particle diameter—ESP outlet--total average.

TABLE 3-8. IMPACTOR PARTICLE SIZE TEST SAMPLING DATA DUST COLLECTOR

Run No.	15 μm Cyclone Mass (mg)[a]	15 μm Cyclone D_{50} size[b] (μm)	15 μm Cyclone Cum. % less than[c]	Stage 0 Mass (mg)	Stage 0 D_{50} size (μm)	Stage 0 Cum. % less than	Stage 1 Mass (mg)	Stage 1 D_{50} size (μm)	Stage 1 Cum. % less than
DC-1-1	158.73	22.00	6.62	0.00	22.00	6.61	0.00	13.76	6.62
DC-1-2	103.56	21.99	5.78	0.00	21.99	5.78	0.00	13.35	5.78
DC-1-3	41.16	20.52	16.50	0.00	20.52	16.50	0.00	12.83	16.50
DC-1-4(1)	227.53	18.43	8.23	1.99	18.47	7.41	0.72	11.54	7.14
DC-2-1	192.48	20.35	8.59	0.17	20.35	8.41	0.00	12.72	8.41
DC-2-2	80.05	20.90	5.81	0.00	20.90	5.81	0.00	13.07	5.81
DC-2-3	138.62	20.65	12.01	0.00	20.65	12.01	0.00	12.91	12.01
DC-2-4[d]	12.10	21.40	0.00	0.00	21.40	0.00	0.00	13.38	0.00
DC-3-1	200.83	20.54	8.91	0.68	20.54	8.59	0.00	12.86	8.59
DC-3-2	159.63	21.24	45.07	102.44	21.24	9.82	1.90	13.28	9.16
DC-3-3	126.01	18.94	12.02	0.00	18.94	12.02	0.00	11.84	12.02
DC-1-4(2)	218.33	21.34	9.64	1.39	21.34	9.07	1.06	13.74	8.63
DC-4-1	176.40	20.36	14.44	2.86	20.36	13.05	1.46	12.71	12.14
DC-4-2	163.06	20.37	3.14	0.00	20.37	3.14	0.00	12.74	3.14
DC-4-3	129.62	20.54	15.74	2.03	20.54	14.42	1.16	12.84	13.66
DC-4-4	139.35	21.13	12.21	3.87	21.13	9.77	1.00	13.21	9.13

Run No.	Stage 2 Mass (mg)	Stage 2 D_{50} size (μm)	Stage 2 Cum. % less than	Stage 3 Mass (mg)	Stage 3 D_{50} size (μm)	Stage 3 Cum. % less than	Stage 4 Mass (mg)	Stage 4 D_{50} size (μm)	Stage 4 Cum. % less than
DC-1-1	0.00	9.35	6.62	0.65	6.39	6.21	2.34	4.12	4.97
DC-1-2	0.04	9.35	5.74	0.00	6.39	5.74	0.00	4.12	5.74
DC-1-3	0.00	8.71	16.50	0.52	5.95	15.44	2.15	3.84	11.07
DC-1-4(1)	2.59	7.84	6.10	4.34	5.35	4.39	5.14	3.45	2.36
DC-2-1	0.12	8.64	8.35	1.35	5.90	7.80	4.58	3.81	5.61
DC-2-2	0.00	8.88	5.81	0.34	6.06	5.41	0.52	3.91	4.79
DC-2-3	0.15	8.77	11.93	1.17	5.99	11.04	4.29	3.86	8.71
DC-2-4[d]	0.00	9.09	0.00	0.00	6.21	0.00	0.00	4.01	0.00
DC-3-1	0.37	8.72	8.52	1.74	5.96	7.73	3.87	3.86	5.97
DC-3-2	3.10	9.02	8.03	3.87	6.36	6.69	6.33	3.97	4.50
DC-3-3	0.00	8.04	12.02	2.01	5.49	10.60	3.99	3.51	7.83
DC-1-4(2)	2.15	9.06	7.74	2.85	6.19	6.56	5.04	4.00	4.47
DC-4-1	2.80	8.65	10.98	3.78	5.91	9.35	5.48	3.81	6.49
DC-4-2	0.00	8.65	3.14	0.10	5.91	3.08	1.80	3.81	2.01
DC-4-3	1.63	8.72	12.60	2.54	5.96	10.95	4.28	3.84	8.17
DC-4-4	1.50	8.97	8.49	3.68	6.13	7.13	2.92	3.96	5.39

Run No.	Stage 5 Mass (mg)	Stage 5 D_{50} size (μm)	Stage 5 Cum. % less than	Stage 6 Mass (mg)	Stage 6 D_{50} size (μm)	Stage 6 Cum. % less than	Stage 7 Mass (mg)	Stage 7 D_{50} size (μm)	Stage 7 Cum. % less than	Filter Mass (mg)	Filter D_{50} size (μm)
DC-1-1	4.79	2.09	2.35	3.33	1.31	0.31	0.52	0.90	0.00	0.00	< 0.90
DC-1-2	1.88	2.09	2.21	2.27	1.31	0.14	0.15	0.90	0.00	0.00	< 0.90
DC-1-3	3.92	1.94	3.13	3.53	1.28	0.00	0.00	0.83	0.00	0.00	< 0.83
DC-1-4(1)	4.23	1.74	0.66	1.50	1.08	0.00	0.00	0.74	0.00	0.00	< 0.74
DC-2-1	7.36	1.92	1.95	1.72	1.20	0.18	0.38	0.83	0.00	0.00	< 0.83
DC-2-2	1.89	1.98	2.56	0.99	1.21	1.39	1.18	0.85	0.00	0.00	< 0.85
DC-2-3	8.56	1.95	2.87	4.06	1.22	0.29	0.46	0.84	0.00	0.00	< 0.84
DC-2-4[d]	0.00	2.01	0.00	0.00	1.27	0.00	0.00	0.87	0.00	0.00	< 0.87
DC-3-1	8.18	1.96	2.26	3.88	1.23	0.49	0.44	0.83	0.29	0.65	< 0.83
DC-3-2	6.34	2.01	2.32	4.46	1.25	0.78	1.42	0.87	0.29	0.86	< 0.87
DC-3-3	7.78	1.78	2.41	3.34	1.11	0.23	0.33	0.76	0.00	0.00	< 0.76
DC-1-4(2)	6.58	2.02	1.75	3.36	1.26	0.44	1.07	0.87	0.00	0.00	< 0.87
DC-4-1	6.35	1.93	1.43	3.80	1.20	1.57	3.81	0.81	0.69	1.42	< 0.83
DC-4-2	2.80	1.91	0.15	0.58	1.20	0.00	0.00	0.83	0.00	0.00	< 0.83
DC-4-3	6.30	1.94	4.07	4.28	1.21	1.29	1.98	0.84	0.00	0.00	< 0.84
DC-4-4	4.45	2.00	2.48	2.86	1.25	0.68	1.07	0.86	0.00	0.00	< 0.86

[a] Net weight, milligrams.

[b] 50% effective cutoff diameter micrometers.

[c] Cumulative percent less than stated size.

[d] Not used in calculations due to suspect stage loading.

TABLE 3-9. EMISSION FACTORS BASED ON TOTAL MASS AND IMPACTOR SIZE DISTRIBUTION DUST COLLECTOR

Run No.	Total mass emission rate (lb/hr)[a]	Production rate (tons/day)	Total mass emission factor (lb/ton)[b]	Ratio of total mass conc. to particle size train conc.	Emission factors for 15 μm (lb/ton)[b]	10 μm (lb/ton)[b]	2.5 m (lb/ton)[b]
DC-1-1	39.3	576=24	1.6		0.11	0.11	0.05
DC-1-2	25.7	576	1.1		0.06	0.06	0.04
DC-1-3	29.2	576	1.2		0.24	0.20	0.09
DC-1-4	38.3	276=11.5	3.3		0.26	0.23	0.05
Average	33.1	501=20.9	1.8	0.89	0.17	0.15	0.06
DC-2-1	53.4	576	2.2		0.19	0.19	0.08
DC-2-2	35.0	576 24	1.5		0.09	0.09	0.05
DC-2-3	41.9	576	1.7		0.21	0.21	0.09
DC-2-4[c]	33.8	576	1.4		0.00	0.00	0.00
Average	41.0	576	1.7	0.62	0.16	0.16	0.07
DC-3-1	54.3	576-24	2.3		0.20	0.19	0.08
DC-3-2	35.3	276-11.5	3.1		0.43	0.26	0.09
DC-3-3	71.4	576	3.0		0.36	0.36	0.15
DC-3-4	37.2	276	3.6		0.29	0.26	0.08
Average	49.6	426-17.8	3.0	0.73	0.32	0.27	0.10
DC-4-1	29.8	276	2.6		0.34	0.30	0.12
DC-4-2	33.1	276	2.9		0.09	0.09	0.03
DC-4-3	13.3	276	1.2		0.17	0.15	0.06
DC-4-4	29.8	276	2.6		0.25	0.22	0.09
Average	26.5	276	2.3	1.09	0.21	0.19	0.08
Total average	37.6	445	2.2	0.80	0.22	0.19	0.08

[a] Pounds per hour.

[b] Pounds per ton of product.

[c] Not used in calculation due to suspect loading of the Anderson stages.

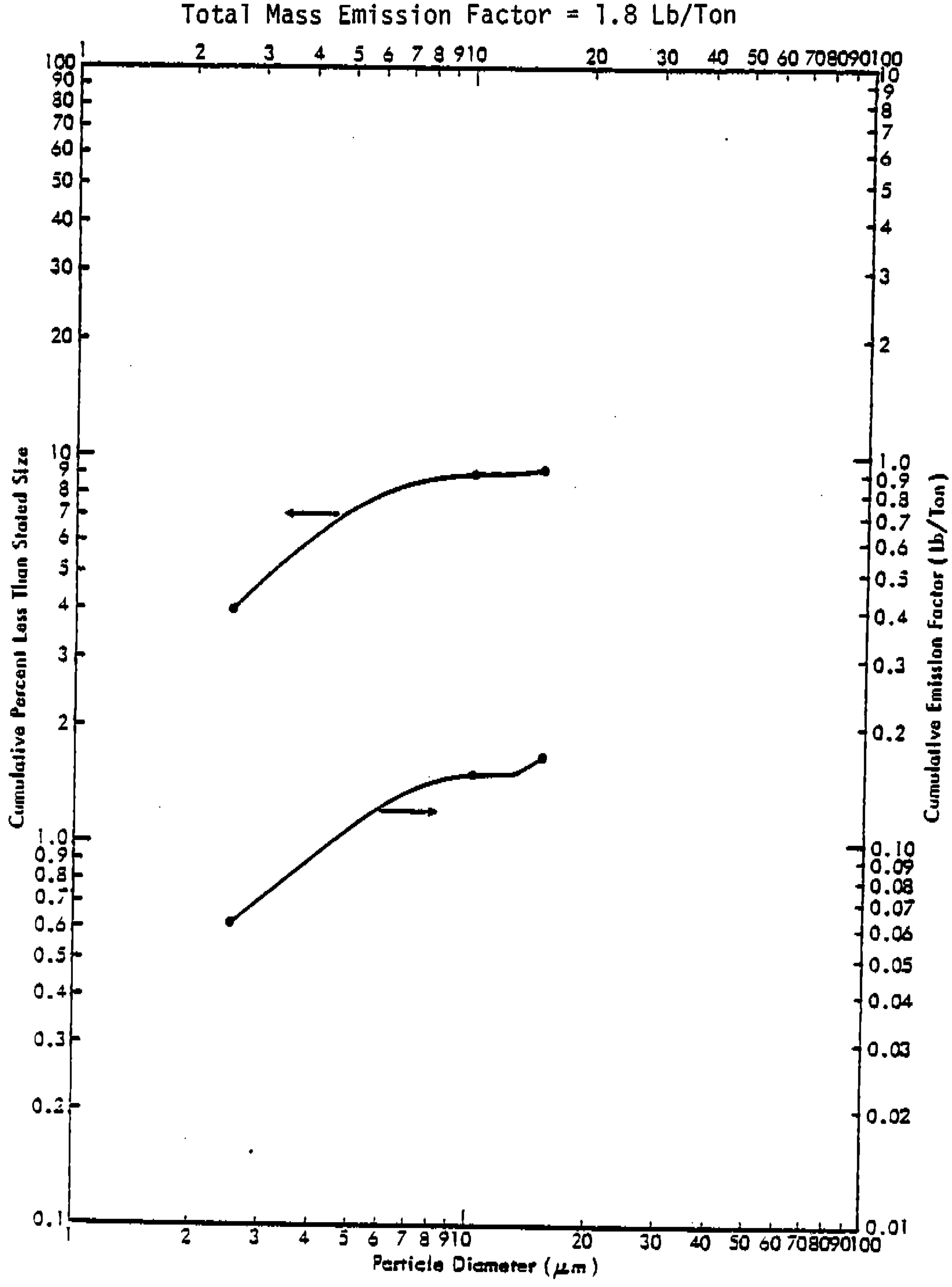


Figure 3-21. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--dust collector--test one.

Total Mass Emission Factor = 1.7 Lb/Ton

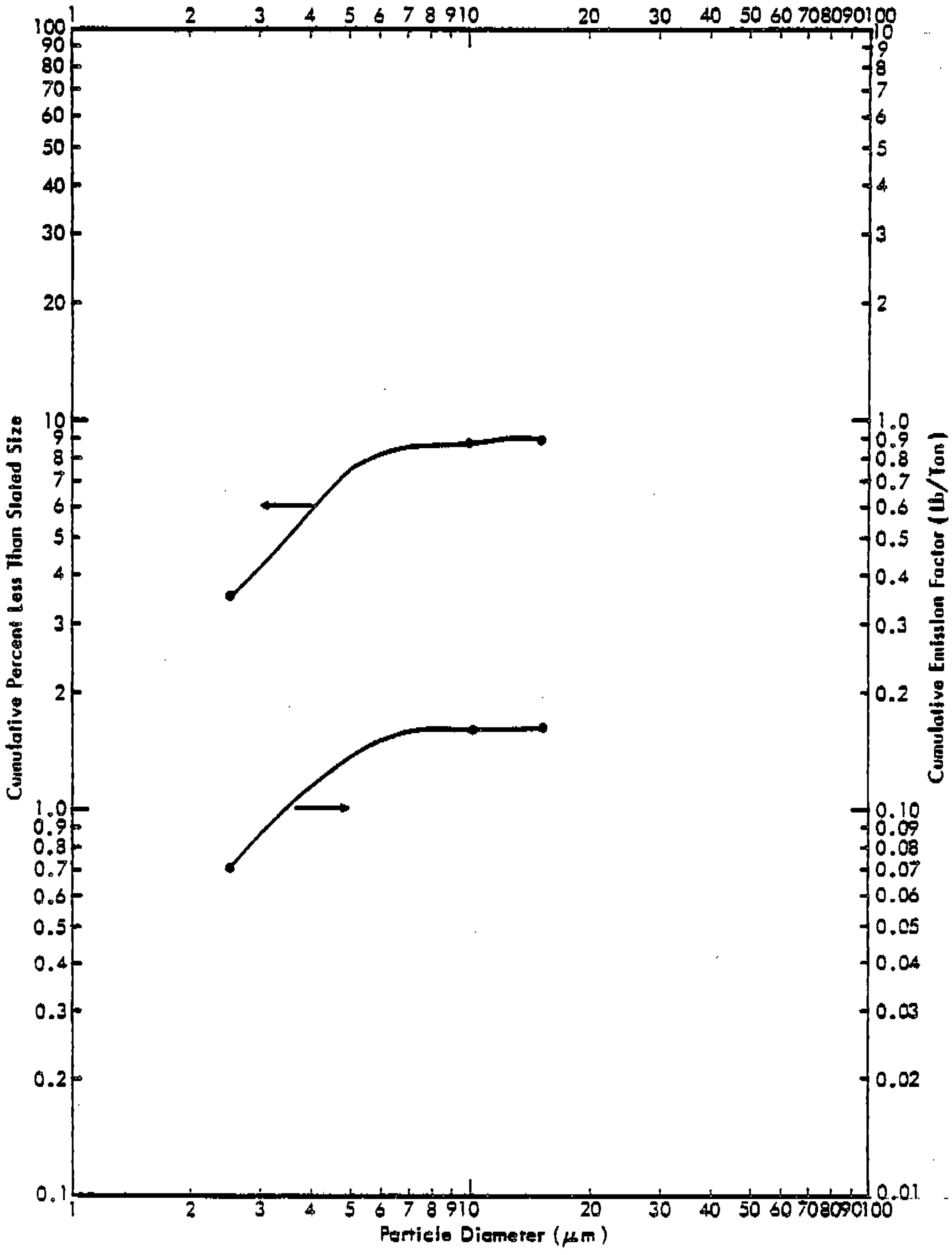


Figure 3-22. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--dust collector--test two.

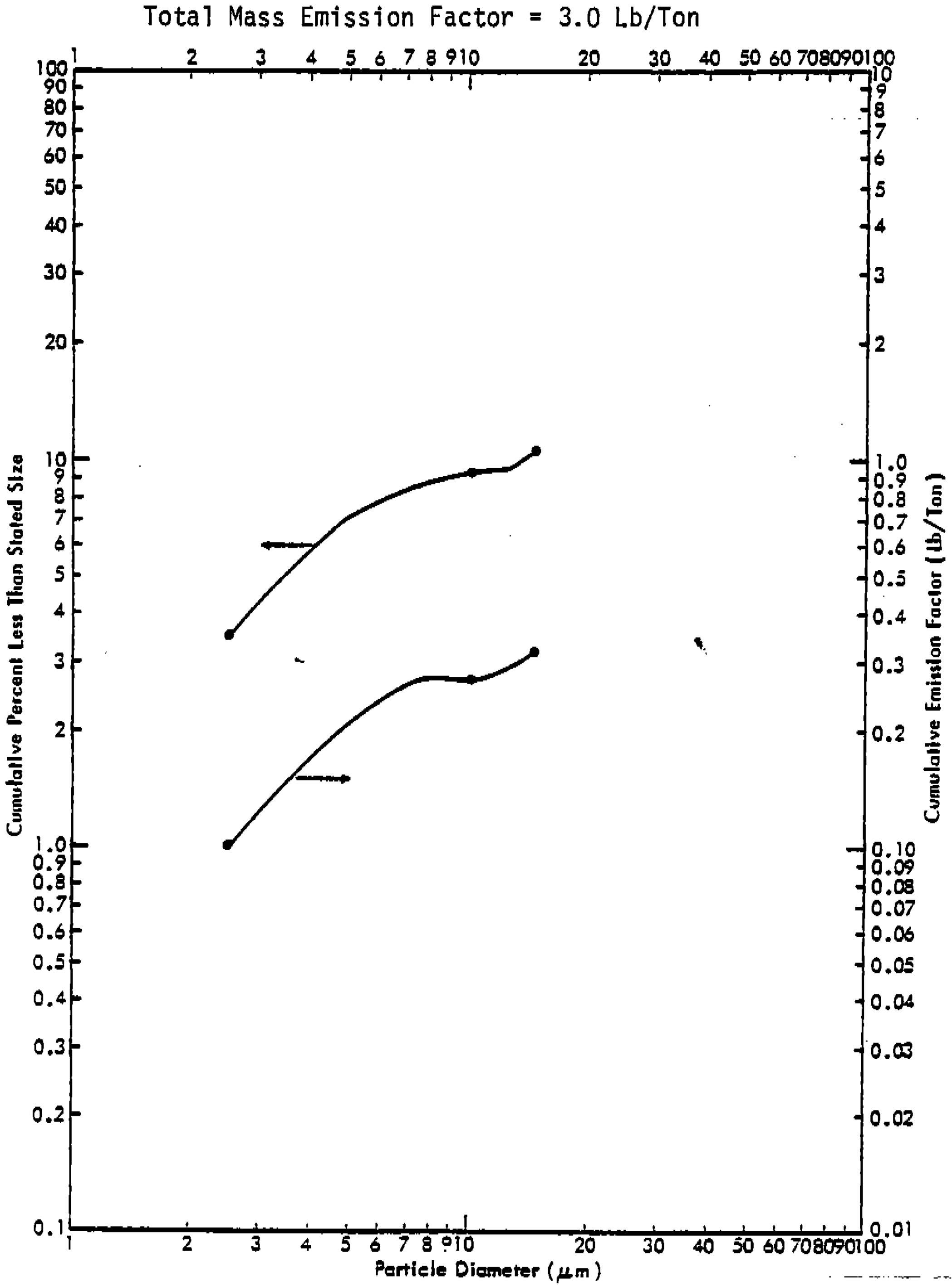


Figure 3-23. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--dust collector--test three.

Total Mass Emission Factor = 2.3 Lb/Ton

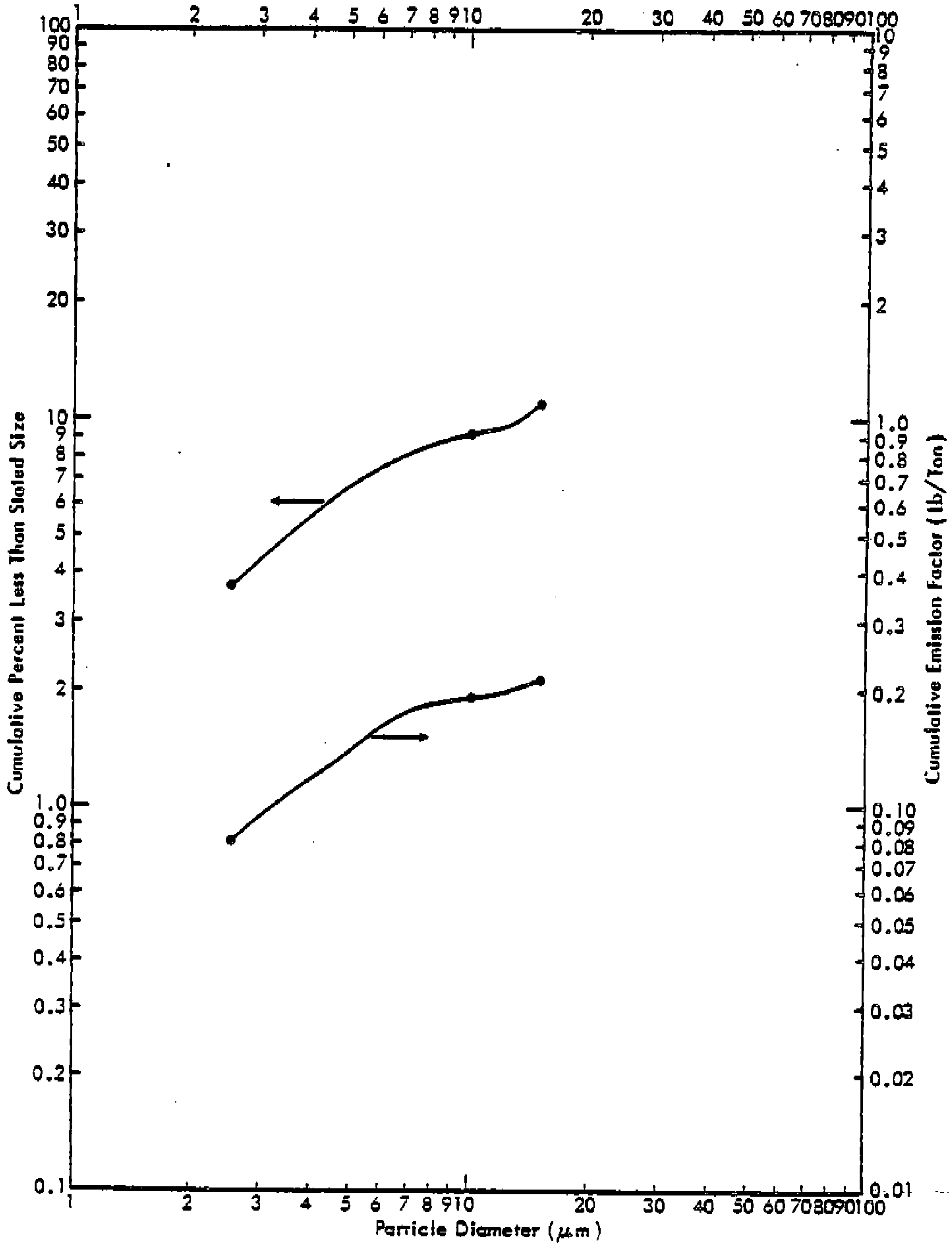


Figure 3-24. Cumulative percent less than stated size and cumulative emission factor versus particle diameter—dust collector—test four.

Total Mass Emission Factor = 2.2 Lb/Ton

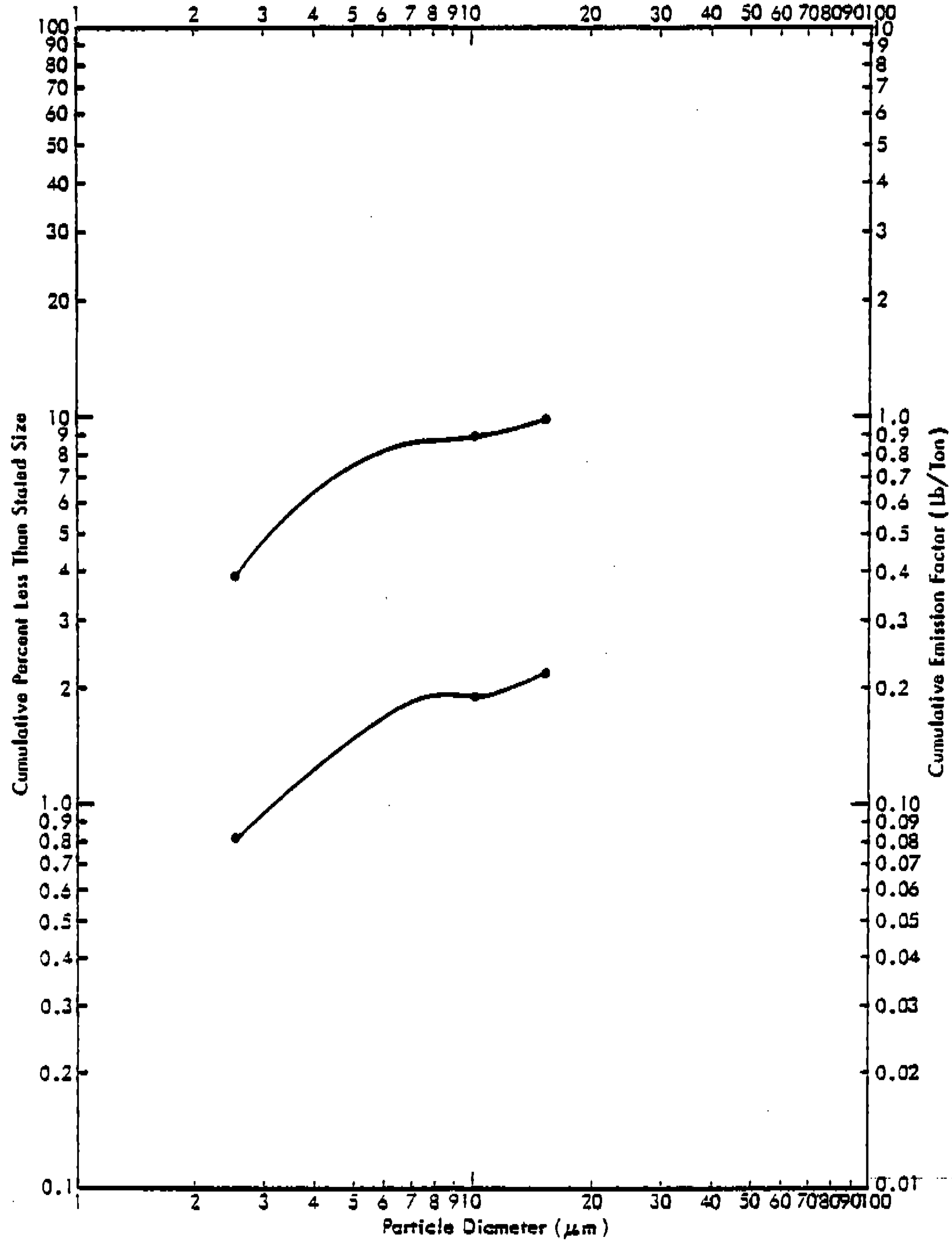


Figure 3-25. Cumulative percent less than stated size and cumulative emission factor versus particle diameter--dust collector--total average.

TABLE 3-10. SUMMARY OF EMISSION FACTORS

	Test No.	Emission factors (lb/ton)[a]			
		Total	15 µm	10 µm	2.5 µm
Baghouse Inlet	1	133.8	74.8	52.0	14.2
	2	120.3	70.8	50.5	12.5
	3	118.9	72.7	53.6	15.6
	4	108.4	64.3	45.0	8.9
	Average	120.4	70.7	50.3	12.8
Outlet	1	0.13	0.09	0.08	0.03
	2	0.09	0.06	0.05	0.02
	3	0.10	0.08	0.07	0.03
	4	0.10	0.09	0.07	0.03
	Average	0.11	0.08	0.06	0.03
Electrostatic Precipitator Inlet	1	354.4	134.0	50.0	3.6
	2	378.4	212.0	69.1	4.0
	3	395.5	154.1	59.7	2.6
	4	359.5	138.0	53.9	2.8
	Average	371.9	159.5	58.2	3.3
Outlet	1	8.1	5.7	4.3	1.1
	2	10.5	5.8	4.7	1.1
	3	9.1	6.2	4.9	1.6
	4	9.5	5.3	4.6	1.2
	Average	9.3	5.8	4.6	1.3
Dust Collector	1	1.8	0.17	0.15	0.06
	2	1.7	0.16	0.16	0.07
	3	3.0	0.32	0.27	0.10
	4	2.3	0.21	0.19	0.08
	Average	2.2	0.22	0.19	0.08

[a] lb/ton = pounds per ton of product

If it is assumed that all of the ash produced in kiln no. 6 enters the ESP, the contribution of the ash to the total inlet emission factor is 12%. Since no direct information was obtained from this test as to the size distribution and collection efficiencies of the coal ash, it is not possible to estimate its contribution to the controlled emissions.

3.2 NONDUCTED SOURCES

This section presents the test results for the nonducted sources in graphic and tabular form. The raw data and the computer printouts for these tests are presented in Appendix M.

3.2.1 Data Reduction Procedures

A computer program developed by MRI was used to reduce the raw lab and field data to actual concentration values expressed in micrograms per cubic meter. This program incorporates a series of algorithms, which not only corrects the air flow through the sampler to standard conditions and calculates the concentration from the mass of material collected, but also automatically subtracts the upwind concentration from the downwind value to provide the net contribution of the source being tested. These calculations are performed for each sampler, including the individual impactor stages, which also determines the percent variation from isokinetic sampling conditions. Since the program does not adjust the various cutpoints (D_{50}) of the cyclone/impactor sampling system for variations in air flow conditions, these calculations were performed manually according to the following equations:

For the Cyclone Preseparator:

$$D_2 = \frac{D_1 Q_1}{Q_2}$$

where: D_2 = Corrected cutpoint (D_{50})
D_1 = Cutpoint at standard conditions
Q_1 = Standard air flow rate
Q_2 = Actual air flow rate

For the Cascade Impactor stages:

$$D_2 = \frac{Q_1}{Q_2} \cdot D_1$$

where: D_1, D_2, Q_1, and Q_2 are the same as above

Tables summarizing the results obtained from the above analysis are included in Tables 3-11 through 3-15 for Runs S-1 through S-5, respectively. A complete copy of the outputs provided by the computer is contained in Appendix A.

TABLE 3-11. SUMMARY OF TEST RESULTS FOR RUN S-1

Sampler ID No.	Type of sample: Upwind (background)	Type of sample: Downwind (source)	Sampling height (m)	Sampling duration (min)	Air flow rate[a] standard conditions ft^3/min	Air flow rate[a] standard conditions ℓ/min	Concentration of particulate matter measured by sampler ($\mu g/m^3$)[b]: Total particulate	Total suspended particulate	Inhalable particulate	Cyclone/impactor stages (µmA): > 11.36[c]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[d]
TSP-1	X		2	60	45	1,274.2	-	-	-	-	-	-	-	-	-	-
TSP-2		X	2.5	5	45	1,274.2	-	248,024	-	-	-	-	-	-	-	-
IP-3	X		2	60	40	1,132.6	-	-	-	-	-	-	-	-	-	-
IP-4		X	2.5	5	40	1,132.6	-	-	165,970	-	-	-	-	-	-	-
IP-5		X	4	5	40	1,132.6	-	-	365,468	-	-	-	-	-	-	-
CI-1	X		2	60	20	566.3	-	-	-	-	-	-	-	-	-	-
CI-2		X	2.5	5	20	566.3	495,333	-	-	342,081	49,808	63,540	23,721	10,201	3,971	2,009
CI-3		X	4	5	20	566.3	614,826	-	-	347,185	10,484	30,728	43,066	105,123	74,677	3;562

[a] Standard conditions = 25°C and 760 mm Hg.

[b] - indicates no data directly available.

[c] Cyclone catch

[d] Backup filter.

TABLE 3-12. SUMMARY OF TEST RESULTS FOR RUN S-2

Sampler ID No.	Type of sample: Upwind (background)	Type of sample: Downwind (source)	Sampling height (m)	Sampling duration (min)	Air flow rate[a] standard conditions: ft³/min	Air flow rate[a] standard conditions: l/min	Concentration of particulate matter measured by sampler (μg/m³)[b]: Total particulate	Total suspended particulate	Inhalable particulate	Cyclone/Impactor stages (μmA): > 11.36[c]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[d]
TSP-1	X		2	60	45	1,274.2	-	-	-	-	-	-	-	-	-	-
TSP-2		X	2.5	5	45	1,274.2	-	299,257	-	-	-	-	-	-	-	-
IP-3	X		2	60	40	1,132.6	-	-	-	-	-	-	-	-	-	-
IP-4		X	2.5	5	40	1,132.6	-	-	172,466	-	-	-	-	-	-	-
IP-5		X	4	5	40	1,132.6	-	-	351,464	-	-	-	-	-	-	-
CI-1	X		2	60	20	566.3	-	-	-	-	-	-	-	-	-	-
CI-2		X	2.5	5	20	566.3	232,775	-	-	108,572	32,829	46,490	22,680	15,196	4,324	2,682
CI-3		X	4	5	20	566.3	244,064	-	-	80,731	40,824	57,009	31,522	22,150	8,101	3,724

[a] Standard conditions = 25°C and 760 mm Hg.

[b] - Indicates no data directly available.

[c] Cyclone catch

[d] Backup filter.

TABLE 3-13. SUMMARY OF TEST RESULTS FOR RUN S-3

Sampler ID No.	Type of sample: Upwind (background)	Type of sample: Downwind (source)	Sampling height (m)	Sampling duration (min)	Air flow rate[a] standard conditions: ft³/min	Air flow rate[a] standard conditions: l/min	Concentration of particulate matter measured by sampler (μg/m³)[b]: Total particulate	Total suspended particulate	Inhalable particulate	Cyclone/impactor stages (μmA): > 11.36[c]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[d]
TSP-1	X		2	60	45	1,274.2	-	-	-	-	-	-	-	-	-	-
TSP-2		X	2.5	5	45	1,274.2	-	107,508	-	-	-	-	-	-	-	-
IP-3	X		2	60	40	1,132.6	-	-	-	-	-	-	-	-	-	-
IP-4		X	2.5	5	40	1,132.6	-	-	78,710	-	-	-	-	-	-	-
IP-5		X	4	5	40	1,132.6	-	-	248,194	-	-	-	-	-	-	-
CI-1	X		2	60	20	566.3	-	-	-	-	-	-	-	-	-	-
CI-2		X	2.5	5	20	566.3	145,350	-	-	92,382	2,047	6,195	10,042	19,909	13,184	1,588
CI-3		X	4	5	20	566.3	359,993	-	-	244,245	4,606	13,519	26,069	43,701	25,698	2,153

a Standard conditions = 25°C and 760 mm Hg.

b - indicates no data directly available.

c Cyclone catch

d Backup filter.

TABLE 3-14. SUMMARY OF TEST RESULTS FOR RUN S-4

Sampler ID No.	Type of sample: Upwind (background)	Type of sample: Downwind (source)	Sampling height (m)	Sampling duration (min)	Air flow rate[a] standard conditions: ft^3/min	Air flow rate[a] standard conditions: ℓ/min	Concentration of particulate matter measured by sampler ($\mu g/m^3$)[b]: Total particulate	Total suspended particulate	Inhalable particulate	Cyclone/impactor stages (μmA): > 11.36[c]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[d]
TSP-1	X		2	60	45	1,274.2	-	625	-	-	-	-	-	-	-	-
TSP-2		X	2.5	5	45	1,274.2	-	86,186	-	-	-	-	-	-	-	-
IP-3	X		2	60	40	1,132.6	-	-	473	-	-	-	-	-	-	-
IP-4		X	2.5	5	40	1,132.6	-	-	125,341	-	-	-	-	-	-	-
IP-5		X	4	5	40	1,132.6	-	-	628,807	-	-	-	-	-	-	-
CI-1	X		2	60	20	566.3	369	-	-	e	e	e	e	e	e	e
CI-2		X	2.5	5	20	566.3	237,711	-	-	184,372	13,308	22,856	8,595	5,648	1,765	1,164
CI-3		X	4	5	20	566.3	586,912	-	-	93,824	17,208	52,508	90,438	194,503	132,692	5,736

[a] Standard conditions = 25°C and 760 mm Hg.

[b] - indicates no data directly available.

[c] Cyclone catch

[d] Backup filter.

[e] Cannot be adequately determined given existing data.

TABLE 3-15. SUMMARY OF TEST RESULTS FOR RUN S-5

Sampler ID No.	Type of sample: Upwind (background)	Type of sample: Downwind (source)	Sampling height (m)	Sampling duration (min)	Air flow rate[a] standard conditions: ft³/min	Air flow rate[a] standard conditions: ℓ/min	Concentration of particulate matter measured by sampler (µg/m³)[b]: Total particulate	Total suspended particulate	Inhalable particulate	Cyclone/impactor stages (µmA): > 11.36[c]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[d]
TSP-1	X		2	60	45	1,274.2	-	273	-	-	-	-	-	-	-	-
TSP-2		X	2.5	5	45	1,274.2	-	8,681	-	-	-	-	-	-	-	-
IP-3	X		2	60	40	1,132.6	-	-	146	-	-	-	-	-	-	-
IP-4		X	2.5	5	40	1,132.6	-	-	5,545	-	-	-	-	-	-	-
IP-5		X	4	5	40	1,132.6	-	-	64,648	-	-	-	-	-	-	-
CI-1	X		2	60	20	566.3	423	-	-	260	5	16	22	32	44	42
CI-2		X	2.5	5	20	566.3	56,609	-	-	53,917	725	755	274	240	205	490
CI-3		X	4	5	20	566.3	59,439	-	-	46,172	4,363	3,206	1,343	853	39	3,461

[a] Standard conditions = 25°C and 760 mm Hg.

[b] - indicates no data directly available.

[c] Cyclone catch

[d] Backup filter.

The output from the computer program was further reduced for the cyclone/impactor data to obtain a particle size distribution for each set of samples collected. This was accomplished using a standard linear regression analysis to obtain the least squares line fit of the data. The analysis was performed using a TI-59 programmable calculator and a program developed by MRI. The results of the linear regression analysis were then used to extrapolate or interpolate as necessary to determine the percentage of the total particulate concentration which contain particles less than 15 μm (aerodynamic) and less than 2.5 μm (aerodynamic) in size.

The results of the above linear regression analyses were plotted on log-probability paper along with the actual data obtained for each cyclone/impactor sample. Wherever applicable, the background (upwind) sample for a particular run has been shown on one graph and the source (downwind) samples shown on another. Also indicated on each graph is the correlation coefficient obtained from the regression analysis, extrapolations of the least squares fit indicated by a dashed line, and actual data obtained from both the standard Hi-Vol and the Hi-Vol W/SSI for comparison purposes. Plots of the data from all five test runs have been provided in Figures 3-26 through 3-31. A plot for sampler CI-1 (background) for Run S-4 was not prepared due to a cyclone catch which was determined to be less than the field blank value, thus giving a size distribution of questionable validity.

3.2.2 Data Analysis

Upon examination of the data obtained from the field sampling program, a number of conclusions and observations can be made. From Tables 3-11 through 3-15, it can be seen that the emissions generated as a result of product loading operations do contribute heavily to the concentrations of particulate matter measured downwind of the source, regardless of particle size. Even though the background concentrations are significant, they are negligible when compared to those determined during product loading. In every case, the background contributes less than 1% to the overall downwind particulate concentrations observed during the five source test runs. For this reason, the background concentrations can, essentially be ignored even though they were used to a minor extent in the emission factor calculations.

From the particle size distribution curves shown in Figures 3-26 through 3-31, it can be determined that the particles collected by the sampler at the 4-m level (CI-3) tend to be somewhat smaller than those collected at the 2.5-m level (CI-2). The magnitude of this varys from run to run. Such a shift in particle size would not be unexpected, however, due to the effects of gravitational settling which would contribute to the production of a higher population of larger particles toward the bottom portion of the loading bay area. It can also be seen that the results obtained with the standard Hi-Vols and Hi-Vols with SSIs do at least somewhat agree with the particle size determined by the Hi-Vols with cyclones and impactors in three of the five runs, even though they can vary significantly depending on the particular sample.

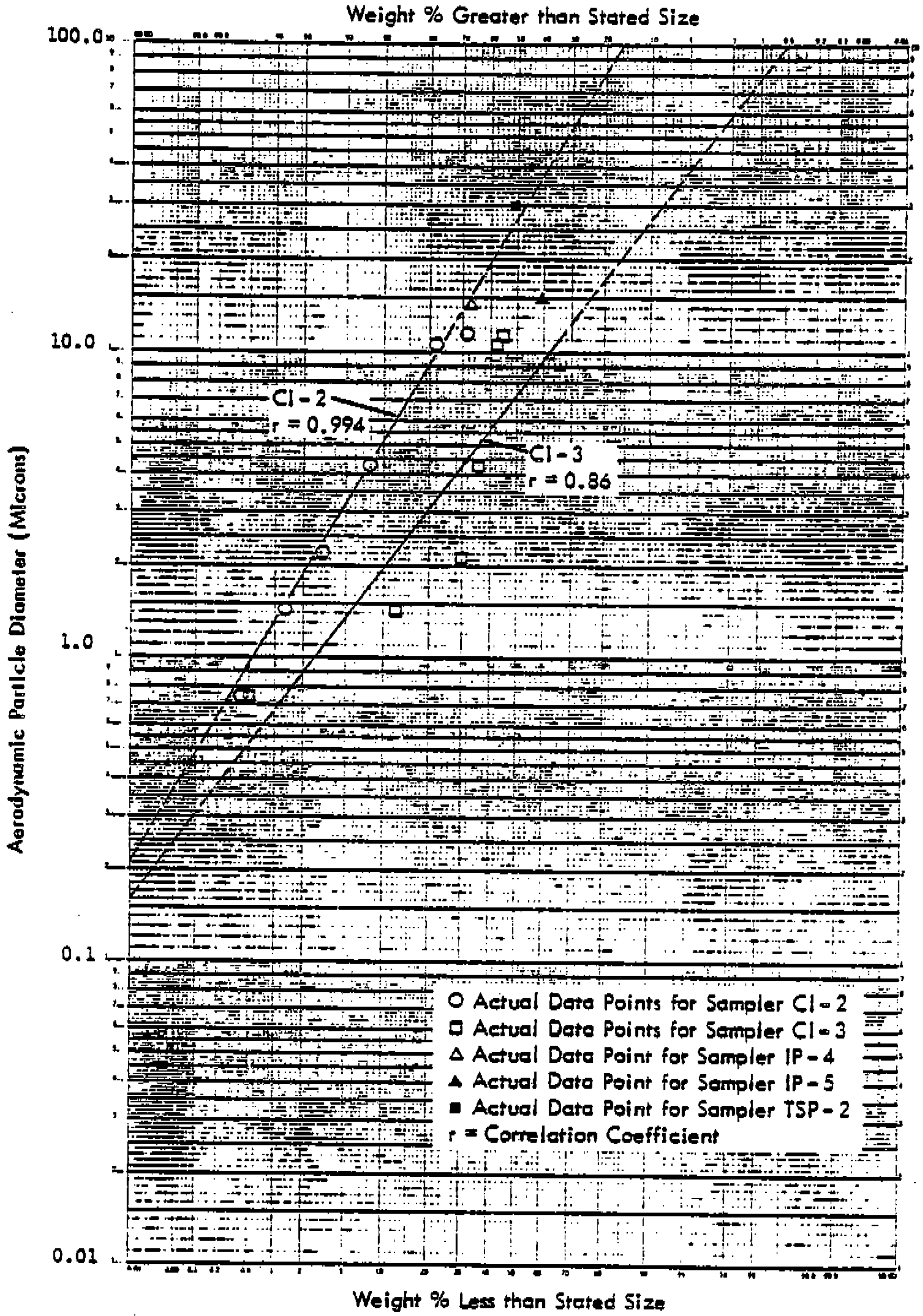


Figure 3-26. Particle size distributions for test run S-1.

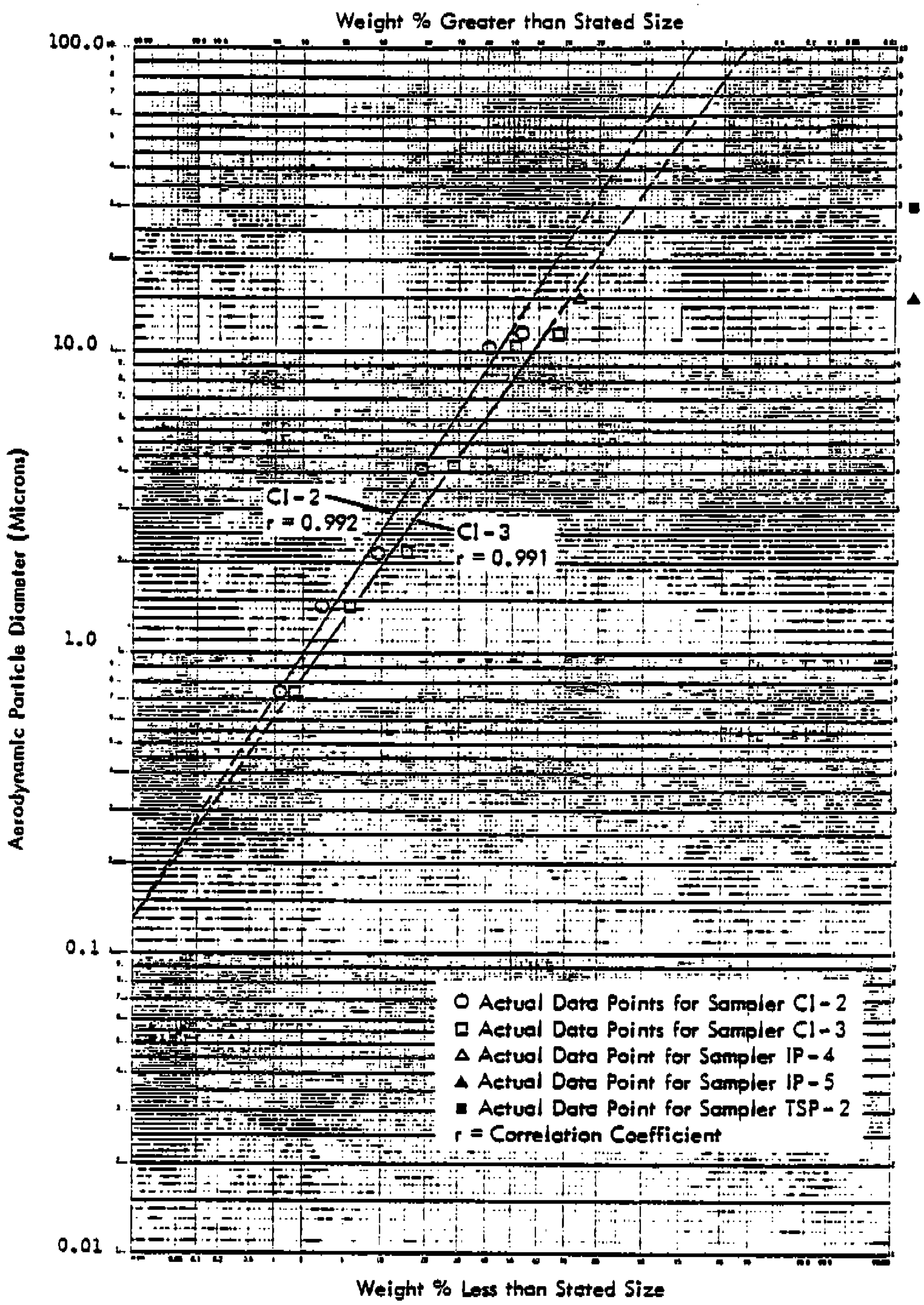


Figure 3-27. Particle size distribution for test run S-2.

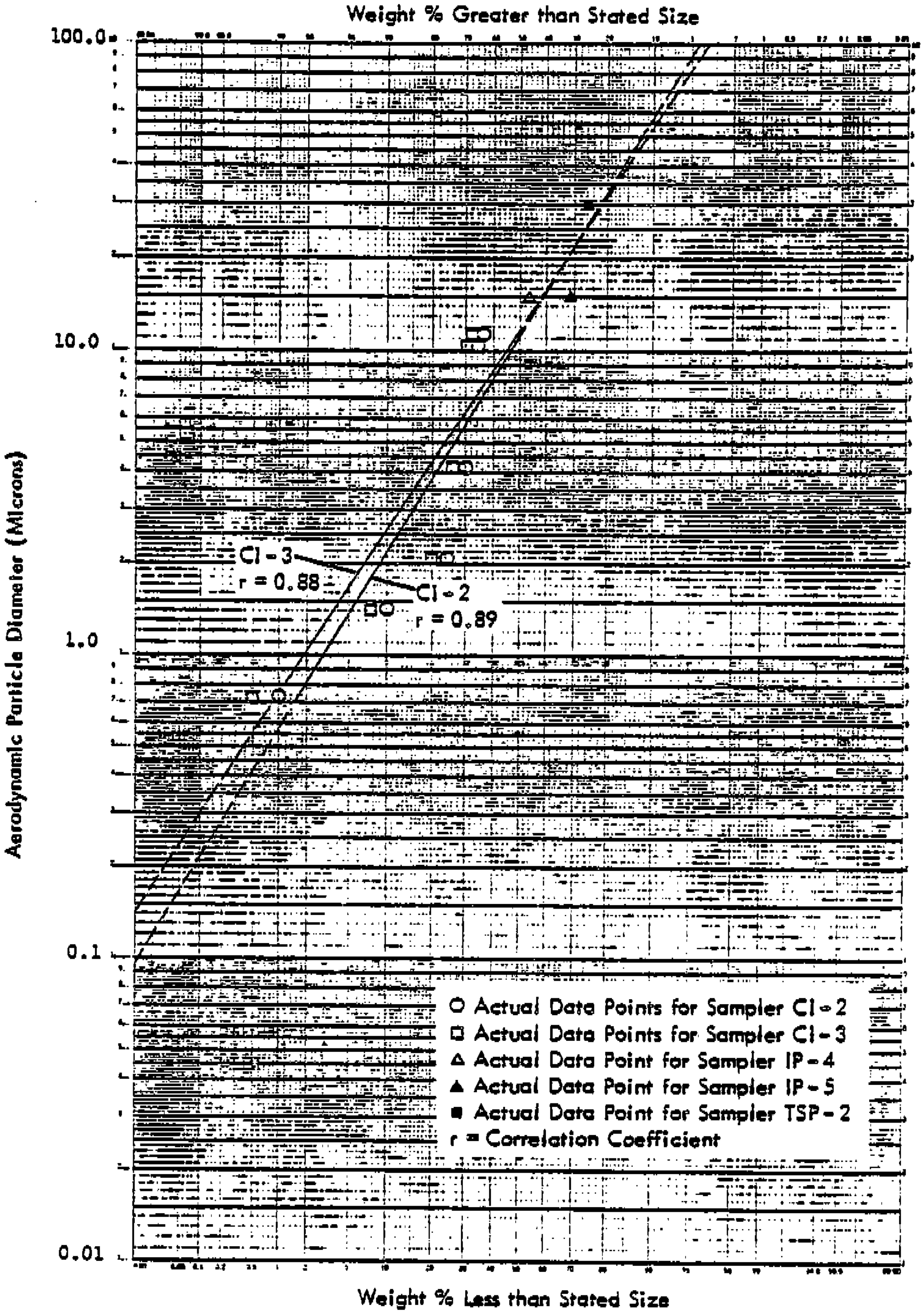


Figure 3-28. Particle size distribution for test run S-3.

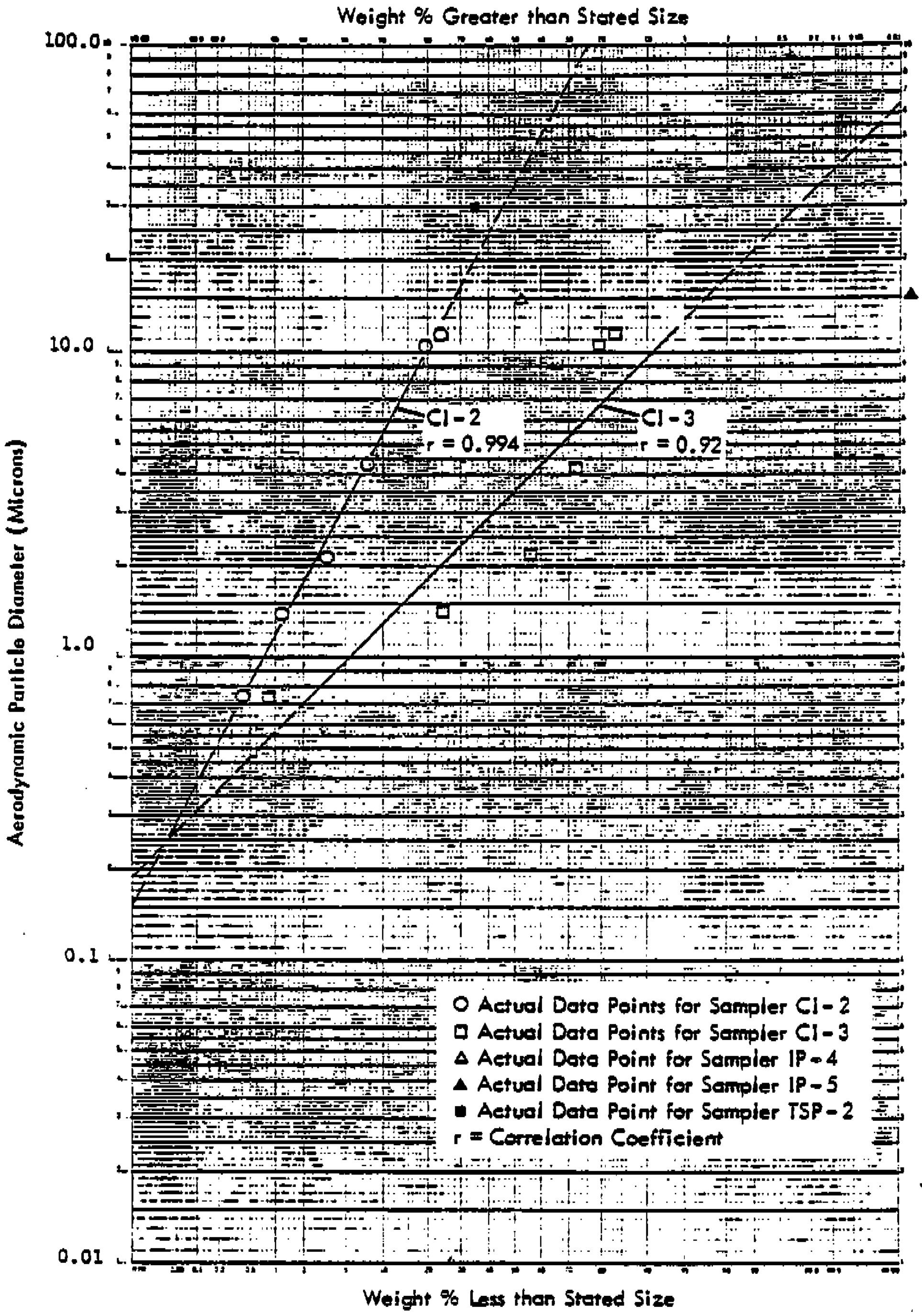


Figure 3-29. Particle size distribution for test run S-4.

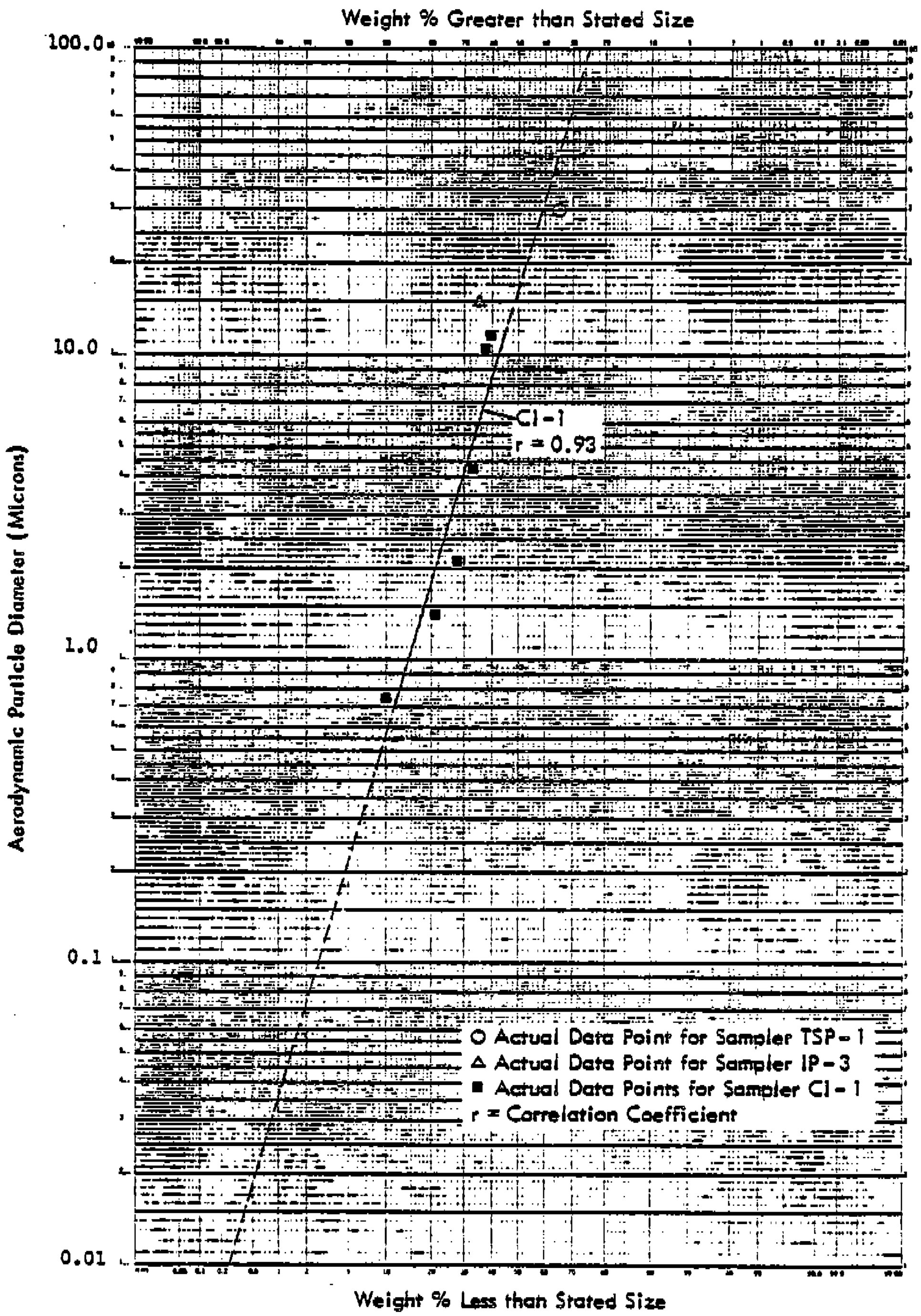


Figure 3-30. Particle size distribution of background sample for test run S-5.

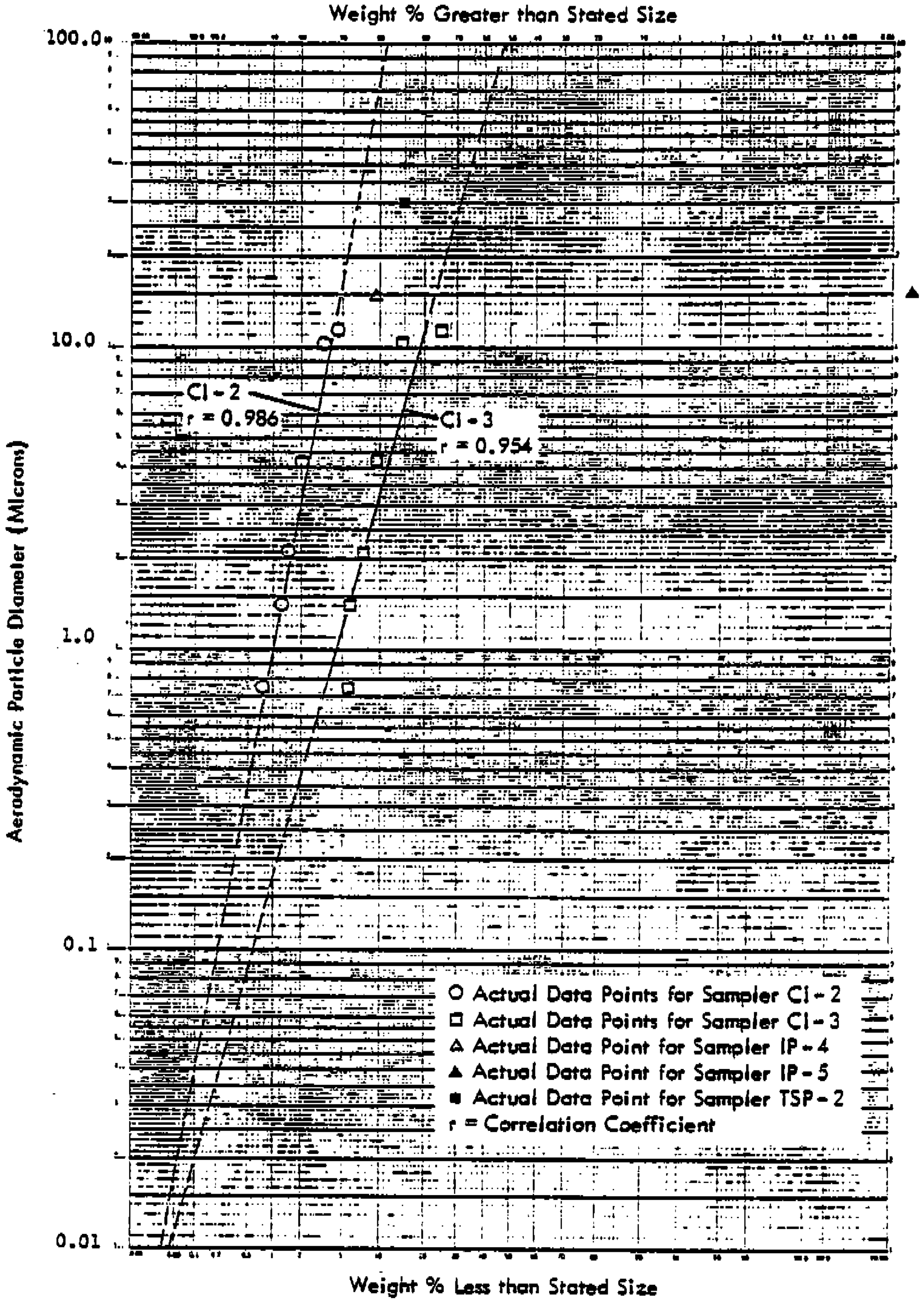


Figure 3-31. Particle size distributions of source samples for test run S-5.

Another interesting point is the high cyclone wash blanks determined in the field. Such high blank values would indicate a definite possibility for contamination of the sample during either equipment setup or recovery operations. Such contamination would tend to produce a positive bias in the results, resulting in higher measure concentrations than were actually present during the test period. The magnitude of any possible error associated with sample contamination cannot truly be assessed based on available data.

3.2.3 Emission Factor Development

From the above discussion, it can be seen that a very simplified approach was taken during the field sampling program to measure the emissions associated with the truck loading operations at the Pfizer plant. For this reason, it was decided to also use a much less rigorous technique than would otherwise be performed to develop appropriate emission factors for the truck loading operation. The following describes the procedures used to develop these emission factors as a function of particle size.

Using the results of the linear regression analysis performed above and the net concentration (downwind-upwind) of total particulate from the computer output, the source contributions of inhalable particulate (< 15 μm) and fine particulate (< 2.5 μm) were calculated for the cyclone/impactor samples. This was accomplished by extracting the percent of the total mass collected in each size fraction from the regression analysis (Figures 3-26 through 3-31) and multiplying it by the net concentration of TP to give the actual contribution of IP and FP from the source. Only the net concentration of total particulate was used in this determination with no attempt being made to subtract out specific background concentrations of IP and FP. This technique seemed justified in light of the negligible background concentrations which were observed, and the fact that the background size distribution for Runs S-1 through S-4 was of questionable validity. Results of these calculations have been provided in Table 3-16.

The emission factors were calculated based on a simple ratio of areas method using total plume mass flux emanating from the truck loading bay. The total cross-sectional area was divided into two separate segments, with one segment representing the upper portion, and a second segment representing the lower portion as shown in Figure 3-32. The samplers located at the 4-m level were considered to adequately characterize the emissions from the upper portion of the bay, and the samplers at the 2.5-m level were considered to characterize emissions from the lower portion. The mean wind velocity measured in the field at 2 and 4 m were used along with the two cross-sectional areas to calculate the total flux through the upper and lower portions of each loading bay using the following relationship:

$$Q_{An} = AV_{Avg}$$

where: Q = Total plume mass flux for either Area 1 or 2
A = Cross-sectional area (m^2)
V_{Avg} = Average observed wind velocity (m/min)

TABLE 3-16. NET CONCENTRATIONS OF INHALABLE AND FINE PARTICULATE MATTER DERIVED FROM CYCLONE/IMPACTOR DATA

Test run No.	Net concentration of inhalable particulate matter (< 15 μm)		Net concentration of fine particulate matter (< 2.5 μm)	
	Sampler CI-2 (μg/m³)	Sampler CI-3 (μg/m³)	Sampler CI-2 (μg/m³)	Sampler CI-3 (μg/m³)
S-1	169,130	461,703	18,809	86,761
S-2	134,795	172,512	22,311	34,069
S-3	88,569	211,675	18,891	35,711
S-4	63,940	568,947	8,165	201,771
S-5	2,663	13,060	950	4,497

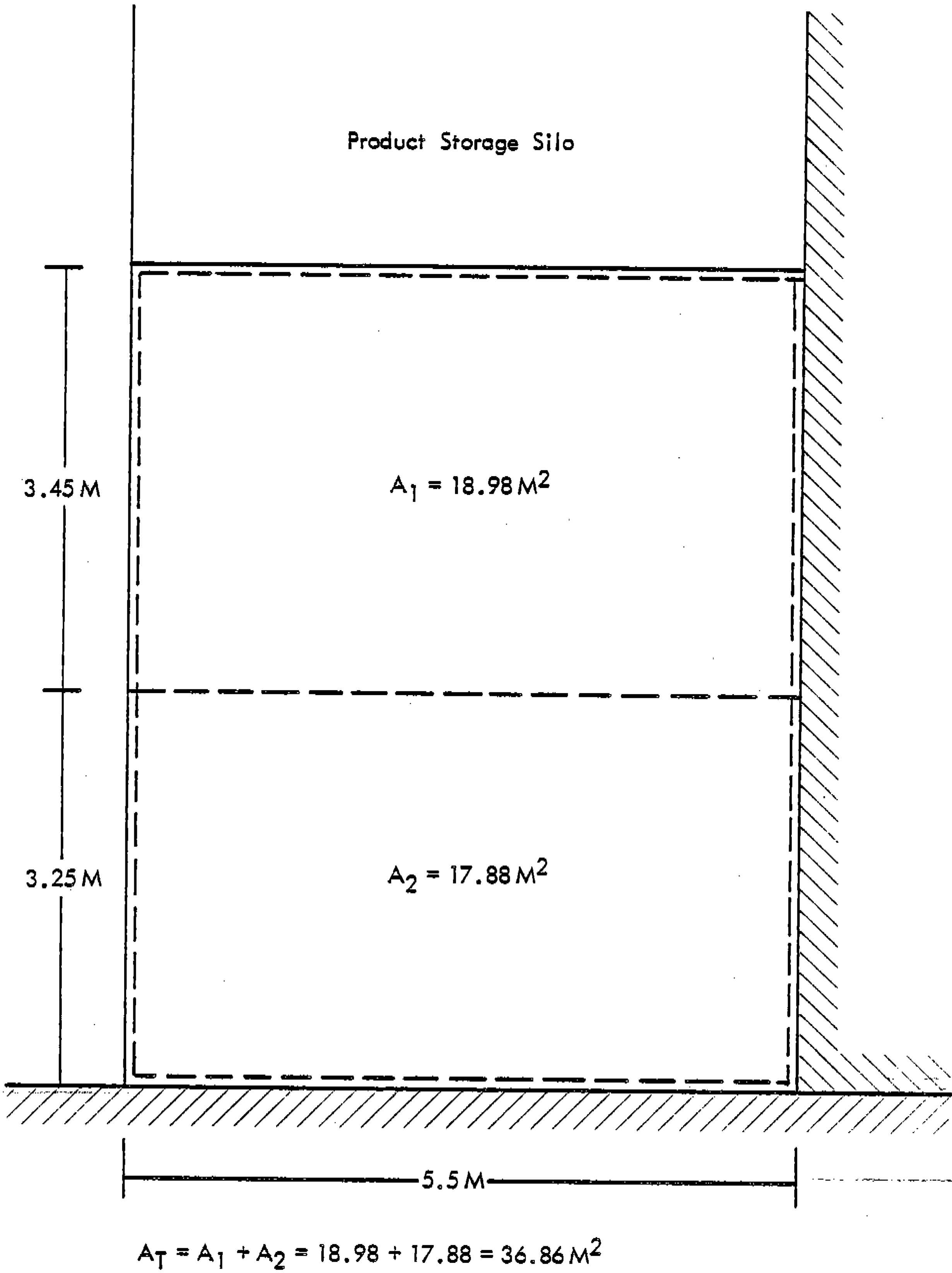


Figure 3-32. Cross-sectional area of truck loading bay.

Since velocity profiles were performed prior to only three of the five test runs, the average wind velocities for Run S-2 were assumed to identical to that determined during Run S-1, and the average velocities for Run S-4 were assumed identical to Run S-3. Results of the mass flux calculations are given in Table 3-17.

Given the mass flux through both portions of the loading bay area, individual emission factors were calculated for total particulate, inhalable particulate (< 15 μm), and fine particulate (< 2.5 μm) for each sample collected during the five test runs. Only information from the Hi-Vols with cyclone/impactors and the Hi-Vols with size selective inlets were used for this purpose. Data from the standard Hi-Vols were not directly included in this analysis, since the normal cutpoint of the sampler inlet was not of interest to this program.

Individual emission factors were calculated for both the upper and lower portions of the loading area using the appropriate concentration of TP, IP, or FP representing that particular segment, the mass flux through that area, and the source extent (material loading rate) determined in the field according to the following relationship:

$$EF_{An} = \frac{PC \times MF}{SE} \times CF$$

where: EF = Particulate emission factor for either Area 1 or 2 (kg of emissions/Mg (10^6 g) of product loaded)

PC = Particulate concentration obtained during testing (10^{-6} gm/m^3)

MF = Mass flux for the appropriate cross-sectional area (m^3/min)

SE = Source extent (tons of product loaded/min)

CF = Conversion factor from English to metric units = $1.101\ (10)^{-3}$

In the case of IP where individual concentration values were obtained from both a Hi-Vol with SSI and by extrapolation of the data from a Hi-Vol with cyclone/impactor, a separate emission factor was calculated for each sample with an arithmetic mean value used to represent that particular portion of the loading area.

To obtain the overall emission factor for the product loading operation, the factors calculated for the upper and lower portions of the area were added together to obtain the cumulative emissions for that particular run. This calculation can be expressed as:

TABLE 3-17. RESULTS OF PLUME MASS FLUX CALCULATIONS

Test run No.	Average observed wind velocity				Plume mass flux			
	Upper portion of loading bay		Lower portion of loading bay		Upper portion of loading bay		Lower portion of loading bay	
	fpm	m/min	fpm	m/min	ft^3/min	m^3/min	ft^3/min	m^3/min
S-1	605.4	184.5	555.4	169.3	123,664.0	3,501.8	106,900.2	3,027.1
S-2	605.4	184.5	555.4	169.3	123,664.0	3,501.8	106,900.2	3,027.1
S-3	633.3	193.0	583.3	177.8	129,360.2	3,663.1	112,260.9	3,178.9
S-4	633.3	193.0	583.3	177.8	129,360.2	3,663.1	112,260.9	3,178.9
S-5	433.3	132.1	366.7	111.8	88,543.8	2,507.3	70,593.5	1,999.0

$$EF_T = EF_{A_1} + EF_{A_2}$$

where: EF_T = Total emission factor for a particular run (kg/Mg product)
EF_{A_1} = Emission factor for Area 1 (kg/Mg product)
EF_{A_2} = Emission factor for Area 2 (kg/Mg product)

A sample calculation for Run S-1 has been included in Appendix B, with a summary of the results of the emission factor calculations provided in Table 3-18.

By using the above method, a weighting factor is applied to the concentration values since they are only used to represent the area where the samplers were located and the plume mass flux in that particular area. The cumulative emission factor was obtained by simply adding the emissions from both areas together to quantify the overall emissions from the source. The technique used to derive the emission factors is simplistic in its approach, but deemed appropriate given the inaccuracies associated with the data obtained during field sampling.

The next step is to determine appropriate emission factors for the entire spectrum of particle sizes not specifically calculated above. To accomplish this, only data from the samplers with cyclones and impactors could be used for this purpose, since they provide information in various size categories and not just a single concentration for particles less than a specified diameter. The same basic procedure as utilized previously for IP and FP was followed, with the emission factor for total particulate used as the basis, and the percent in various particle size fractions extracted from the linear regression analyses. Again, separate factors were determined for both the upper and lower portions of the tunnel, using data from the appropriate sampler, which were subsequently added together to obtain the cumulative emission factor for that particular run.

In order to plot the emission factor versus particle size, it is necessary to determine the maximum particle size included in the TP sample collected. Since such a determination was not actually performed experimentally estimates were formulated based on certain assumptions. From previous studies conducted by MRI of various types of fugitive emission sources, the maximum particle size has been determined to be approximately 100 µm using optical microscopy. On the other hand, a simple Stokes' law calculation, using the average observed wind velocity and a particle density of 1 g/cm^3, reveals that particles in the 300-µm (aerodynamic) range are theoretically possible. Based on this information, plots of the emission factor versus particle size were prepared for all five test runs with a maximum particle size of both 100 and 300 µm used as the upper limit. These plots have been shown in Figures 3-33 through 3-37.

TABLE 3-18. EMISSION FACTOR SUMMARY

Run No.	Type of truck	Type of material	Silt content (%)	Average air velocity through tunnel (ft/sec)	Calculated emission factor: Total particulate[a] (lb/ton)	Inhalable particulate[b] (lb/ton)	Fine particulate[c] (lb/ton)
S-1	Open	Limestone	40.1	580.4	1.676	0.896	0.166
S-2	Enclosed	Limestone	40.1	580.4	0.714	0.636	0.084
S-3	Enclosed	Limestone	40.1	608.3	0.816	0.508	0.088
S-4	Open	Limestone	40.1	608.3	1.332	1.144	0.352
S-5	Enclosed	Lime	29.6	400.0	0.302	0.124	0.016

Note: Overall emission factor = f(% silt, velocity, type of truck loaded).

[a] Particles < ~ 300 µmA

[b] Particles < 15 µmA

[c] Particles < 2.5 µmA

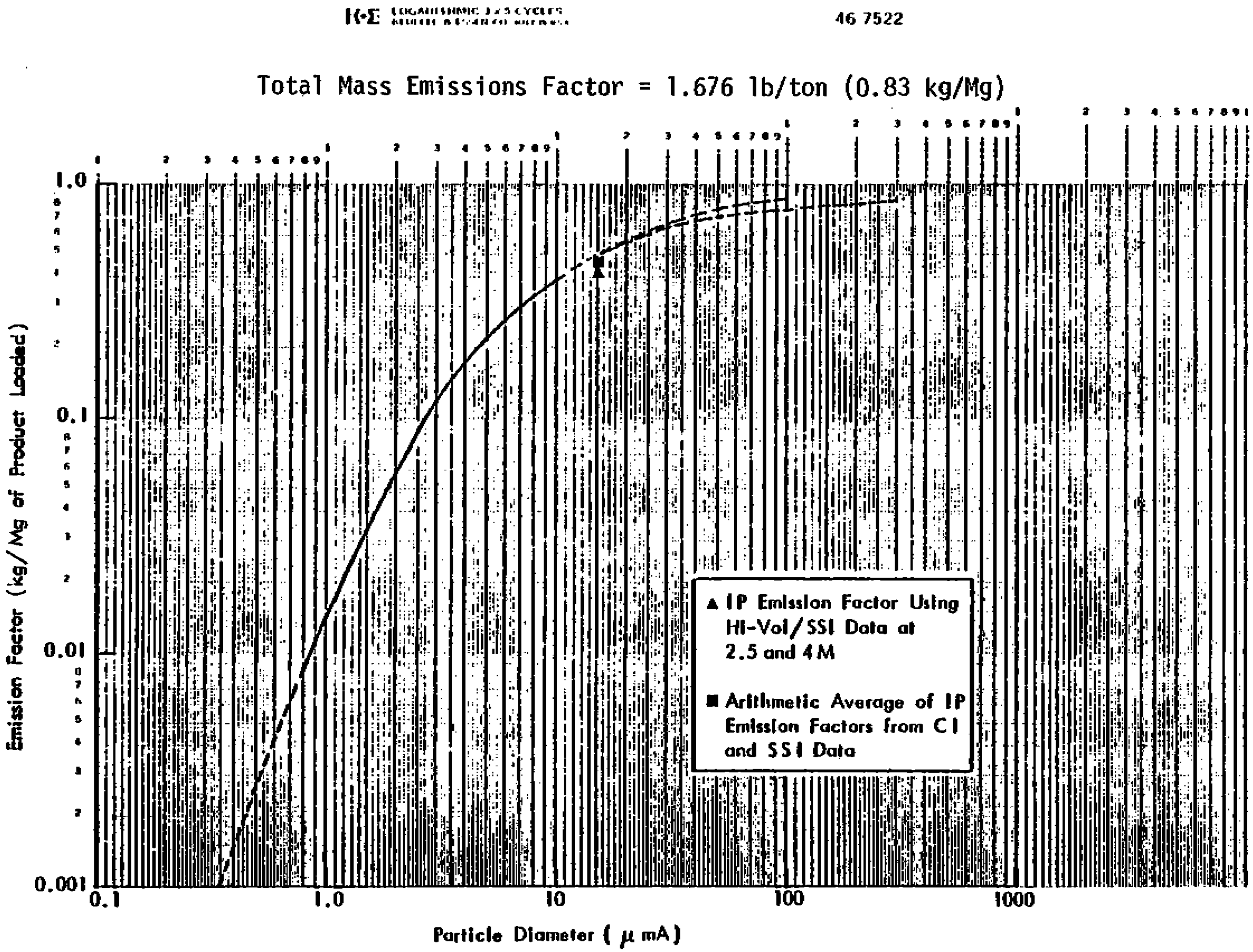


Figure 3-33. Emission factor by particle size for test run S-1.

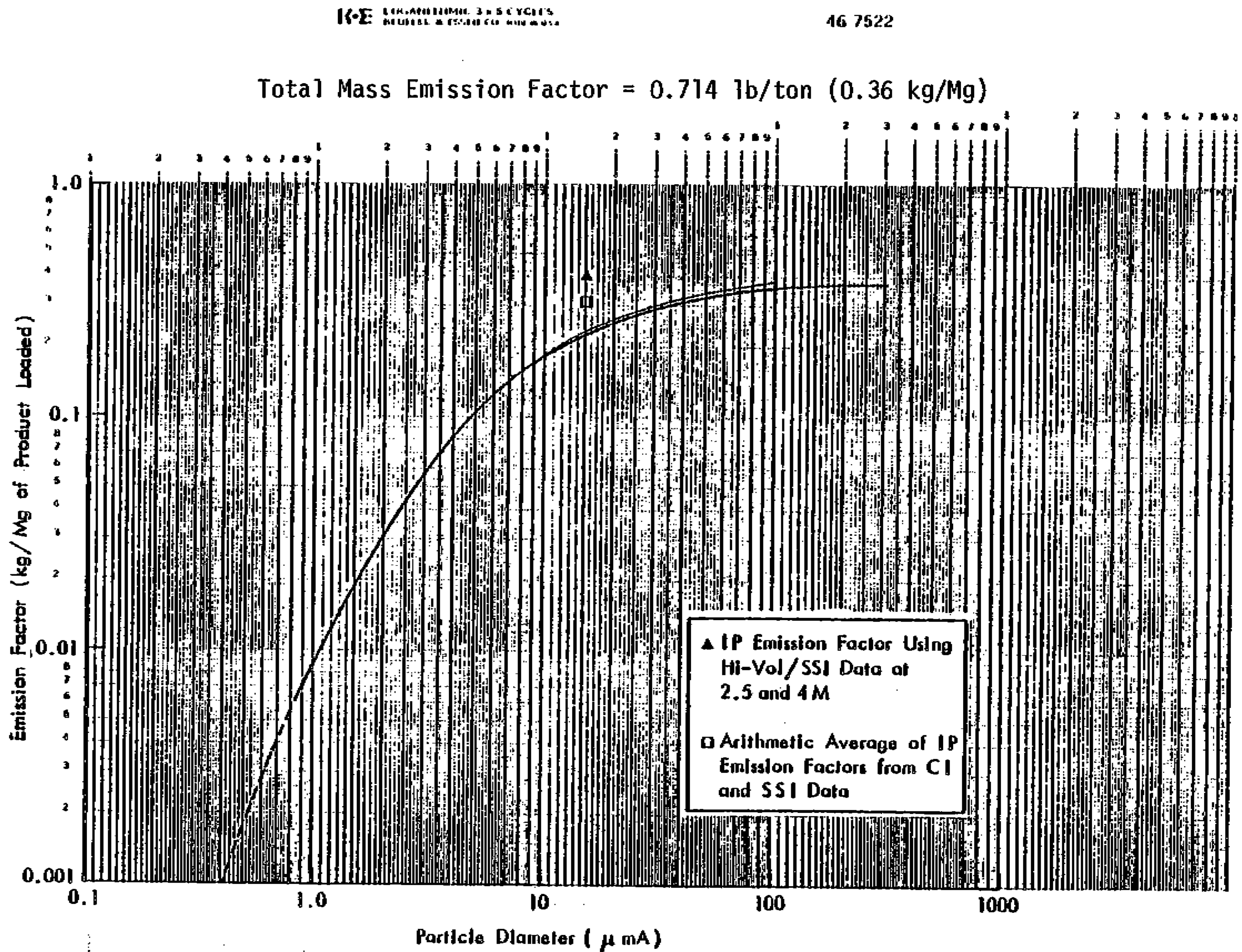


Figure 3-34. Emission factor by particle size for test run S-2.

Total Mass Emission Factor = 0.816 lb/ton (0.408 kg/Mg)

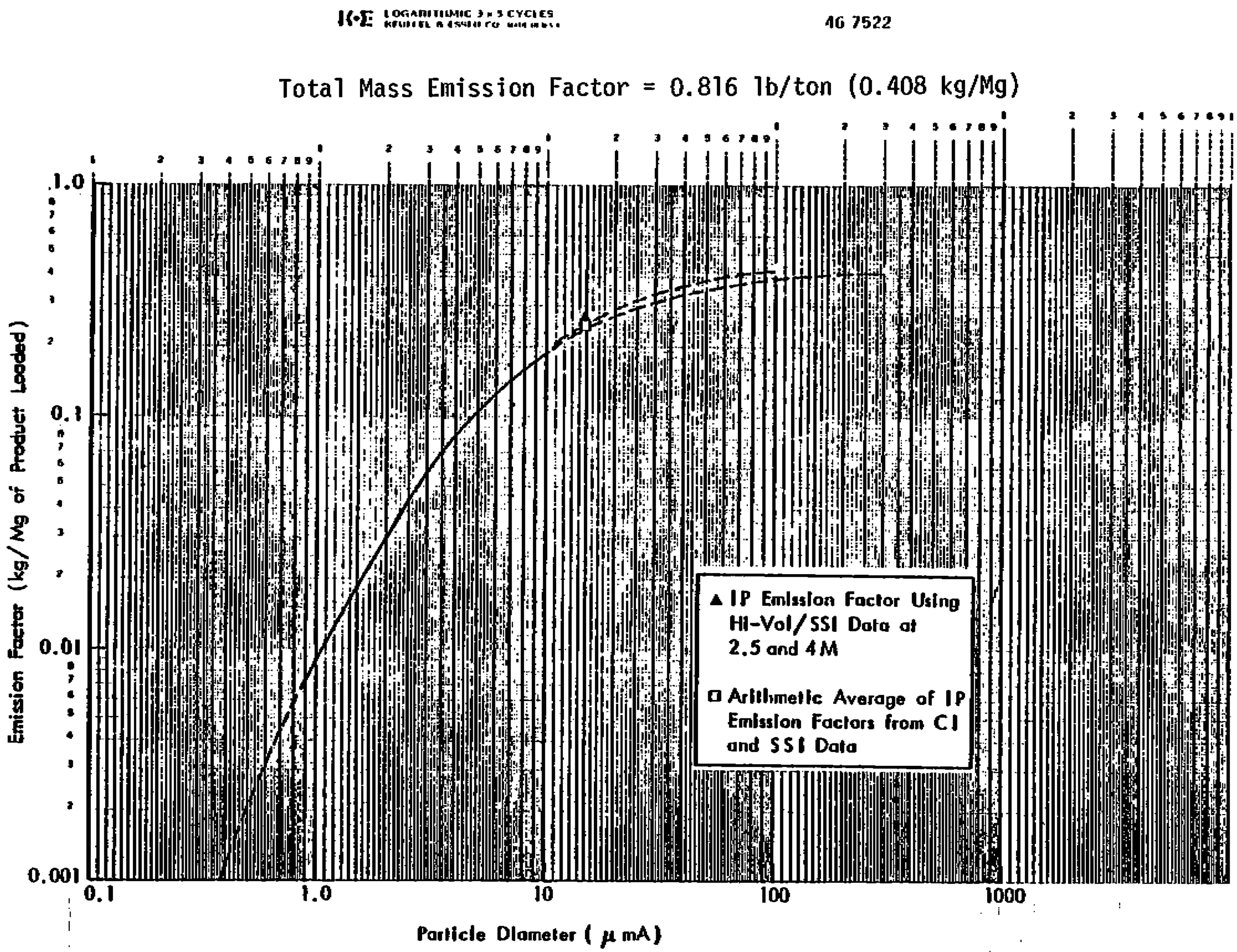


Figure 3-35. Emission factor by particle size for test run S-3.

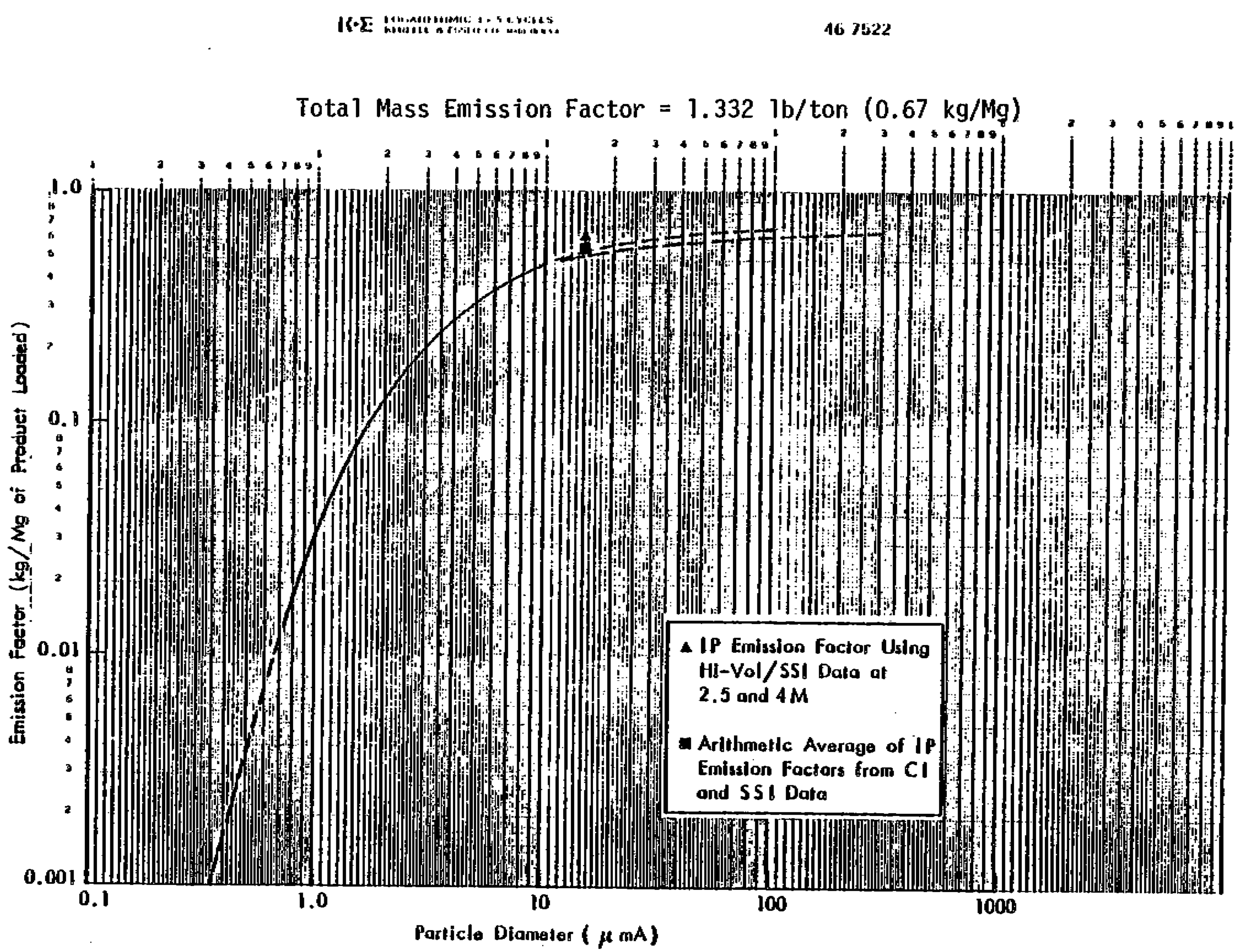


Figure 3-36. Emission factor by particle size for test run S-4.

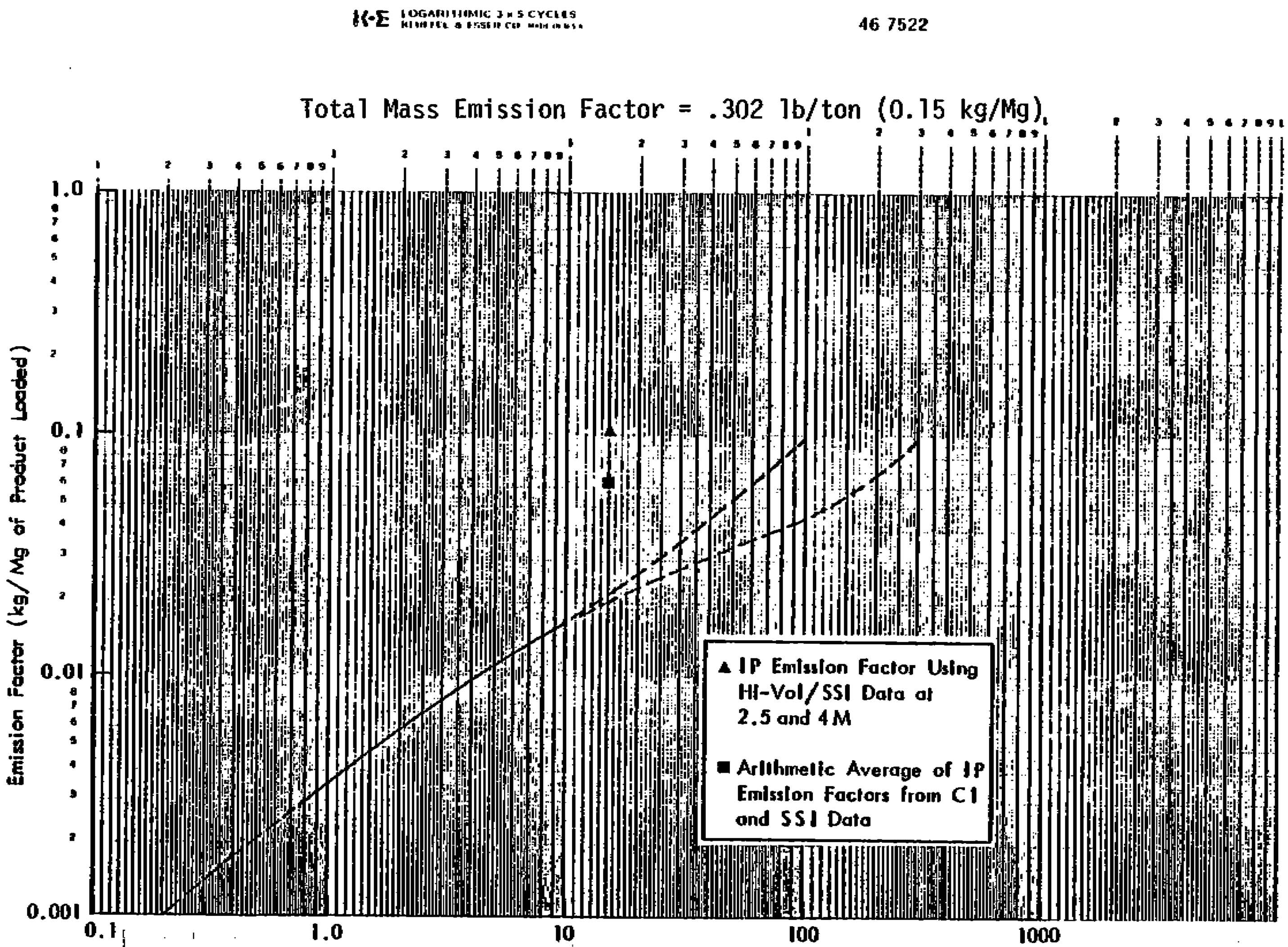


Figure 3-37. Emission factor by particle size for run S-5.

From Table 3-18, it is evident that the emission factor for the loading of limestone into enclosed trucks is somewhat smaller than that for the loading of limestone into open trucks. Such a conclusion also seems reasonable in light of observations made on-site. For this reason, it was determined appropriate to arithmetically average the calculated emission factors of TP, IP, and FP for Runs S-1 and S-4 to obtain overall factors for the loading of limestone into open trucks and likewise to average the factors for Runs S-2 and S-3 to obtain overall emission factors for the loading of limestone into enclosed trucks. A summary of these calculations has been provided in Table 3-19. Likewise, a cumulative emission factor versus particle size curve was prepared using a similar averaging technique and is shown in Figure 3-38 for the loading of limestone into open trucks and Figure 3-39 for loading into enclosed trucks. Figures 3-38 and 3-39 also provides an indication of the spread of the data by means of bars wherever such variation was significant and could be shown graphically.

From Figure 3-37 it can be seen that the shape of the emission factor versus particle size curve for Run S-5 is noticably different from those shown for the other four test runs. It is also significant that the data from the cyclone/impactors result in a much lower average IP emission factor than that obtained with the samplers equipped with SSIs.

As mentioned previously, it is suspected that the electrostatic properties of the bulk material (lime) may have affected the normal inertial separation of the particles. These effects would have been much more pronounced in a multiple stage device such as a cyclone/impactor system than in a single stage device such as a SSI. Any change in the nominal cutpoints of the cyclone/impactors based on aerodynamic theory would most certainly bias the results obtained. The magnitude of this potential bias could not be determined from currently available data.

Related data appears in the following appendices for ducted and unducted sources tested:

Appendix C - Raw Field Data

Appendix D - Accepted Runs But Not Used in Calculations

Appendix E - Suspect and Bad Runs

Appendix F - Laboratory and Analytical Data

Appendix H - Project Participants

Appendix K - Graphs of Mass Loading (dm/d log D) versus Geometric Mean of Particle Diameter

Appendix L - Sampling Logs

TABLE 3-19. AVERAGE EMISSION FACTORS FOR THE LOADING OF LIMESTONE

Type of loading operation	Average emission factor		
	Total particulate[a] (kg/Mg)[d]	Inhalable particulate[b] (kg/Mg)[d]	Fine particulate[c] (kg/Mg)[d]
Loading of limestone into open-bed trucks	0.75	0.51	0.13
Loading of limestone into tanker-type trucks	0.38	0.29	0.04

[a] Particles < ~ 300 μm.

[b] Particles < 15 μm.

[c] Particles < 2.5 μm.

[d] 1 kg = 10^3 g = 2.2 lb_m

1 Mg = 10^6 g = 1.1 short tons

1 kg/Mg = 2 lb/short ton

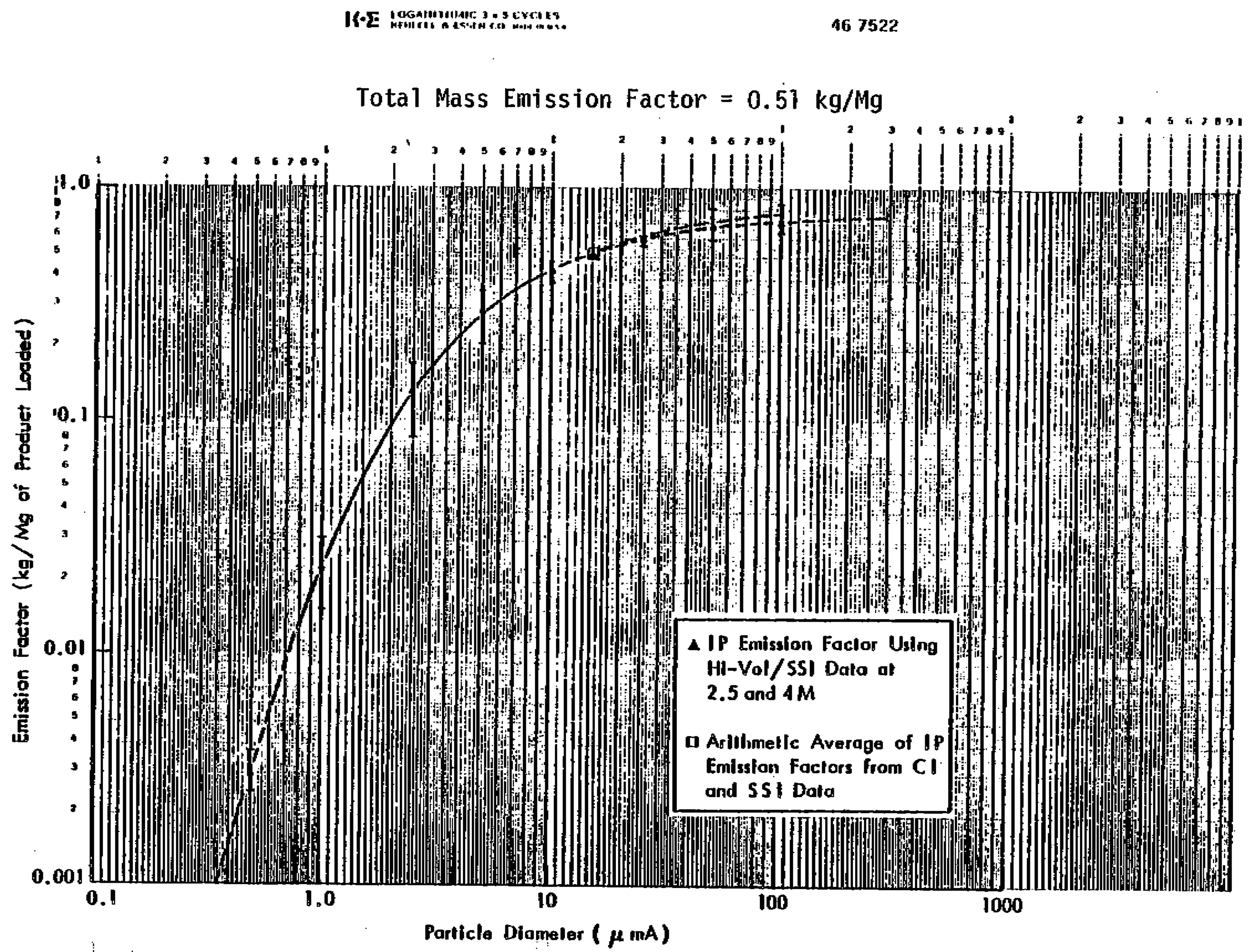


Figure 3-38. Emission factor by particle size for the loading of limestone into open-bed trucks.

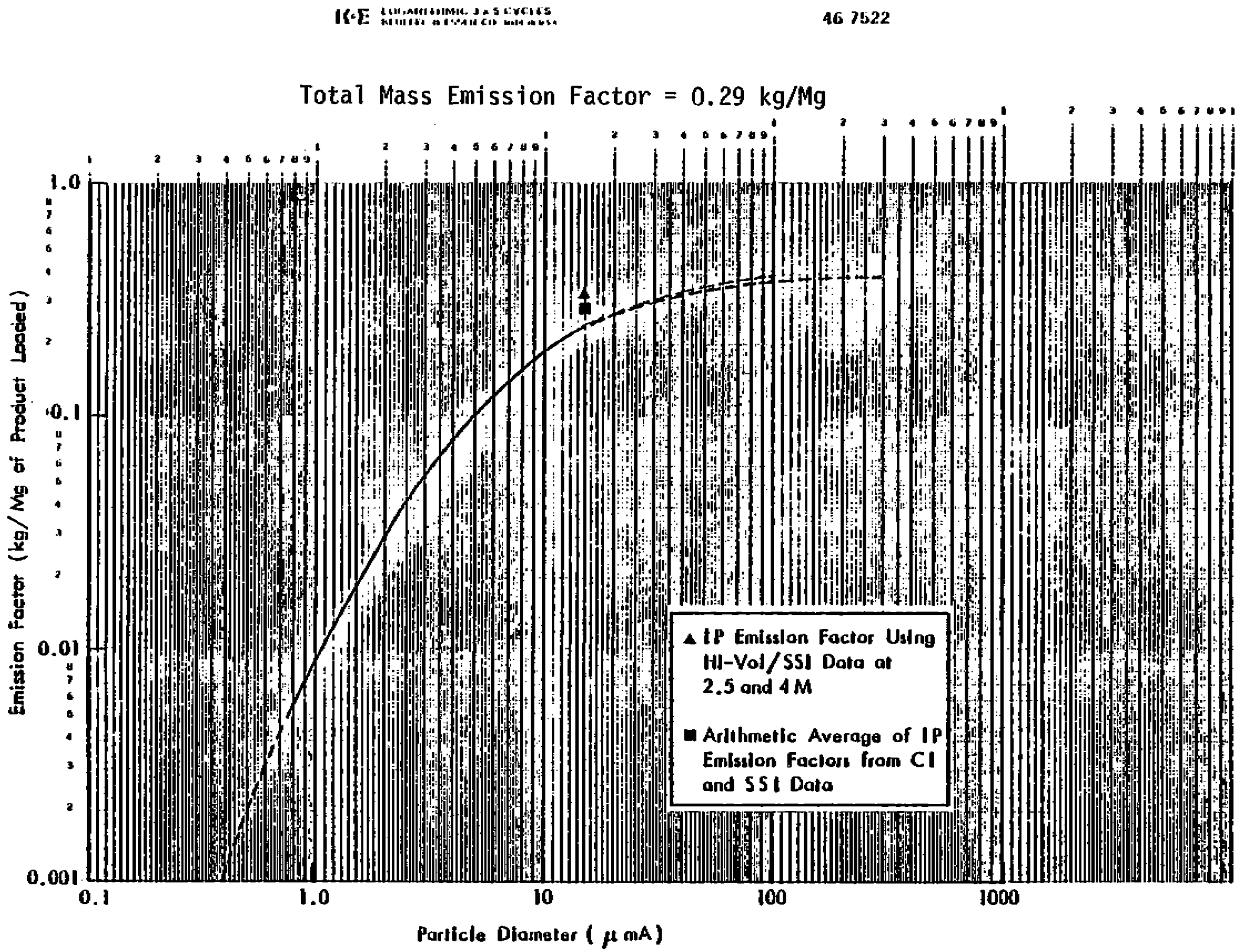


Figure 3-39. Emission factor by particle size for the loading of limestone into enclosed trucks.