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REPORT

CHARACTERIZATION OF INHALABLE PARTICULATE MATTER EMISSIONS FROM A DRY PROCESS CEMENT PLANT

FINAL REPORT

February 24, 1983

Volume I

EPA Contract No. 68-02-3158, Technical Directive No. 16
MRI Project No. 4892-L(64)

For

Industrial Environmental Research Laboratory
Environmental Protection Agency
5555 Ridge Avenue
Cincinnati, Ohio 45268

Attn: Charles H. Darvin

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by

Mark D. Hansen
John S. Kinsey

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PREFACE

This report was prepared for the Environmental Protection Agency (EPA), Industrial Environmental Research Laboratory, under Conract No. 68-02-3158, Technical Directive No. 16. It describes the results of emission testing conducted by Midwest Research Institute (MRI) for the study, "Characterization of Inhalable Particulate Matter Emissions from the Cement Industry." The field testing was conducted at the Monarch Cement Company cement plant, Humboldt, Kansas, during the period November 10 through 17, 1981.

The work was conducted by the Field Programs Section of the Environmental Systems Department under the general supervision of Dr. Ken Wilcox, Head, Field Programs Section. Mark D. Hansen was the project leader, and also served as field team leader. He was assisted in the field by George Cobb, Marilyn Gabriel, Ed Whited, Kent Hall, Cecily Beall, and Ed Olson. John Kinsey was responsible for the evaluation of the production process.

We would like to express our appreciation to personnel of the Monarch Cement Company plant, Humboldt, Kansas, who gave their assistance and cooperation. We especially want to thank Ken Howard, Vice President, Ken Miller, Plant Manager, and Russ Runnels, Chief Chemist and Environmental Coordinator.

Approved for:

MIDWEST RESEARCH INSTITUTE

M. P. Schrag, Director
Environmental Systems
Department

February 24, 1983

ABSTRACT

This report presents data for the characterization of inhalable particulate emissions at a dry process cement plant. The plant selected for this study was the Monarch Cement Company plant located at Humboldt, Kansas. This plant is typical of dry process operations within the cement industry.

Ducted emissions testing for both total mass and particle size was conducted on the No. 5 kiln. Emissions from the kiln are controlled by a 10-and a 3-cell baghouse. The inlet to the 10-cell baghouse and the common outlet stack from both baghouses were tested concurrently.

Inhalable particulate emission factors were calculated for the selected particle diameters of 2.5, 10.0, and 15.0 μm. The calculated emission factors for each testing location are based on the total mass emission rate and the particle size data from that source.

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SECTION 1.0

PROCESS DESCRIPTION AND OPERATION

1.1 PROCESS DESCRIPTION

The process which was evaluated during the test program was the No. 5 cement kiln at the Monarch Cement Company in Humboldt, Kansas. The No. 5 unit is a refractory-lined 12- x 165-ft rotary kiln designed by the Fuller Company of Catasauqua, Pennsylvania, originally installed in 1975. The No. 5 kiln has a maximum rated production capacity of 750 tons of clinker per day. This kiln is equipped with a four-stage suspension preheater with the effluent gas being cleaned by a fabric filter dust collector. A grate-type clinker cooler is utilized downstream of the kiln to cool the clinker prior to its being stored and finally ground into finished cement. Table 1-1 gives the design specifications for the No. 5 kiln as provided by the manufacturer. Figure 1-1 presents an overall process flow diagram of the Monarch Cement Company's Humboldt, Kansas, cement plant.

TABLE 1-1. NO. 5 ROTARY KILN DESIGN SPECIFICATIONS

Drum size: 12 ft diameter x 165 ft long
Production capacity: 750 tons/day of cement clinker
Clinker exit temperature: 2400°F
Speed of rotation: 1.6 rpm
Kiln off-gas: 85,000 acfm at 550°F
Maximum bypass of kiln off-gas: 25%
Installation date: 1975
Preheater: Fuller-Humboldt size 26.46, four-stage suspension preheater
Clinker cooler: Fuller size 6105-828H grate cooler

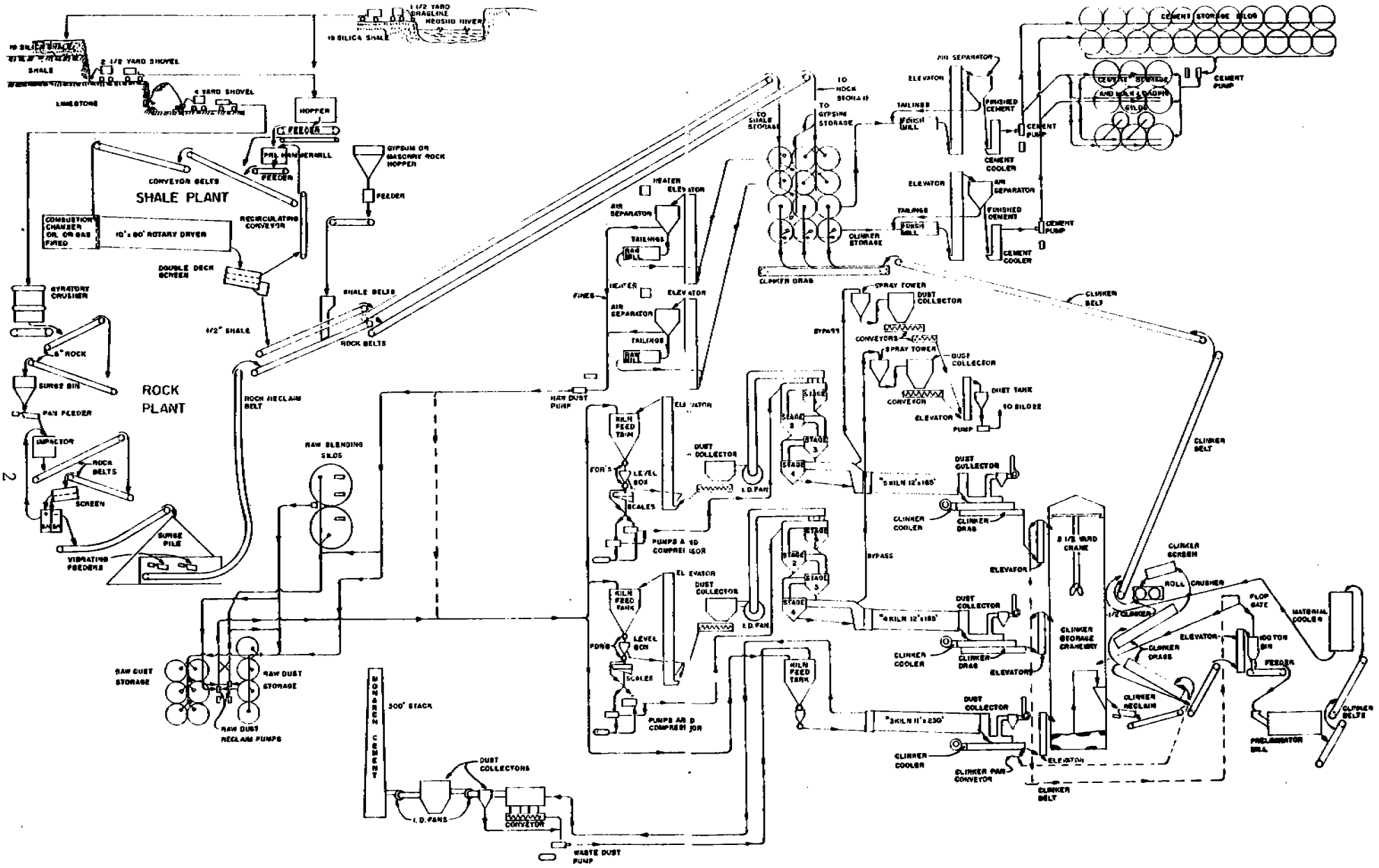


Figure 1-1. Process flow diagram of the Monarch Cement Company's Humboldt, Kansas, cement plant.

During normal operation, raw materials (silica shale and limestone) are fed pneumatically from the No. 5 feed tank to the kiln preheater. In the preheater, the material is heated in successive stages to approximately 1500°F by utilizing the hot off-gas from the kiln. The preheated material then enters the uphill end of the kiln where it is heated further and mixed. Heat is provided to the process by a burner located at the discharge end of the kiln which is fired by a combination of coal and coke.

When the material in the kiln reaches a temperature between 1470 to 1800°F, carbon dioxide is driven off the calcium carbonate. At a temperature around 2700°F, the raw material becomes partially sintered and forms a complex of chemical compounds called clinker. The hot clinker is mechanically removed from the kiln and transported across a grate in the clinker cooler through which a stream of ambient air is passed. During this process the hot clinker is cooled from approximately 2400 to 150°F prior to its being transported to storage.

Particulate matter in the preheater off-gas is removed by a high temperature fabric filter dust collector (baghouse). The preheater baghouse consists of 10 individual modules containing silicon/graphite impregnated fiberglass bags. The collector is a pressure-type baghouse with a gross (no compartments out of service) air-to-cloth ratio of 1.4:1. A flow of reverse air is utilized in each module for cleaning of the bags. Specifications for the No. 5 kiln preheater baghouse are presented in Table 1-2.

Control of the inlet gas temperature to the preheater baghouse is accomplished with a gas bypass system. This system contains a series of water sprays which cool the gas and is designed to accommodate up to 25% of the total off-gas from the kiln preheater. The bypass system is equipped with its own separate 3-cell baghouse collector for the control of particulate emissions. Both baghouses are essentially the same, on a per cell basis. Specifications of the baghouse on the No. 5 kiln preheater bypass system are presented in Table 1-3.

TABLE 1-2. NO. 5 KILN PREHEATER BAGHOUSE DESIGN SPECIFICATIONS

Make:	Fuller-Dracco
Model:	6000
No. of modules:	10
Air-to-cloth ratio:	1.41:1 (gross) 1.57:1 (one compartment off-line)
Total filter area:	60,080 ft^2
No. of filter bags:	296/module or 2,960 total
Bag size:	5 in. diameter x 186 in. long
Type of fabric:	Silicon/graphite impregnated fiberglass
Maximum operating temperature:	550°F
Type of cleaning:	Reverse air
Design volumetric gas flow:	85,000 acfm at 550°F

TABLE 1-3. NO. 5 KILN PREHEATER BYPASS BAGHOUSE DESIGN SPECIFICATIONS

Make:	Fuller-Dracco
Model:	6000
No. of modules:	3
Air-to-cloth ratio:	1.55:1 (gross) 2.33:1 (one compartment off-line)
Total filter area:	18,024 ft^2
No. of bags:	296/module or 888 total
Bag size:	5 in. diameter x 186 in. long
Type of fabric:	Silicon/graphite impregnated fiberglass
Maximum operating temperature:	550°F
Type of cleaning:	Reverse air
Design volumetric gas flow:	28,000 acfm at 425°F

1.2 PROCESS OPERATION

Inhalable particulate matter testing was conducted of the emissions from the No. 5 kiln on November 12, 13, 14, and 16 of 1981. During that period, the plant was producing a standard Type II portland cement. Data on the chemical composition of both the raw material feed and the clinker produced by No. 5 kiln for the above testing period were supplied by plant personnel. The results of these analyses are presented in Table 1-4.

TABLE 1-4. RAW MATERIAL FEED AND CLINKER CHEMICAL ANALYSES[a,b]

Chemical species	Feed analyses (wt. %)				Clinker analyses (wt. %)[c]			
	11/12/81	11/13/81	11/14/81	11/16/81	11/12/81	11/13/81	11/14/81	11/16/81
SiO_2	14.8	14.6	14.9	14.8	22.4	22.2	22.5	22.5
Fe_2O_3	2.13	2.11	2.07	2.08	3.58	3.44	3.21	3.27
Al_2O_3	2.54	2.51	2.54	2.60	4.08	4.13	4.05	3.99
CaO	42.2	42.2	42.3	42.1	64.2	64.2	64.9	64.3
MgO	1.67	1.66	1.60	1.69	2.22	2.28	2.13	2.30
Na_2O	0.10	0.90	0.90	0.90	0.16	0.18	0.20	0.19
K_2O	0.40	0.40	0.41	0.41	0.53	0.62	0.50	0.57
SO_3[d]	-	-	-	-	2.08	2.19	1.97	2.27

[a] Analyses by X-ray diffraction.

[b] Analyses provided by the Monarch Cement Company.

[c] Type II portland cement.

[d] SO_3 = SO_3 in clinker + SO_3 in added gypsum.

As stated previously, the fuel used to fire the No. 5 kiln is a combination of coal and coke. The composition ratio of this fuel is 70% (by weight) coke and 30% raw coal. Table 1-5 presents the proximate fuel analysis of both fuel components for the period in which emission testing was performed.

TABLE 1-5. PROXIMATE FUEL ANALYSES[a,b]

Parameter	Coal analysis (weight %) As received	Coal analysis (weight %) Dry	Coke analysis (weight %)
Volatile matter	34.05	35.32	14.00
Fixed carbon	44.94	46.62	83.38
Ash	17.40	18.06	2.62
Sulfur	3.94	4.09	4.57
Heating value	11,240[c]	11,660[c]	14,819[c]
Moisture	3.6	0	-

[a] Fuel is a 70:30 mixture of coke and raw coal.

[b] Analyses provided by the Monarch Cement Company.

[c] Btu/lb of fuel.

In addition to the information presented above, selected process operating data were also collected on an hourly basis for the period during which testing was conducted. These data were obtained from the kiln operating logs in the control room at the plant. The process operating parameters which are routinely monitored by plant personnel include the kiln feed rate, clinker production rate, kiln off-gas exit temperature, and the inlet gas temperature to the 10-cell preheater baghouse. A summary of the process operating data for the test period is presented in Table 1-6. Also presented in Table 1-6 is an arithmetic average of the hourly observations for each parameter during the appropriate 24-hr period. Copies of the kiln operating logs for the test period are presented in Appendix A. From the information contained in Table 1-6, it was determined that the operation of the No. 5 kiln was reasonably constant over the entire test period.

TABLE 1-6. SUMMARY OF NO. 5 KILN OPERATING PARAMETERS[a]

Time	Kiln feed rate (short tons/hr)				Clinker production rate[b] (short tons/hr)				Kiln exit temperature (°F)[c]				Baghouse inlet temperature (°F)			
	11/12/81	11/13/81	11/14/81	11/16/81	11/12/81	11/13/81	11/14/81	11/16/81	11/12/81	11/13/81	11/14/81	11/16/81	11/12/81	11/13/81	11/14/81	11/16/81
0100	-	52	55	50	-	33.8	35.8	32.5	-	1690	1690	1690	-	570	570	570
0200	-	52	55	50	-	33.8	35.8	32.5	-	1690	1690	1690	-	570	570	560
0300	-	52	55	50	-	33.8	35.8	32.5	-	1690	1690	1690	-	570	570	570
0400	-	54	55	51	-	35.1	35.8	33.2	-	1690	1690	1690	-	570	570	570
0500	-	54	55	51	-	35.1	35.8	33.2	-	1690	1690	1690	-	570	570	570
0600	-	54	49	51	-	35.1	31.9	33.2	-	1690	1690	1690	-	570	570	570
0700	51	55	53	51	33.2	35.8	34.5	33.2	1690	1640	1690	1690	560	570	570	570
0800	51	50	53	51	33.2	32.5	34.5	33.2	1690	1640	1690	1690	560	570	570	570
0900	51	53	53	51	33.2	34.5	34.5	33.2	1690	1690	1690	1690	560	570	570	570
1000	51	54	53	51	33.2	35.1	34.5	33.2	1690	1690	1690	1690	560	570	570	570
1100	51	54	54	51	33.2	35.1	35.1	33.2	1690	1690	1690	1690	560	570	570	570
1200	51	55	54	51	33.2	35.8	35.1	33.2	1690	1680	1690	1690	560	570	570	570
1300	51	55	52.5	51	33.2	35.8	34.1	33.2	1690	1665	1665	1690	560	570	570	570
1400	51	55	53	51	33.2	35.8	34.5	33.2	1690	1690	1665	1690	560	570	570	570
1500	51	55	53	51	33.2	35.8	34.5	33.2	1690	1690	1690	1690	560	560	570	570
1600	51	55	53	51	33.2	35.8	34.5	33.2	1690	1690	1690	1690	560	560	570	570
1700	51	55	45	51	33.2	35.8	29.3	33.2	1690	1690	1690	1665	570	570	570	570
1800	51	55	51	51	33.2	35.8	33.2	33.2	1690	1690	1690	1690	570	570	570	570
1900	51	55	54	51	33.2	35.8	35.1	33.2	1690	1690	1690	1665	570	570	570	570
2000	51	55	53	51	33.2	35.8	34.5	33.2	1690	1690	1690	1665	570	570	570	570
2100	50	55	53	51	32.5	35.8	34.5	33.2	1690	1690	1690	1665	570	570	570	570
2200	52	55	54	51	33.8	35.8	35.1	33.2	1690	1690	1690	1665	570	570	570	570
2300	52	55	54	42	33.8	35.8	35.1	27.3	1690	1690	1690	1665	570	570	570	570
2400	51.5	55	54	49	33.5	35.8	35.1	31.9	1690	1690	1690	1690	570	570	560	570
Daily average[d]		51	54	53	50	33.2	35.2	34.5	32.8	1690	1684	1688	1684	564	570	570

[a] Data provided by the Monarch Cement Company.

[b] For production of Type II portland cement.

[c] Calculated based on a 140°F temperature rise from the fourth stage of the preheater to the outlet of the kiln as noted by plant operating personnel.

[d] Arithmetic mean of hourly observations.

SECTION 2.0

SAMPLING LOCATIONS, EQUIPMENT, AND PROCEDURES

This section describes the sampling locations, equipment, and procedures used for inhalable particulate emission sampling at the Monarch Cement Company's dry process cement plant. Figure 2-1 presents a general overview of the Monarch Cement Company's Humboldt, Kansas, cement plant facilities.

2.1 SAMPLING LOCATIONS

The cement plant of the Monarch Cement Company, Humboldt, Kansas, operates three rotary kilns for the dry process production of cement product. Nos. 5 and 4 kilns are the primary production kilns utilized. No. 3 kiln is used as production demand necessitates and as a standby kiln. Emissions from each kiln are controlled by separate baghouses. Each kiln also has a separate outlet stack.

Nos. 5 and 4 kilns are essentially identical in design. Both kilns have a 10- and a 3-cell baghouse controlling emissions. At each kiln emissions from both the 10- and 3-cell baghouses are exhausted to the atmosphere through a common outlet stack.

No. 5 kiln was selected for testing for two reasons. First, the kiln is one of the primary production kilns at the plant. Secondly, the kiln was scheduled to be brought down, at which time sampling ports could be installed. Sampling at the No. 5 kiln was conducted at two locations: inlet to the 10-cell baghouse and common outlet stack from the 10- and 3-cell baghouses. The inlet to the 3-cell baghouse was not sampled. Figure 2-2 presents a general overview of the inlet and outlet sampling locations at No. 5 kiln.

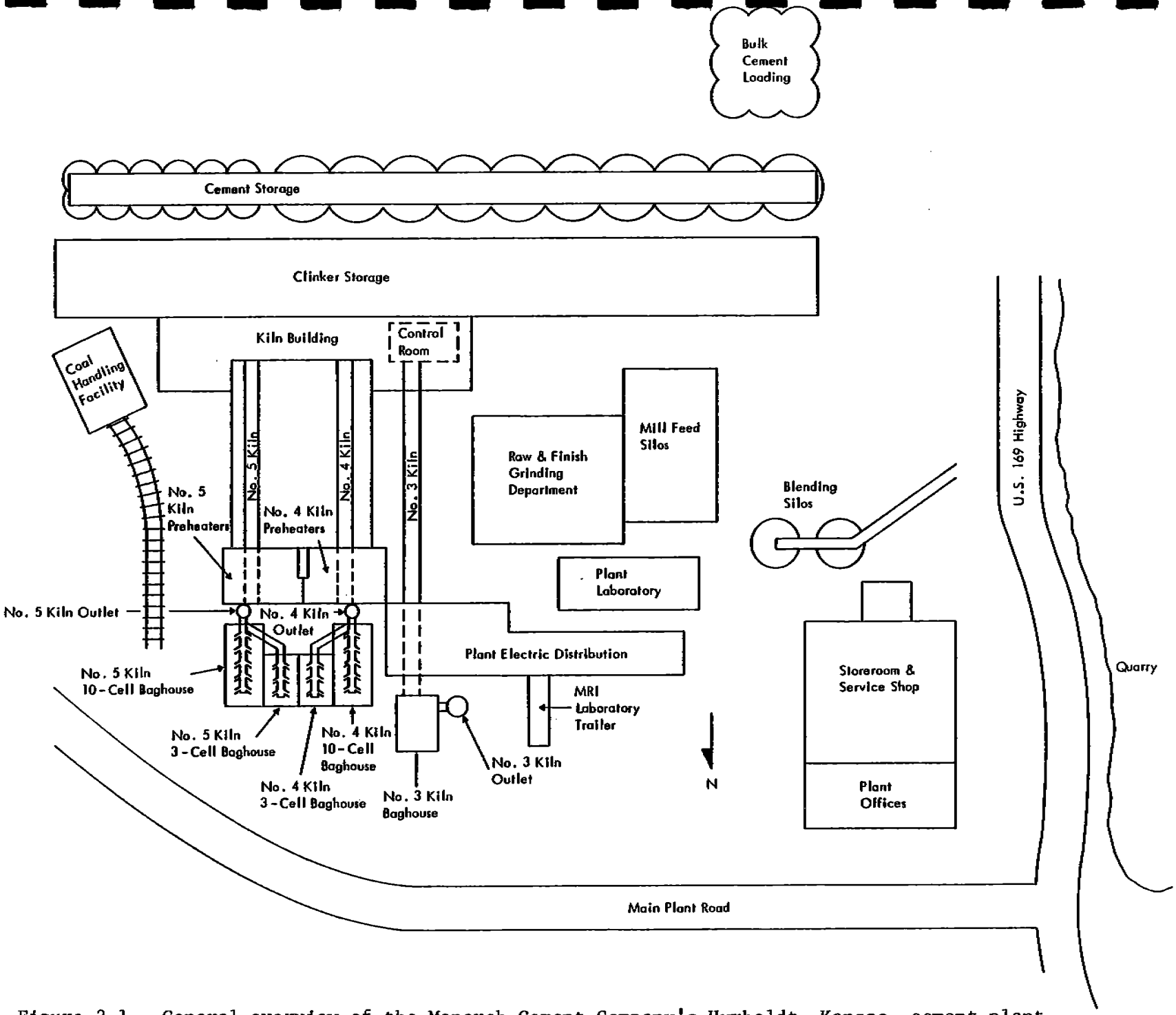


Figure 2-1. General overview of the Monarch Cement Company's Humboldt, Kansas, cement plant.

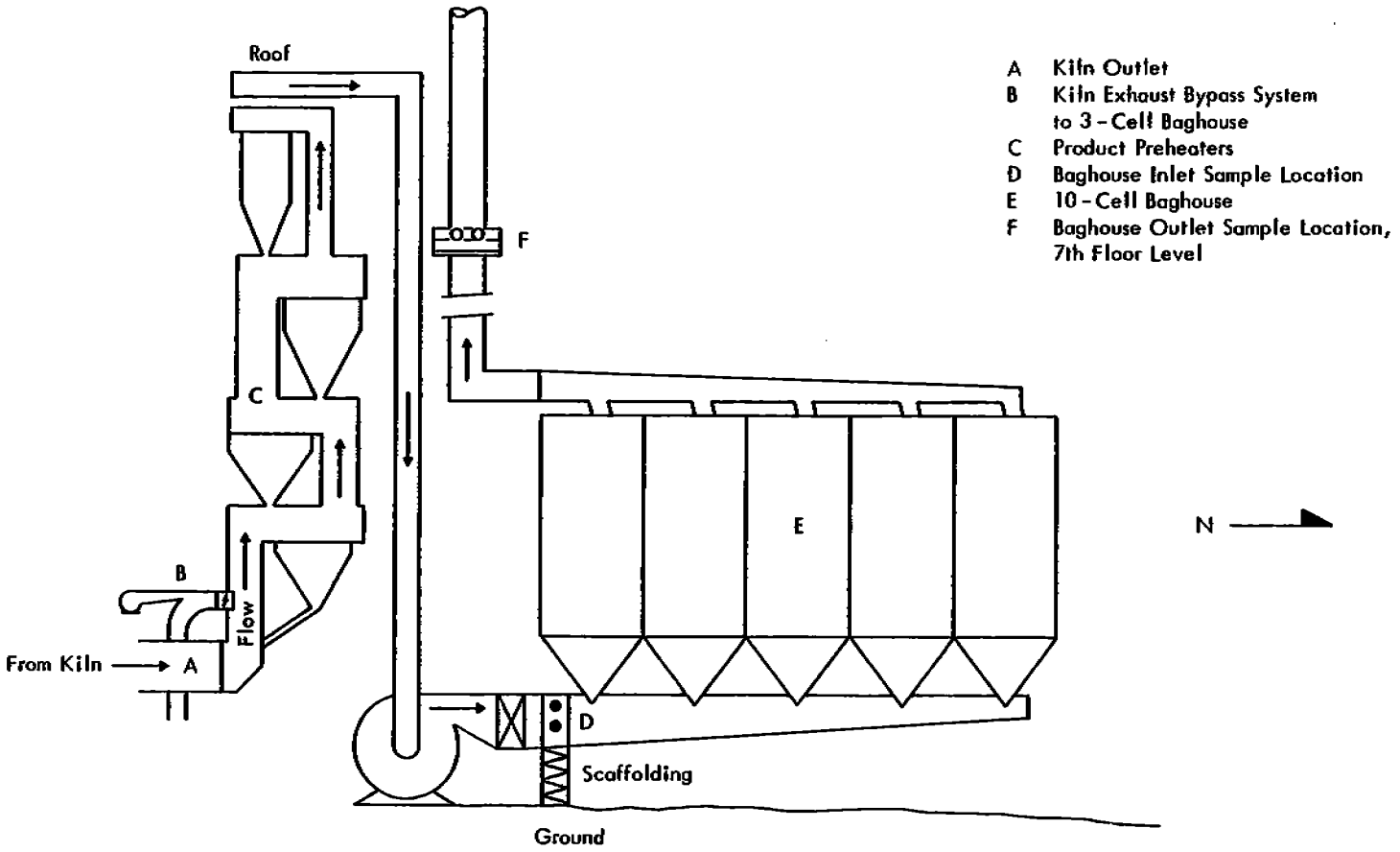


Figure 2-2. General overview of the No. 5 kiln inlet and outlet sampling locations.

2.1.1 Inlet to No. 5 Kiln 10-Cell Baghouse

Inhalable particulate matter emissions testing was conducted on No. 5 kiln emissions prior to their entering the 10-cell baghouse control device. Testing was accomplished using two 6-in. ID sample ports located on the side of the rectangular duct connecting the kiln and the 10-cell baghouse. Figure 2-3 shows the relevant physical measurements of this sampling site, and the sample port, sample quadrant, and sample point locations.

During the preliminary survey of the plant facilities, the possibility of an accumulation of material in the bottom of the inlet duct to the 10-cell baghouse was noted. Plant personnel were informed of this possibility and instructed how to account for any accumulated material during location and installation of the two sample ports. Plant personnel measured 22 in. of accumulated material when No. 5 kiln was brought down for minor repairs. Plant personnel followed the calculation instructions provided by MRI personnel and installed the sampling ports in the nonobstructed area of the duct as required. The depth of accumulated material is noted in Figure 2-3.

2.1.2 Common Outlet from No. 5 Kiln 10- and 3-Cell Baghouses

Inhalable particulate matter emissions testing was conducted on No. 5 kiln emissions after they exited the 10-cell baghouse control device. A common outlet stack exhausts emissions from both the 10- and 3-cell baghouses on No. 5 kiln. The sampling ports on the outlet stack were located approximately 75 ft up from the base of the approximately 140-ft tall stack. Access to the sampling ports was obtained from the seventh floor (Stage 2) of the preheater building. Testing was accomplished using two 6-in. ID sampling ports 90 degrees apart on the side of the 82-1/2 in. ID stack. Figure 2-4 shows the relevant physical measurements of this sampling site, and the sample port, sample quadrant, and sample point locations.

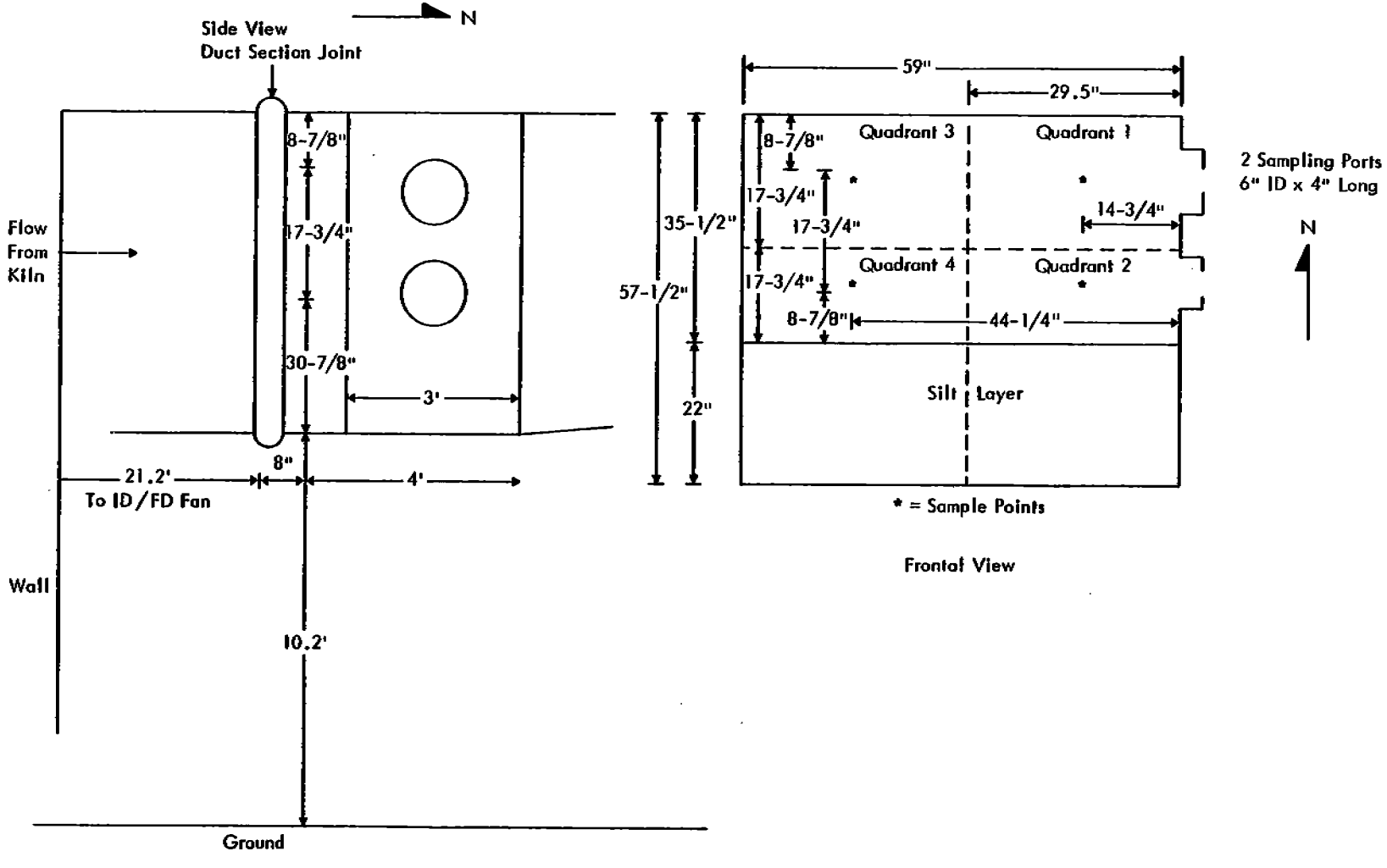


Figure 2-3. Schematic of No. 5 kiln 10-cell baghouse inlet sampling site with sample port, sample quadrant, and sample point locations.

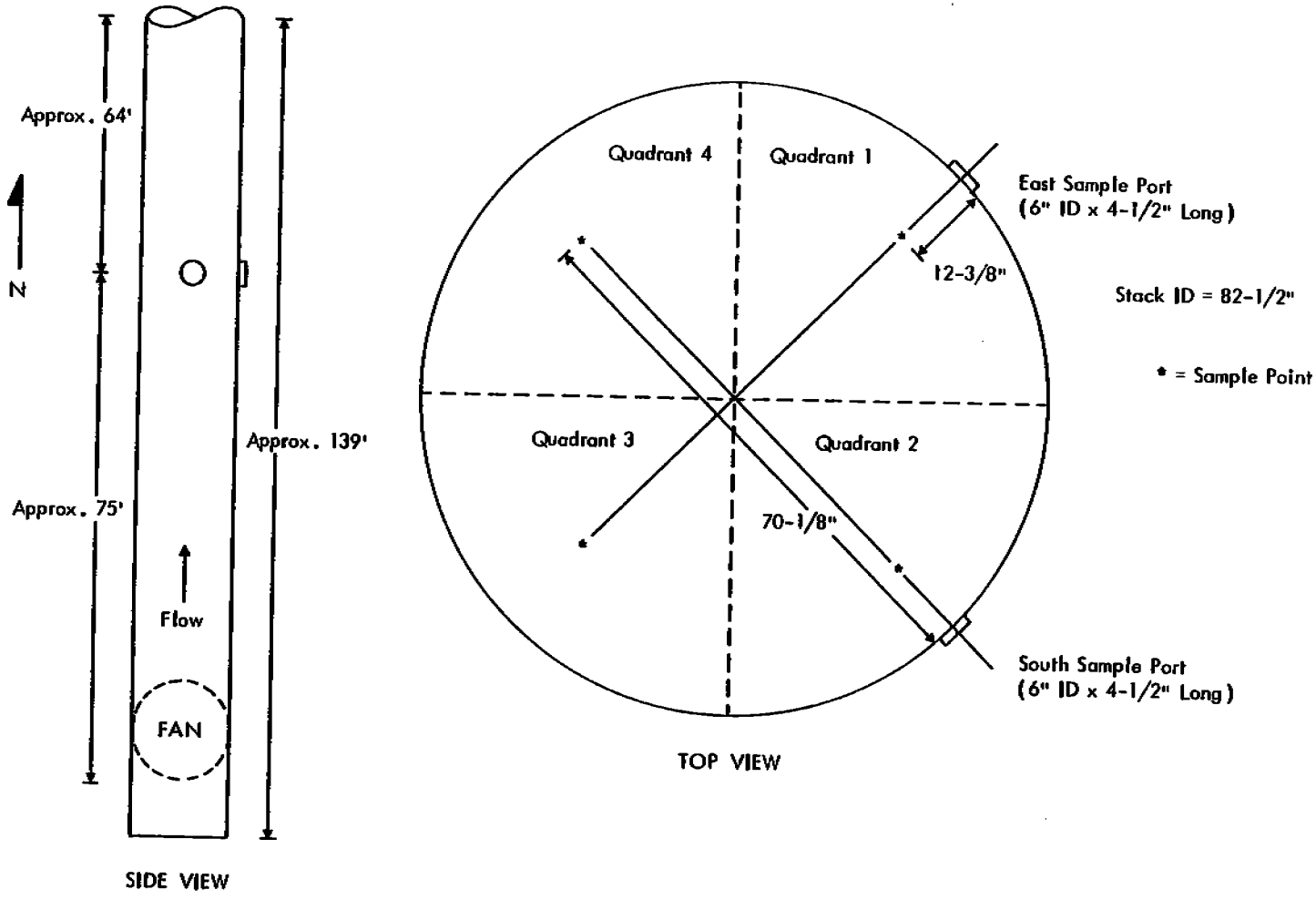


Figure 2-4. Schematic of No. 5 kiln common outlet stack with sample port, sample quadrant, and sample point locations.

2.1.3 No. 5 Kiln Bypass to 3-Cell Baghouse

The No. 5 kiln bypass to the 3-cell baghouse is located on the second floor of the preheater building. This location was not utilized as a testing site for inhalable particulate matter emissions. However, EPA Methods 2 and 3 measurements were performed at this location. The data from these measurements were used to determine the flow rate from No. 5 kiln entering the 3-cell baghouse. These data, together with velocity measurements at the inlet to the 10-cell baghouse, provided for the calculation of the total flow exiting No. 5 kiln.

Figure 2-5 shows an overview of the No. 5 kiln bypass system that controls exhausts to the 3-cell baghouse. Also shown are the three ports used to obtain EPA Methods 2 and 3 measurements. As indicated in Figure 2-5, the three ports were not on a single axis, nor did their location meet EPA Method 1 criteria. The top port was a typical sampling port, i.e., a threaded pipe nipple with cap. The bottom two ports were cleanout ports. Plant personnel used these two ports and others in this area to remove particulate buildup on the inner walls of the duct with a high pressure water spray.

2.2 SAMPLING EQUIPMENT

2.2.1 Particulate Mass

2.2.1.1 EPA Method 5 Train--

The EPA Method 5 train used for mass sampling at the inlet to the 10-cell baghouse is shown schematically in Figure 2-6. The sampling train consisted of a Research Appliance Company (RAC) console and sample box. The probe nozzle and liner were made of 316 stainless steel, and the remainder of the train was made of borosilicate glass. Particulate matter was collected on 3-1/2 in. diameter, preweighed, glass fiber filters.

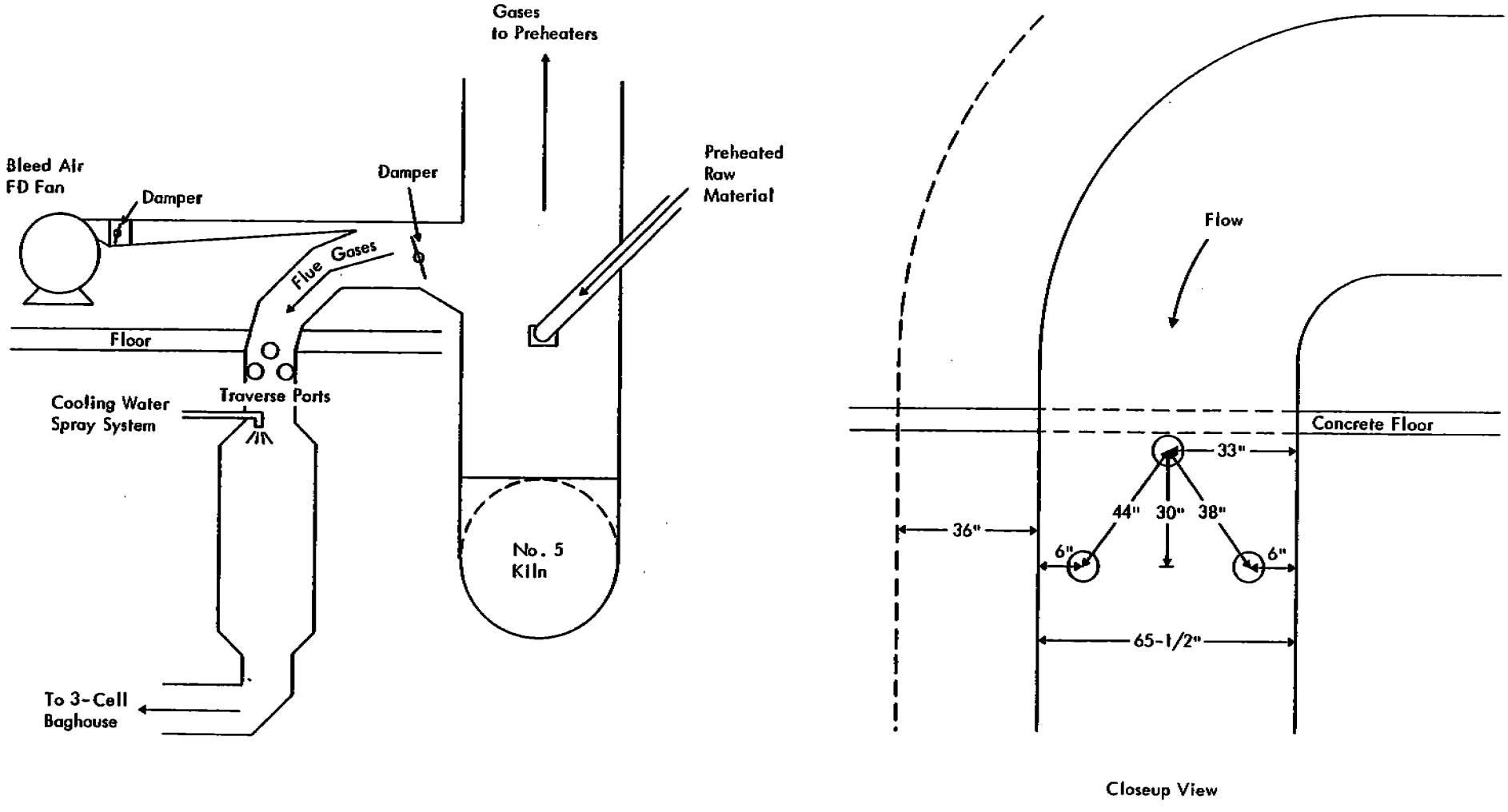
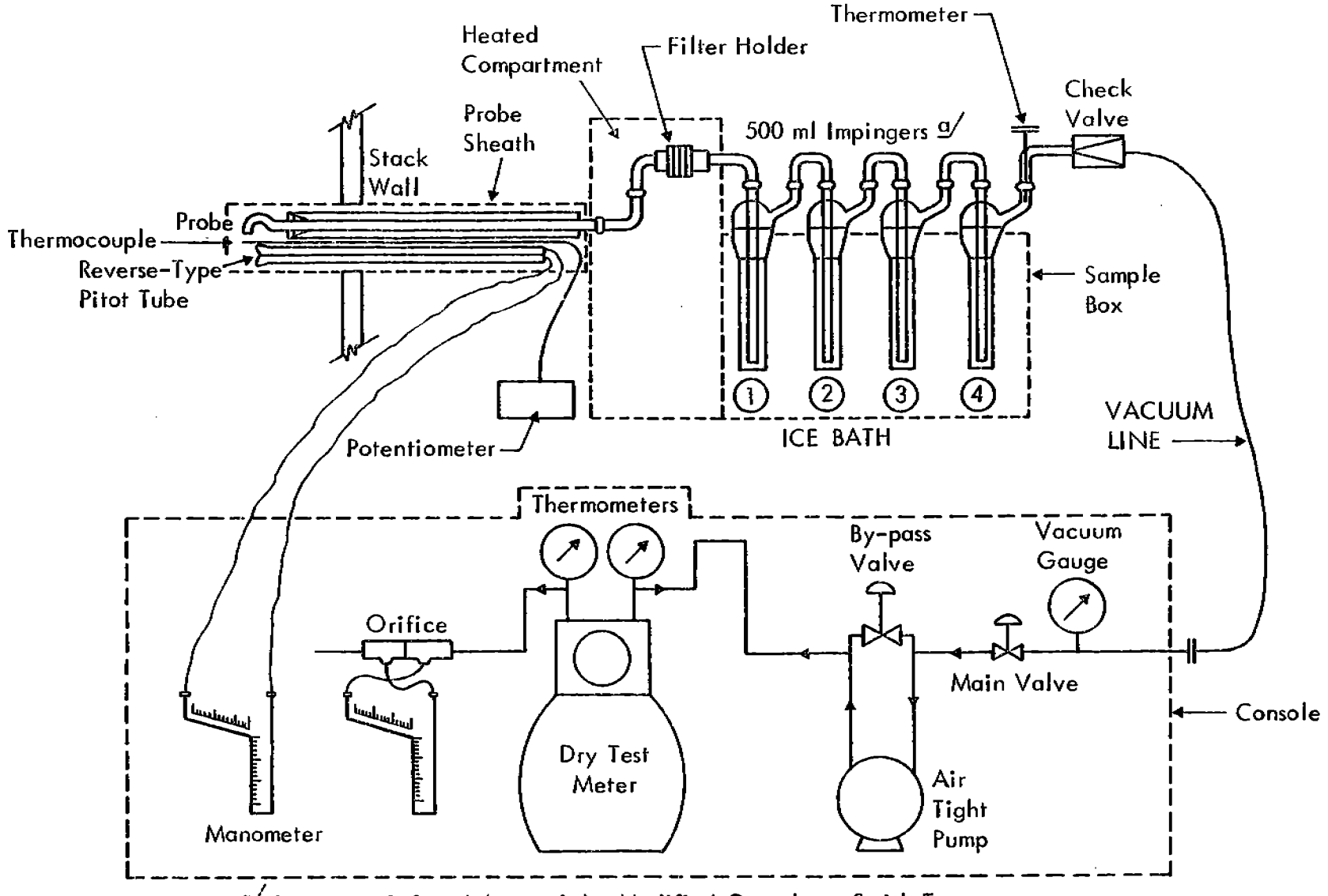


Figure 2-5. No. 5 kiln bypass to 3-cell baghouse.



a/ Impingers 1, 3 and 4 are of the Modified Greenburg-Smith Type
Impinger 2 is of the Greenburg-Smith Design
Impinger 1 and 2 Contain 100 ml Water
Impinger 3 Empty
Impinger 4 Contains 200-300 g Silica Gel

Figure 2-6. Schematic illustration of EPA Method 5 sampling train in sampling position.

2.2.1.2 EPA Method 17 Train--

The EPA Method 17 train used for mass sampling at the common outlet stack on No. 5 kiln is shown schematically in Figure 2-7. The in-stack filtration sampling system used is in accordance with the configuration presented in the Federal Register, Vol. 43, No. 37, Thursday, February 23, 1978.

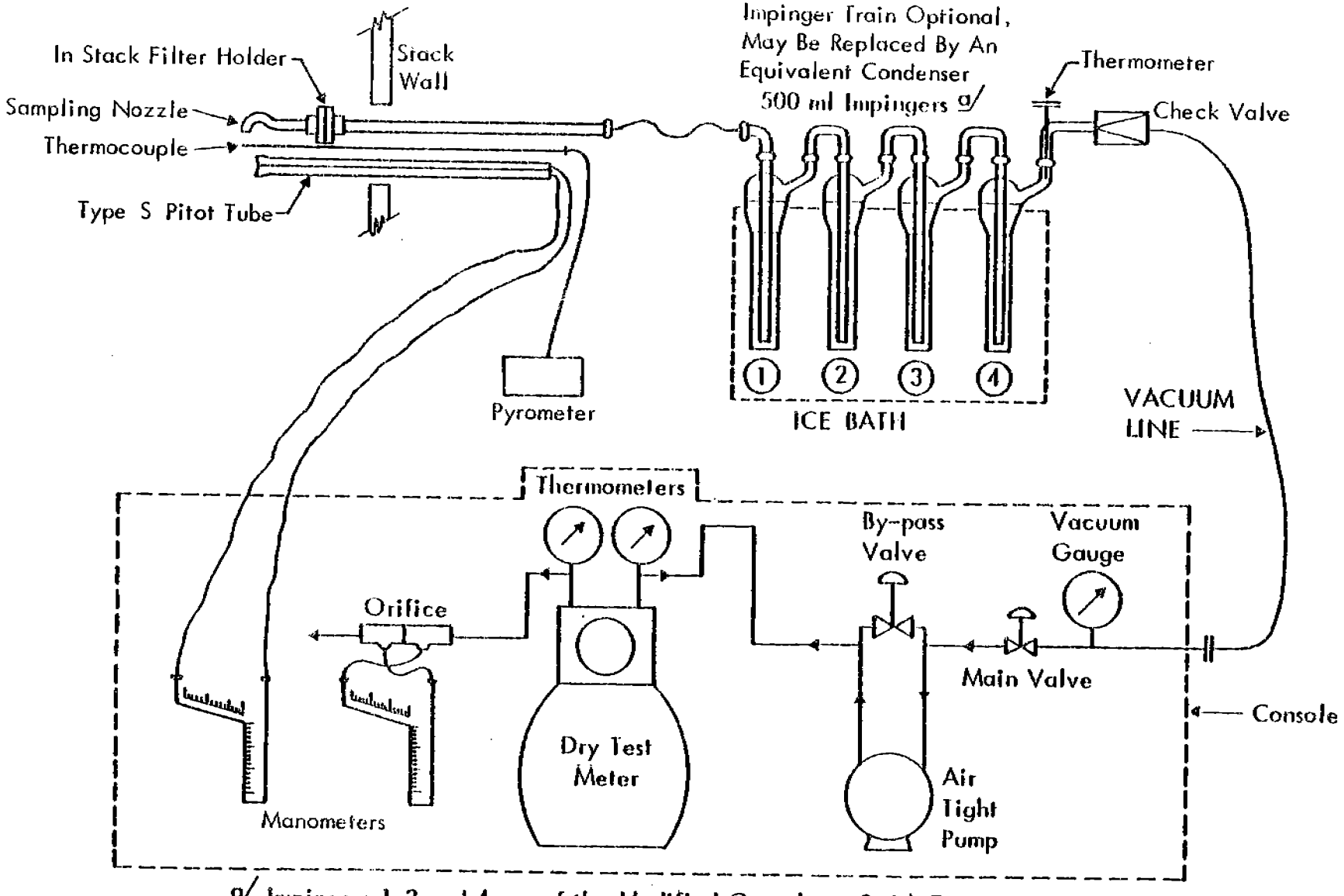
The metering and flow control system for this train consisted of an RAC console. The filtration system consisted of an in-stack filter holder (Sierra Instruments, Inc., Model 273) coupled to a 5/8-in. OD pipe. The nozzle and filter holder are made of 316 stainless steel. Particulate matter was collected on 47-mm diameter, preweighed, glass fiber filters. A conventional EPA Method 5 impinger train was used for determining moisture content.

2.2.2 Particle Size

2.2.2.1 Andersen High Capacity Stack Sampler (HCSS)--

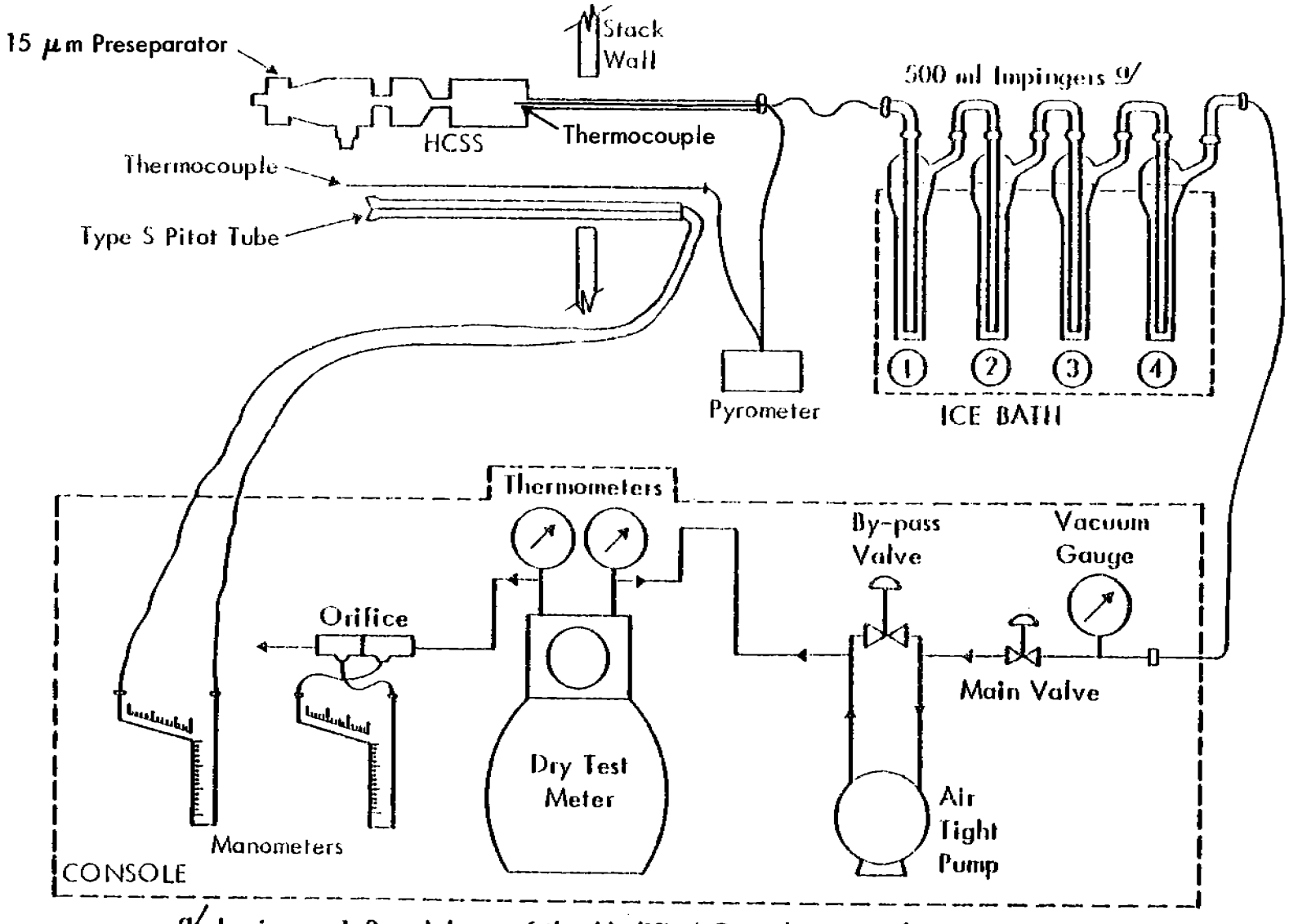
An Andersen HCSS (Andersen 2000) cascade impactor with 15-μm preseparator (Sierra Instruments, Inc.) was used for particle size distribution measurements of emissions at the inlet to the 10-cell baghouse on No. 5 kiln. This system was used for heavy loading situations encountered at the inlet sampling site. Figure 2-8 shows the Andersen HCSS impactor with 15-μm preseparator in the sampling mode.

The Andersen HCSS cascade impactor consists of two, single jet impaction chambers followed by a third stage cyclone and a backup thimble filter. An RAC console was used for control and metering of flows. A conventional EPA Method 5 impinger train was used for determining moisture content. Particulate matter was collected from the 15-μm preseparator attached to the top of the impactor. Inside the impactor, particulate matter was collected from the Stages 1 and 2 impactor chambers and the Stage 3 cyclone. All particles remaining in the gas stream downstream of the Stage 3 cyclone were collected in a preweighed, high efficiency glass fiber thimble filter.



a/ Impingers 1, 3 and 4 are of the Modified Greenburg-Smith Type
Impinger 2 is of the Greenburg-Smith Design
Impinger 1 and 2 Contain 100 ml Water
Impinger 3 Empty
Impinger 4 Contains 200-300 Grams Silica Gel

Figure 2-7. Schematic illustration of EPA Method 17 sampling train in sampling position.



g/ Impingers 1, 3 and 4 are of the Modified Greenburg-Smith Type
Impinger 2 is of the Greenburg-Smith Design
Impinger 1 and 2 Contain 100 ml Water
Impinger 3 Empty
Impinger 4 Contains 200-300 Grams Silica Gel

Figure 2-8. Schematic illustration of an Andersen HCSS impactor with 15 μm preseparator sampling train in sampling position.

Two thermocouples (Figure 2-8) were attached to the sample probe for temperature monitoring during testing. The thermocouple near the impactor nozzle monitored the stack temperature. The stack temperature data were used in the computer calculations to determine the cutpoint and flow rate through the 15-μm preseparator. The second thermocouple was placed inside the impactor support pipe and positioned near the thimble filter at the gas exit point of the impactor. This thermocouple monitored the temperature of the stack gas as it passed through the impactor. These data were used in the computer calculations to determine the flow rate and cutpoints of all impactor stages, excluding the 15-μm preseparator.

2.2.2.2 Andersen Mark III--

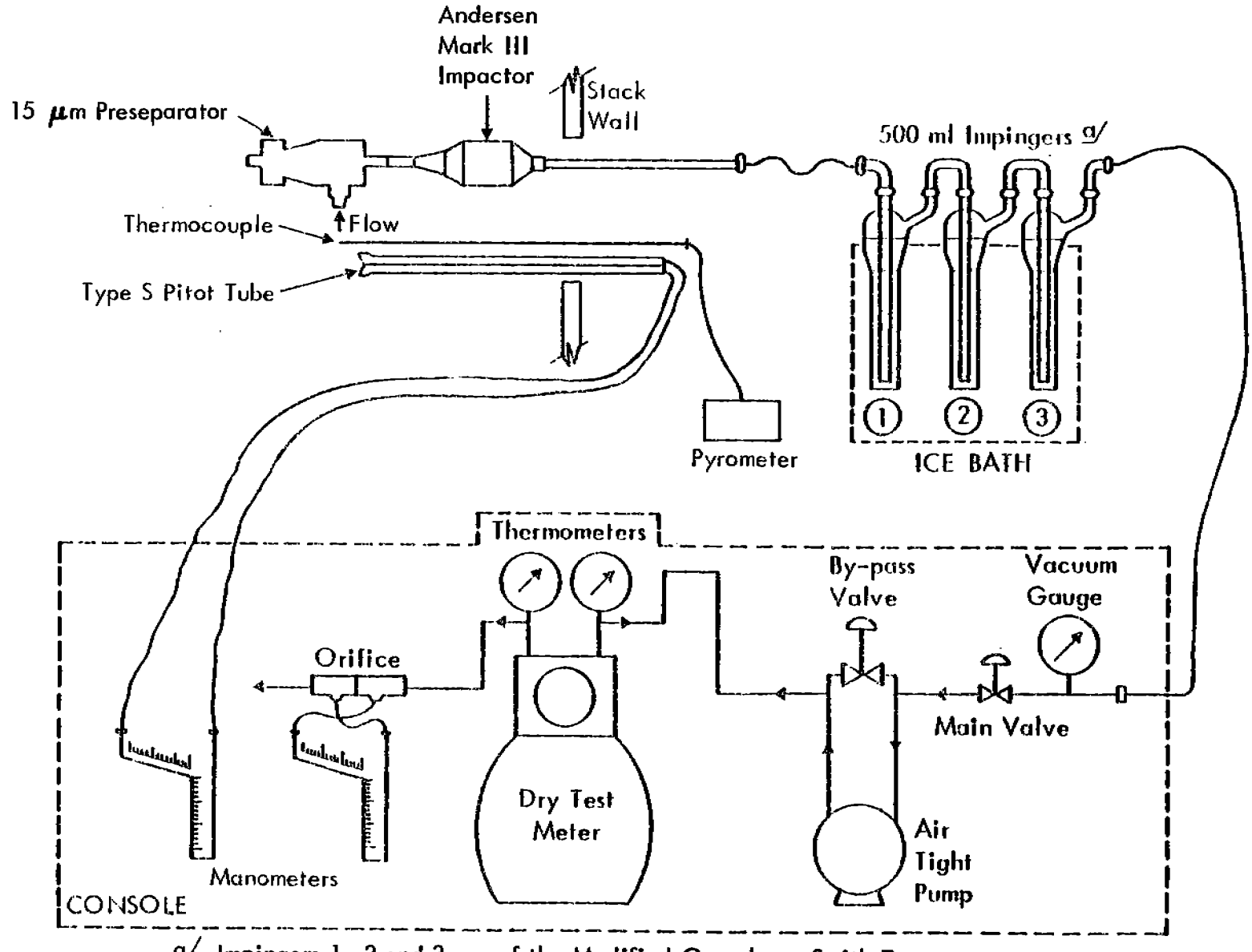
An Andersen Mark III (Andersen 2000) cascade impactor with 15-μm preseparator (Sierra Instruments, Inc.) was used for particle size distribution measurements of emissions at the common outlet stack on No. 5 kiln. This system was used for light loading situations encountered at the outlet site. Figure 2-9 shows the Andersen Mark III impactor with 15-μm preseparator in the sampling mode.

The Andersen Mark III is a multistage, multijet cascade impactor. An RAC console was used for control and metering of flows. Three EPA Method 5 impingers were used for determining moisture content. Particulate matter was collected on 2-1/2 in. diameter (manufactured by Andersen 2000) preweighed glass fiber filters.

A thermocouple was attached to the sample probe to monitor duct temperatures during the test. These temperature data were used in the computer calculations for the determination of the particle size data for each stage of the impactor.

2.2.3 Equipment Calibration

All ducted emission sampling equipment calibration was performed according to EPA requirements as stated in the Federal Register, Vol. 42, No. 160,



a/ Impingers 1, 2 and 3 are of the Modified Greenburg-Smith Type
Impinger 1 Contains 100 ml Water
Impinger 2 Empty
Impinger 3 Contains 200-300 Grams Silica Gel

Figure 2-9. Schematic illustration of an Andersen Mark III impactor with 15 μm preseparator sampling train in sampling position.

August 18, 1977. Appendix B contains the calibration data for the equipment used during this field test.

2.3 SAMPLING PROCEDURES

2.3.1 Pretest Preparations

2.3.1.1 Particulate Mass

2.3.1.1.1 EPA Method 5 train--Type A/E (Gelman Sciences, Inc.) glass fiber filters (3-1/2 in. diameter) were used for particulate collection substrates in the EPA Method 5 train used at the inlet test location. The filters were placed in numbered 4-3/4 in. diameter by 3/16 in. deep aluminum weighing pans. The filters and weighing pans were desiccated for 24 hr according to EPA Method 5 procedures. Each filter and its corresponding numbered weighing pan were then weighed on a Mettler Model AK 160 electronic balance. Weighings were recorded to the nearest 0.1 mg. The filters and weighing pans were desiccated for 6 hr and reweighed. This procedure was repeated until two consecutive weighings agreed within 1.0 mg. Laboratory weighing data are presented in Appendix C. Plastic petri dishes were used as shipping containers.

For recovery of EPA Method 5 samples, 250-ml glass beakers were used. The beakers were washed in Alconox and then rinsed with tap water. They were numbered with a lead pencil applied to their etched surface. The beakers were then rinsed with distilled water and heated in an oven to 500°F for 1 hr to burn off any organic material present. Then they were transferred by means of beaker tongs to a desiccation chamber and desiccated for 24 hr. The beakers were then weighed to the nearest 0.1 mg on a Mettler Model AK 160 electronic balance. After being returned to the desiccation chamber where they remained for 6 hr, they were reweighed. This procedure was repeated until two consecutive weighings agreed within 1.0 mg. After completion of weighing, the beakers were placed in sterile plastic Whirl-Pak containers and placed in their original box for shipping.

2.3.1.1.2 EPA Method 17 train--Gelman-type A/E 47-mm diameter glass fiber filters were used for particulate collection substrates in the EPA Method 17 train used at the outlet test location. The filters were placed in numbered 57-mm diameter aluminum weighing pans. The desiccation and weighing procedures used on these filters were identical to the procedures used for the EPA Method 5 filters. Plastic petri dishes were also used as shipping containers.

For recovery of EPA Method 17 samples, 150-ml glass beakers were used. The beakers were cleaned, desiccated, and weighed according to the procedures described for the EPA Method 5 sample beakers. These beakers were also transported in sterile plastic Whirl-Pak containers.

2.3.1.2 Particle Size

2.3.1.2.1 Andersen high capacity stack sampler (HCSS) with 15-μm preseparator--An Andersen HCSS impactor with 15-μm preseparator was used for particle sizing at the baghouse inlet test location. The entire assembly, including nozzles, was washed in detergent and rinsed with distilled water and acetone. The acceleration and vent tubes were cleaned with a high pressure air stream.

A 1-1/2 in. diameter by 4-3/4 in. long aluminum tube was used as a container for each glass fiber thimble filter. The aluminum tube also served as a weighing container. The thimble filters and aluminum tubes were prepared for field use as follows:

* The aluminum tubes were numbered with an engraver.

* The aluminum tubes and lids were washed in Alconox detergent.

* After washing, the aluminum tubes and lids were rinsed first with tap water, then with deionized, distilled water.

* The aluminum tubes and lids were heated in an oven to 500°F for 1 hr to remove any potential organic contaminants. After heating, the aluminum tubes were handled only with beaker tongs. The aluminum lids were handled with latex surgical gloves since they were not weighed.

* The aluminum tubes and lids were removed from the oven and allowed to cool.

* A glass fiber thimble filter was placed in each aluminum tube container.

* The thimble filters and aluminum tubes were placed in a desiccator for 24 hr. Desiccation was at ambient temperature and pressure.

* The aluminum tubes and thimble filters were weighed to the nearest 0.1 mg on a Mettler Model AK 160 electronic balance. The aluminum tube lid was not desiccated or weighed.

* The aluminum tubes and thimble filters were desiccated a second time for 6 hr.

* The aluminum tubes and thimble filters were weighed a second time.

* Desiccation and weighing was repeated until two consecutive weighings agreed within 1.0 mg.

* The lids were placed on the aluminum tubes.

* The aluminum tubes were wrapped in aluminum foil for shipment.

Aluminum weighing pans 57 mm in diameter and 20 mm deep were used in recovering samples from the first four impactor stages. A metal engraver was used to number each weighing pan. The aluminum weighing pans were then

desiccated and weighed according to the procedures describe for the aluminum tubes and thimble filters. The aluminum weighing pans were placed in 100 mm in diameter by 20 mm deep plastic petri dishes used as shipping containers.

2.3.1.2.2 Andersen Mark III impactor with 15-μm preseparator--The entire Andersen Mark III impactor assembly, including nozzles, was cleaned prior to field use. Ten square pieces of aluminum foil were cut to serve as holders for each filter set. The aluminum foil squares were folded in half, labeled, and the appropriate glass fiber filter substrate (Andersen 2000) placed inside. The desiccation and weighing procedures used were as follows:

* The filter sets, including the aluminum foil holders, were conditioned by vacuum desiccation for a period of 1 hr.

* Each filter, including its aluminum foil square, was weighed to the nearest 0.01 mg on a Cahn Instruments Model 27 electrobalance.

* The filter sets were vacuum desiccated a second time for 15 min.

* The filter sets were weighed a second time.

* The vacuum desiccation and weighing procedures were repeated until two consecutive weighings agreed within 0.05 mg.

* Each complete filter set was placed in a glassine envelope for shipping.

2.3.2 Testing, Recovery, and Analysis

The "Procedure Manual for Inhalable Particulate Sampler Operation" by Southern Research Institute (SoRI-EAS-79-761, 4181-37), November 30, 1979, for EPA, was used to determine most of the sampling criteria for both the particle size and mass tests. Four individual sampling points were used

rather than a standard traverse. The four sampling points used were determined according to the format presented in Figure 2-10. Also, the criterion for isokinetic sampling was expanded to ± 20% rather than the standard ± 10%.

A system of identification was developed for tests at the Monarch Cement Company plant. A typical test number, I-1-2, was derived as follows:

* The letter designation indicates the inlet (I) or outlet (O) of the control device.

* The first number ("1" in the above example) is the number of the quadrant being tested (four quadrants at each site).

* The second number ("2" in the above example) is the run number (one run in each of four quadrants).

At each testing site a test constituted four runs, one in each quadrant. Two total mass tests (EPA Method 5) and four particle size tests (Andersen HCSS with 15-μm preseparator) were conducted at the No. 5 kiln 10-cell baghouse inlet site. Each quadrant, therefore, was sampled twice by the total mass train and four times by the IP train.

At the outlet test site on No. 5 kiln, two tests for both total mass (EPA Method 17) and particle size (Andersen Mark III with 15-μm preseparator) were conducted. Therefore, each quadrant in the duct was sampled twice by both the total mass and IP trains.

2.3.2.1 Particulate Mass

2.3.2.1.1 EPA Method 5 train--An EPA Method 5 sampling train was used for total particulate mass sampling at the 10-cell baghouse inlet site on No. 5 kiln. EPA Methods 1, 2, 3, and 4 of the Federal Register were followed in obtaining preliminary test data. The sampling train was operated according to EPA Method 5 guidelines using the following changes. As previously mentioned, four individual sampling points were used rather than a standard

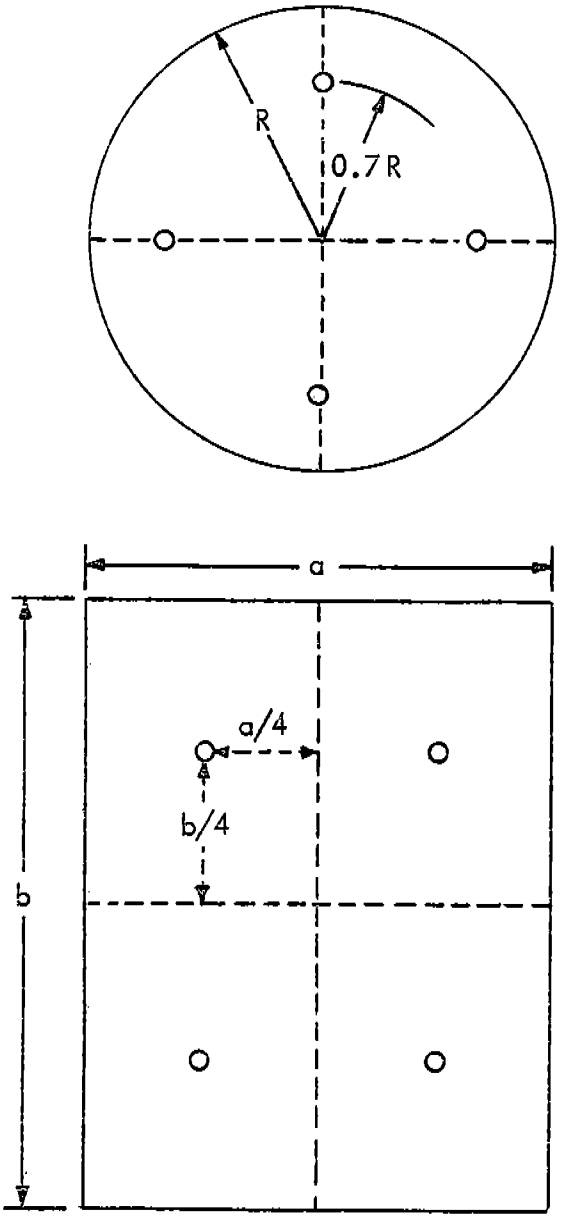


Figure 2-10. Recommended sampling points for circular and square or rectangular ducts.

traverse. A run was conducted at each of the four sampling points, and these four runs constituted a test. There were two tests conducted at the inlet test location. The isokinetic criterion for sampling was expanded to ± 20% rather than ± 10%. Sample calculations are shown in Appendix D.

The EPA Method 5 mass train sample recovery was performed in accordance with EPA Method 5 guidelines. Desiccation and gravimetric analysis of the filters and sample beakers followed the same procedures discussed in Section 2.3.1.1.1 (Pretest Preparations). Sample weights are presented in Appendix C.

2.3.2.1.2 EPA Method 17 train--An EPA Method 17 sampling train (in-stack filtration system) was used for total particulate mass sampling at the outlet test site on No. 5 kiln. EPA Methods 1, 2, 3, and 4 of the Federal Register were followed in obtaining preliminary test data.

Prior to testing, the filter was loaded into the in-stack filter holder and the two halves screwed together. The filter was handled with nonserrated forceps and latex surgical gloves. After attaching the proper size nozzle, the filter holder body, excluding the nozzle, was wrapped in aluminum foil to keep it clean during sampling and to prevent filter contamination during recovery.

The EPA Method 17 train was operated according to EPA Method 17 guidelines. The modifications to these guidelines, as described for the EPA Method 5 sampling train operation, were also followed during the operation of this sampling train. There were two tests for a total of eight EPA Method 17 total mass runs conducted at the No. 5 kiln outlet test location.

Duct pressures at the outlet test location were negative. The sample probe was withdrawn from the duct at the completion of each test with the sample pump running to prevent loss of the sample. The pump was then turned off at the completion of the sampling period. This operation was regulated so that the pump was running only a few seconds after the probe had been removed from the duct.

The recovery of the EPA Method 17 sampling train was accomplished as follows:

* The filter holder was removed from the probe and the protective aluminum foil wrapping discarded.

* The filter was removed from the filter holder and placed in its numbered weighing pan.

* The nozzle and front half of the filter holder assembly were rinsed with acetone directly into a preweighed, numbered 150-ml glass beaker.

* The volume of acetone rinse used was recorded to the nearest 10 ml using the graduations on the 150-ml glass beaker.

Desiccation and gravimetric analysis of the EPA Method 17 filters and 150-ml sample beakers were accomplished using the same procedures as for the EPA Method 5 filters and sample beakers. These procedures were discussed in Section 2.3.1.1.1 (Pretest Preparations). Sample weights are presented in Appendix C.

2.3.2.2 Particle Size

2.3.2.2.1 Andersen high capacity stack sampler (HCSS) with 15-μm preseparator--An Andersen HCSS impactor with 15-μm preseparator was used for particle size testing at the inlet to the 10-cell baghouse on No. 5 kiln. This impactor was chosen for use at the inlet test location because it is designed for heavy grain loading situations in which standard impactors cannot be used because of either overloading or unacceptably short sampling times. The standard impactor provides four particle size cutpoints. The addition of the 15-μm preseparator to the top of the impactor provided a fifth cutpoint.

Preliminary test data were obtained from previous EPA Method 5 train tests and from EPA Methods 1, 2, 3, and 4 determinations. The four sampling points used for the EPA Method 5 mass train were also used for these particle size tests. At the completion of a total mass test, two successive particle size tests were conducted in the same quadrant using the Andersen HCSS with 15-μm preseparator. This testing strategy was followed at each of the four quadrant sampling points. There were four tests of four runs per test for a total of 16 particle size runs conducted at the No. 5 kiln inlet test location.

The Andersen HCSS impactor was operated according to the procedures described by the impactor manufacturer. During sampling, a sample was drawn from the duct at a constant velocity through the nozzle. The constant flow rate allowed for a predetermined 15-μm cutoff in the preseparator while still remaining within the ± 20% isokinetic criterion range. Preliminary and isokinetic sample calculations are presented in Appendix D. At the completion of each run, the impactor was held at a 45-degree angle with the nozzle at the top. It was transported to the laboratory recovery site in this position. This was done as a precaution to minimize the possibility of sample relocation from one stage to another during transport.

Figure 2-11 shows an exploded view of the five particulate recovery stages of the Andersen HCSS impactor with 15-μm preseparator. The procedures used for recovery of particulate samples from the impactor are as follows:

* While holding the impactor at a 45-degree angle with the inlet nozzle at the top, the 15-μm preseparator was removed and set aside in a horizontal position.

* Keeping Stages 2, 3, 4, and 5 at a 45-degree angle, Stages 2 and 3 were removed and set aside in a horizontal position.

* Stages 4 and 5 were removed and set aside in a horizontal position.

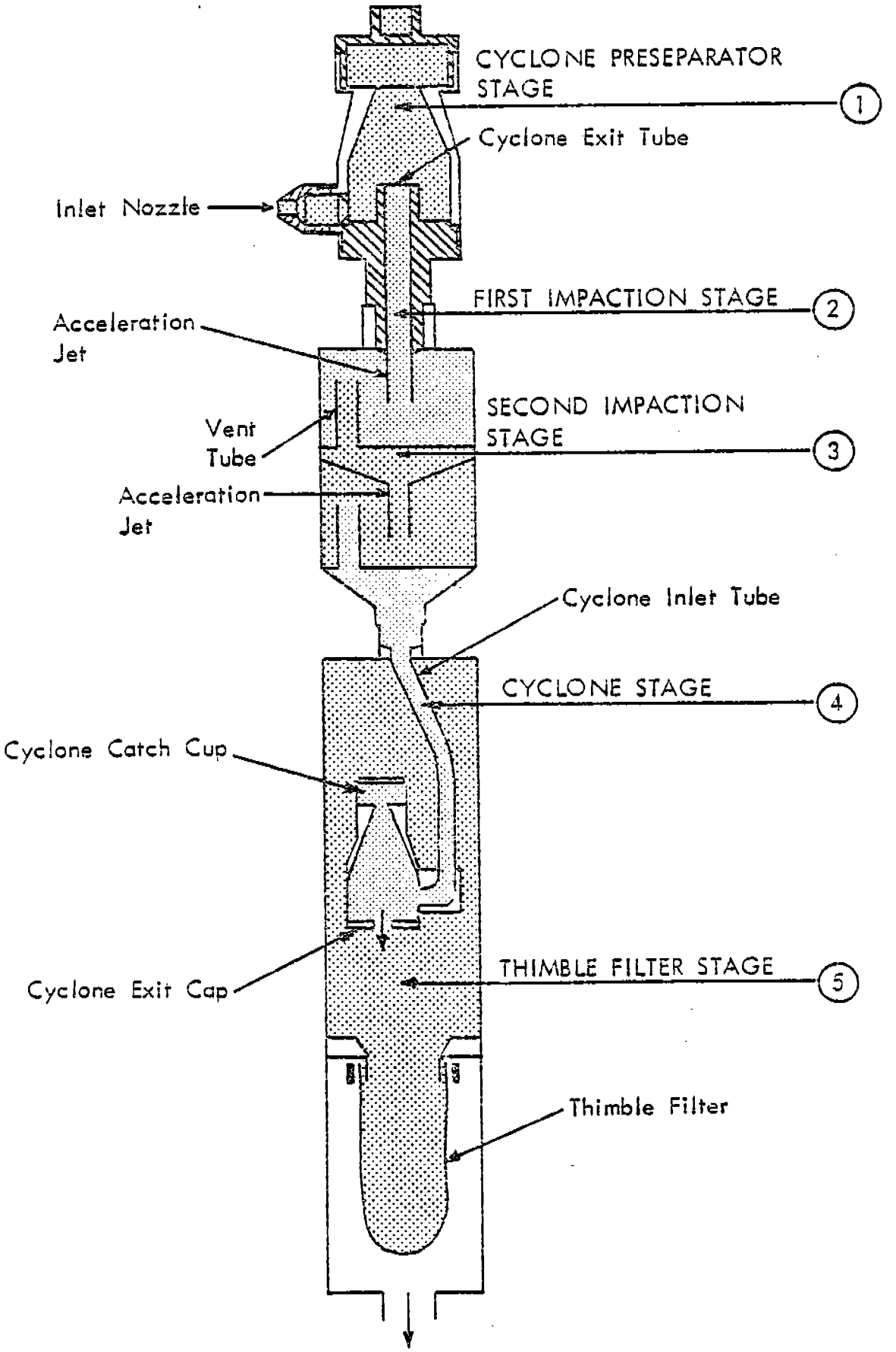


Figure 2-11. Clean-up schematic of an Andersen HCSS impactor with 15 μm preseparator.

* The recovery of each impactor stage was carried out over a piece of glassine paper so that any particulate that was spilled could be recovered.

* While holding the 15-μm cyclone preseparator at a 45-degree angle with the cyclone exit tube pointing up, the sides of the cyclone were tapped lightly to free clinging particulate matter. The exit tube was removed. The particulate on the outer sides of the tube was brushed into the collection cup. Particulate on the inside of the inlet nozzle was also brushed into the collection cup. The particulate from the collection cup was emptied into sample container No. 1.

* The interior sides of the cyclone exit tube and the interior surfaces of Stage 2 were brushed into sample container No. 2.

* The interior surfaces of the vent tubes from Stage 2, the acceleration jet going into Stage 3, and the interior surfaces of Stage 3 were brushed into sample container No. 3.

* While holding Stages 4 and 5 horizontally, the cyclone was removed from the body of Stage 5. Particulate on the exterior surface of the cyclone was brushed into Stage 5. Particulate in the interior of the cyclone and its inlet tube were recovered in sample container No. 4.

* Particulate matter on the interior surfaces of Stage 5 was brushed into the thimble filter. The thimble filter was removed and placed in sample container No. 5 (aluminum tube).

The samples were desiccated and gravimetrically analyzed in the field laboratory using the same procedures as discussed in Section 2.3.1.2.1 (Pretest Preparations). Sample weights are presented in Appendix C.

2.3.2.2.2 Andersen Mark III impactor with 15-μm preseparator--An Andersen Mark III impactor with 15-μm preseparator was used for particle size testing at the outlet location on No. 5 kiln. This impactor was chosen for use at the outlet test location because it is designed for moderate grain loading situations. The standard impactor provides nine particle size cutpoints. The addition of the 15-μm preseparator to the top of the impactor provided a 10th cutpoint.

Preliminary test data for these particle size tests were obtained from previous EPA Method 17 train tests and from EPA Methods 1, 2, 3, and 4 determinations. The four sampling points used for the EPA Method 17 mass train were also used for these particle size tests. This particle size train was operated concurrently with the EPA Method 17 mass train, but in separate quadrants. A particle size run was conducted at each of the four sampling points and these four runs constituted a test. There were two tests for a total of eight particle size runs conducted at the No. 5 kiln outlet test location.

The Andersen Mark III impactor was operated according to the procedures described by the impactor manufacturer. During sampling, a sample was drawn from the duct at a constant velocity through the nozzle. The constant flow rate allowed for a predetermined 15-μm cutoff in the preseparator while still remaining within the ± 20% isokinetic criterion range. Preliminary and isokinetic sample calculations are presented in Appendix D.

At the completion of each run the impactor was withdrawn from the duct with the sample pump running because of the negative pressure in the duct. This procedure is the same as was described for the EPA Method 17 mass train. During transport to the field laboratory recovery site, the Andersen Mark III impactor with 15-μm preseparator was held at a 45-degree angle with the inlet nozzle pointing up. This precaution prevented possible sample movement from one stage to another during transport.

Figure 2-12 shows an exploded view of the impactor stages of the Andersen Mark III impactor. Figure 2-13 shows an exploded view of the 15-μm preseparator mounted on top of the Andersen Mark III impactor. The procedures used for recovery of particulate samples from this impactor are as follows:

* The sampler was held at a 45-degree angle while the exterior surface was brushed clean. This prevented contamination of the substrate collection surfaces inside the impactor during recovery.

* The preseparator was removed while holding the impactor assembly at a 45-degree angle. The preseparator was set aside in a horizontal position.

* The plate assembly housing and impactor inlet cone were removed from the support pipe and set aside in a vertical position with the impactor inlet cone pointing up.

* Recovery of all impactor stages was carried out over a sheet of glassine paper so that if some of the sample spilled, it could, be recovered and returned to the appropriate stage.

* The aluminum foil square labeled "X-Pres" was unfolded and placed on the sheet of glassine paper. All interior surfaces of the preseparator, including the nozzle and the cyclone collection cup, were brushed onto the aluminum foil square. The sides of the square were folded, and it was returned to the filter holder.

* The impactor inlet cone was unscrewed from the plant assembly housing.

* The interior surfaces of the preseparator cyclone exit tube and impactor inlet cone, the crosshair gasket, plate "0," inconel spacer, and crosshair gasket were brushed onto the aluminum foil

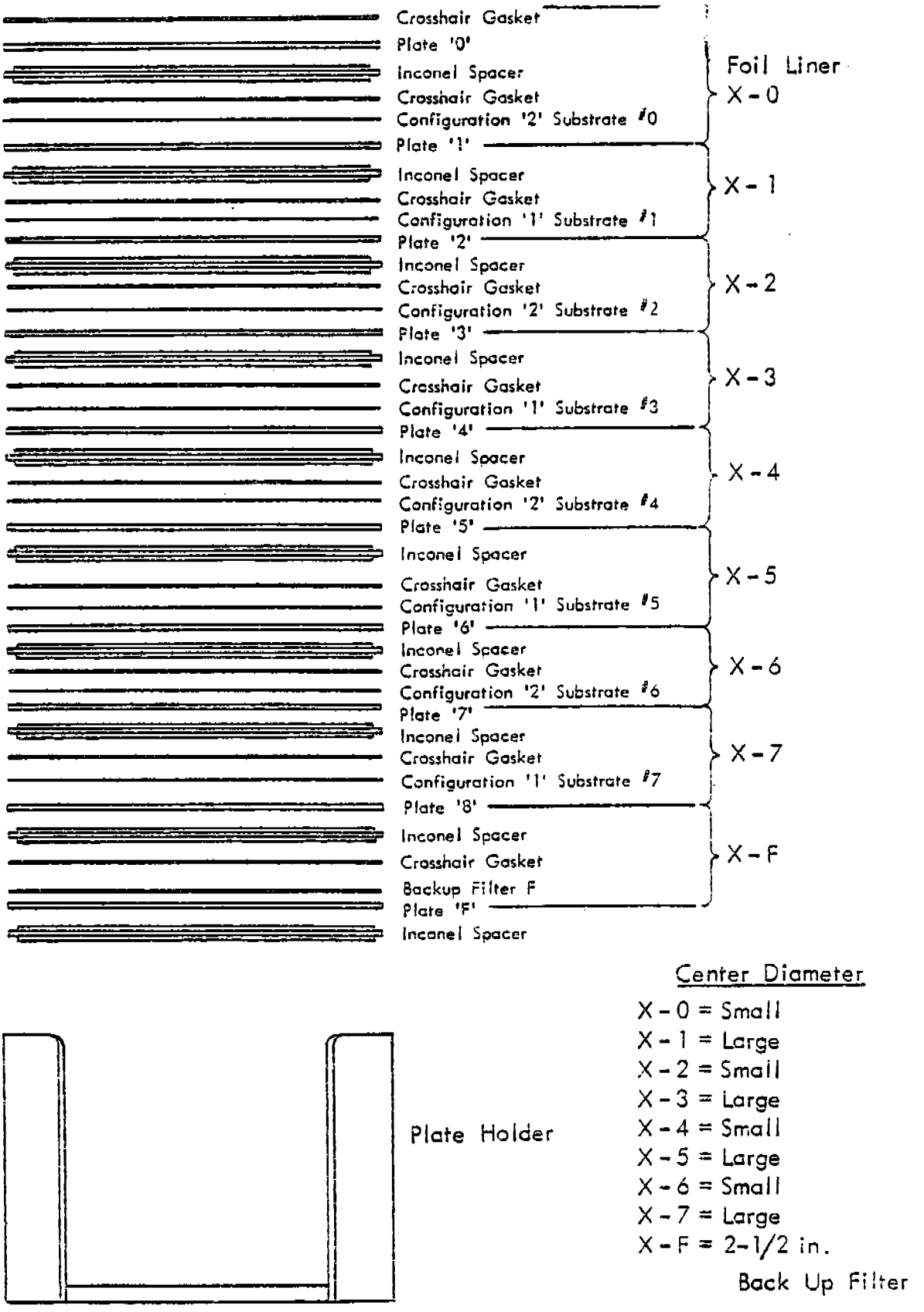


Figure 2-12. Exploded view of an Andersen Mark III impactor.

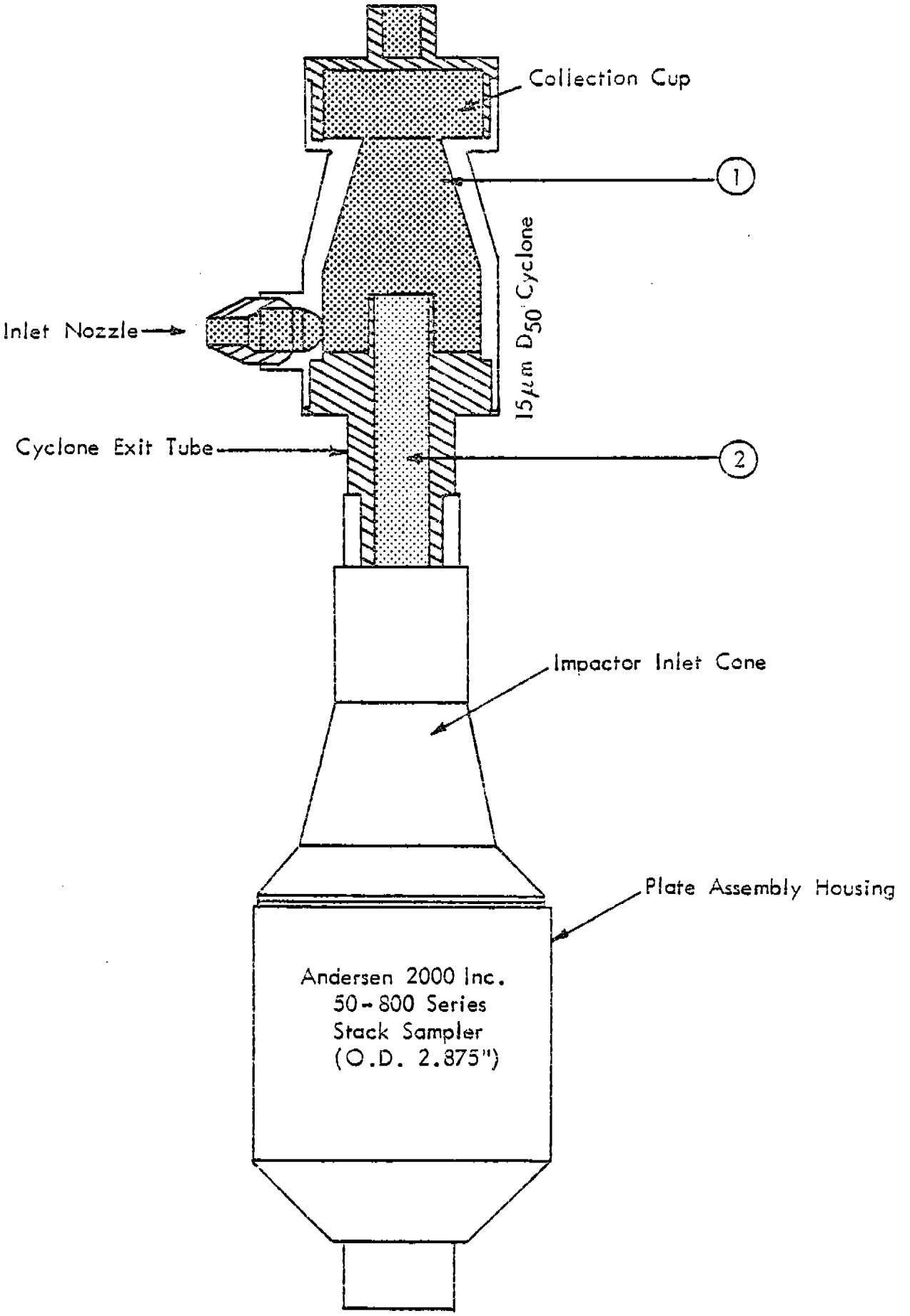


Figure 2-13. Exploded view of a 15 μm preseparator on top of an Andersen Mark III impactor.

square labeled "X-0." Substrate No. 0 was placed inside the foil square. The top side of plate "1" was also brushed onto foil "X-0." The sides of the aluminum foil square were folded, and it was returned to the filter holder.

* The bottom side of plate "1," the inconel spacer, and crosshair gasket were brushed onto foil "X-1." The top side of plate "2" was also brushed onto foil "X-1." The aluminum foil square was folded at the sides and returned to the filter holder.

* The above described recovery procedures were repeated for the remaining stages.

The samples were desiccated and gravimetrically analyzed in the field laboratory using the same procedures as discussed in Section 2.3.1.2.2 (Pretest Preparations). Sample weights are presented in Appendix C.

2.3.3 Sample Blanks

2.3.3.1 Particulate Mass--

One each of the EPA Methods 5 and 17 filters was randomly selected in the field to be used as a blank for their respective test results. The two filters were not distinguished from other filters of their type during the pretest preparations.

The two blank filters were weighed three times each day that actual sample filters of their respective type were final weighed. The blank filters were weighed prior to actual sample weighing, during weighing, and at the completion of all sample weighing. The three blank filter weights were totaled and then averaged for each day. The average blank final weight was subtracted from its average tare weight. The difference was applied as a correction factor to all actual samples of that respective type that were final weighed on that day.

A weight gain was recorded on the EPA Method 5 blank filter every day that actual EPA Method 5 samples were final weighed. The weight gain recorded each day was subtracted from the sample final weights performed on that day. The blank EPA Method 17 filter gained weight one day that actual EPA Method 17 samples were final weighed. The weight gain was subtracted from the sample final weighings performed that day. On all other field test days, the weight of the blank EPA Method 17 filter did not change from its average initial tare weight. The results of the analyses for these blank filters are presented in Appendix C.

Acetone evaporations were performed at MRI to determine the amount of residue in the acetone. Three, clean 250-ml glass beakers were selected for this purpose. The beakers had been prepared for the field test but had not been used for sample recovery. A 200-ml quantity was used to determine the amount of acetone residue. The beakers were evaporated and weighed according to the same procedures used in the field for sample beakers. The average final weight of each beaker was subtracted from its average tare weight. Each of the three beakers had gained weight. The difference between the final and tare weighings of the three beakers was summed, and an average weight gain was determined. The average weight gain was then divided by the volume of acetone used to determine an acetone blank in milligrams per milliliter. This acetone blank correction was applied to all EPA Methods 5 and 17 test results. The weight gain of the acetone blank was subtracted from the weight of sample recovered. The results of the acetone blank analyses are presented in Appendix C.

An acetone "procedural" blank was also performed daily in the field. This entailed pouring 20 ml of acetone into a 150-ml glass beaker. The beakers used for this purpose were evaporated, desiccated, and weighed in the same manner as other beakers containing recovered sample. The weighings of these daily acetone "procedural" blanks were recorded (Appendix C) but were not used as a correction factor. These blanks served as a check on the cleanliness and efficiency of the sample recovery and evaporation procedures.

2.3.3.2 Particle Size

2.3.3.2.1 Andersen Mark III impactor with 15-μm preseparator--One set of Andersen filters for the Andersen Mark III impactor was used as a blank. This set did not include the total number of nine filters normally loaded into the impactor. The blank filter set consisted of the following components:

* One 3-in. square piece of aluminum foil to serve as a blank for the 15-μm preseparator.

* One slotted impaction substrate (large or small center) and 3-in. square aluminum foil holder.

* One 2-1/2 in. diameter, unslotted final filter and 3-in. square aluminum foil holder.

The blank set was labeled as such; then desiccated, weighed, and handled in the same manner as actual sets used for testing. The blank set was weighed in the field on any day that final weighings were conducted on actual Andersen Mark III impactor samples. The blank set was weighed three times each day. The set was weighed prior to actual sample weighings, during weighing, and after all test samples had been weighed.

Daily correction factors for the Andersen Mark III impactor particle size test results were derived by totaling and then averaging the three final weights of the blank set. A separate correction factor was determined for the preseparator aluminum foil square, the slotted impactor substrates, and the unslotted final filter. The daily average final weight of each blank set component was subtracted from its respective average tare weight. The result each day for all blank set components was a weight loss. The weight loss on each blank set component was added to its corresponding sample component final weight performed that day. The blank weighing results for the Andersen Mark III impactor are presented in Appendix C.

2.3.3.2.2 Andersen HCSS impactor with 15-μm preseparator--One glass fiber thimble filter was used as a blank for the Andersen HCSS impactor tests. No blank weights were performed on the aluminum weighing pans used for sample recovery of the preseparator sample or the first three impactor stages. The blank thimble filter was desiccated, weighed, and shipped to the field in the same manner as thimble filters used for testing.

The blank thimble filter was weighed in the field on any day that final weighings were conducted on actual Andersen HCSS impactor samples. The blank thimble filter was weighed three times each day in the same manner as the blank filter set for the Andersen Mark III impactor. At the end of each day, the three blank weights were totaled and then averaged. The average final weight of the blank thimble filter was subtracted from its average tare weight. The weight difference was used as a correction factor and was applied to actual sample final weighings performed that day. A weight gain on the blank thimble filter was subtracted from sample final weights. A weight loss was added to sample final weights. The blank thimble filter weighing data are presented in Appendix C.

SECTION 3.0

SUMMARY OF TEST RESULTS

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

3.1 ACCEPTANCE CRITERIA

Only data that have met specific acceptance criteria are summarized in this section. These criteria, as obtained from "Procedure Manual for Inhalable Particulate Sampler Operation" (SoRI-EAS-79-761, 4181-37), November 30, 1979, prepared by Southern Research Institute for 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 (EPA Method 5 or EPA Method 17) and the IP train (Andersen HCSS or Andersen Mark III with 15-μm preseparator) must be within ± 50%.

Two total mass and four particle sizing tests consisting of four runs per each test (one run per quadrant) were conducted at the No. 5 kiln 10-cell baghouse inlet test location. Two total mass and two particle sizing tests consisting of four runs each (one run per quadrant) were conducted at the No. 5 kiln baghouse outlet test site. The average particulate grain loading for each set of four runs was determined, as well as the average for the number of tests conducted. Any measurement of the total mass which differed

from the mean by more than 50% was considered suspect. The suspect value was compared with that found by the particle size train at the same sampling point. If these values disagreed by less than 50%, it was assumed that the deviations probably were due to stratification of the particulate, and all of the data were retained.

Table 3-1 summarizes the data used for the acceptance criteria for the No. 5 kiln baghouse inlet and outlet test locations.

3.2 EMISSION FACTOR

The emission factors for the No. 5 kiln baghouse inlet and outlet test locations were calculated for 2.5, 10.0, and 15.0 μm as follows:

1. A total mass emission factor was calculated for each run of each test using the data collected from the EPA Method 5 train (inlet test location) or the EPA Method 17 train (outlet test location) and the standard EPA Method 5 calculations (Appendix D). IP emission factors were calculated using this total mass emission rather than the particle sizing emission factor. The emission factors are presented in pounds per hour and pounds per ton of product. The product tonnage data were provided by the Monarch Cement Company. 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

TABLE 3-1. SUMMARY OF NO. 5 KILN BAGHOUSE INLET AND OUTLET TEST ACCEPTANCE CRITERIA RESULTS

Test No.	Quadrant No.	Run No.	Test date	% Isokinetic	Particulate loading (gr/dscf)[a]	$\bar{x}$[b]	% From $\bar{x}$
Inlet mass train (EPA Method 5)							
1	1	1	11-14-81	102.6	14.8		
	2	1	11-12-81	90.1	19.7		
	3	1	11-13-81	98.9	17.9	17.3	2
	4	1	11-13-81	92.9	16.7		
2	1	2	11-14-81	103.7	16.9		
	2	2	11-16-81	104.5	17.8		
	3	2	11-16-81	106.5	15.0	16.6	2
	4	2	11-16-81	103.1	16.5		
						$\bar{x}$ = 17.0	
Outlet mass train (EPA Method 17)							
1	1	1	11-12-81	88.3	0.053		
	2	1	11-13-81	98.3	0.052		
	3	1	11-13-81	98.3	0.050	0.051	16
	4	1	11-14-81	99.2	0.050		
2	1	2	11-14-81	92.9	0.057		
	2	2	11-16-81	96.4	0.063		
	3	2	11-16-81	91.3	0.084	0.071	16
	4	2	11-16-81	96.6	0.079		
						$\bar{x}$ = 0.061	

Test No.	Quadrant No.	Run No.	Test date	% Isokinetic	(gr/dscf)	$\bar{x}$	% From $\bar{x}$
Inlet IP train (Andersen High Capacity Stack Sampler with 15 m Preseparator							
1	1	1	11-14-81	95.2	9.3		
	2	1	11-12-81	104.7	23.6		
	3	1	11-13-81	101.3	24.0	19.4	8
	4	1	11-13-81	106.2	20.9		
2	1	2	11-14-81	98.8	18.2		
	2	2	11-12-81	102.8	15.6		
	3	2	11-13-81	99.4	17.6	17.4	3
	4	2	11-13-81	88.5	18.3		
3	1	3	11-14-81	101.2	24.9		
	2	3	11-16-81	102.9	23.4		
	3	3	11-16-81	104.7	15.1	18.2	1
	4	3	11-16-81	94.7	9.5		
4	1	4	11-14-81	87.9	22.6		
	2	4	11-16-81	95.6	13.0		
	3	4	11-16-81	106.9	17.4	17.1	5
	4	4	11-16-81	103.6	15.5		
						$\bar{x}$ = 18.0	
Outlet IP train (Andersen Mark III Impactor with 15 µm Preseparator							
1	1	1	11-14-81	93.2	0.0259		
	2	1	11-13-81	99.3	0.0285		
	3	1	11-13-81	93.8	0.0346	0.0308	14
	4	1	11-12-81	86.7	0.0342		
2	1	2	11-16-81	99.0	0.0473		
	2	2	11-16-81	105.6	0.0361		
	3	2	11-16-81	97.0	0.0381	0.0409	14
	4	2	11-14-81	94.5	0.0422		
						$\bar{x}$ = 0.0358	

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

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

which theoretically has a 50% probability of striking the collection surface. The computer printouts in Appendix F indicate cumulative percent greater than the stated D_{50}, whereas the graphs and tables presented in this section present the D_{50} as cumulative percent less than stated size. The equations for the Andersen HCSS and Andersen Mark III impactor calculations are presented in Appendix D. It should be noted that the grain loading on several Andersen Mark III impactor stages is low. In a few instances, application of the blank correction factor led to negative weights. These were recorded as zero in the computer.

3. The cumulative percentages for each impactor stage were then applied to the total mass emission factor (calculated from the EPA Method 5 and Method 17 trains) 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. Emission factors were calculated for 2.5, 10.0, and 15.0 μm. The particle diameter upper limit was set at 50.0 μm for the calculations using the spline equation.

3.3 DATA PRESENTATION FORMAT

Summary tables for the No. 5 kiln baghouse inlet and outlet test locations have been presented as follows:

1. Impactor Particle Size Test Sampling Data--Mass weights (mg), D_{50} (effective cut size), and the cumulative percent less than stated size for each stage of the impactor are presented in Tables 3-2 and 3-4 of Section 3.4.

2. Emission Factors Based Upon Total Mass and Impactor Particle Size Distribution--Tables 3-3 and 3-5 of Section 3.4 present the total emission factor, a ratio of particle size train concentration to total mass concentration based on grains per dry standard cubic foot, and the emission factors for 2.5, 10.0, and 15.0 μm. The computer results of the EPA Method 5 and Method 17 train field data that were used in the calculations of total mass and the emission rate, presented in pounds per hour, are presented in Appendix E.

The results have also been presented in graphic form for both the No. 5 kiln baghouse inlet and outlet test locations. These graphs have been presented as follows:

1. Individual Test Results--Figures 3-1 through 3-4 and 3-6 and 3-7 of Section 3.4 present the results of each individual test that consisted of four separate runs, one per quadrant. The data presented include particle size (D_{50}) versus cumulative percent less than stated size, and the emission factors (pounds per ton of product) for 2.5, 10.0, and 15.0 μm.

   The particle size (D_{50}) versus cumulative percent less than stated size data have been presented for each of the four separate runs. Data from all stages of the particular particle size device are presented. The average of the results from the four runs has also been plotted. The average values were calculated by averaging the spline equation results at the selected diameters from the four runs.

   The calculated inhalable emission factors (lb/ton of product) have also been graphically presented for the selected particle diameters of 2.5, 10.0, and 15.0 μm. These results are presented both as an average of the four runs and as a range of values for the four runs per test.

2. Average Test Results--Figures 3-5 and 3-8 of Section 3.4 graphically present the average of the results of all tests conducted at the inlet and outlet locations, respectively. These figures present the averages of both the particle size (D_{50}) versus cumulative percent less than stated size data and the emission factors for all tests. These averages are plotted at the selected particle diameters. The range of individual test average values which were used to plot the overall testing average has also been presented.

3.4 PRESENTATION OF TEST RESULTS

3.4.1 No. 5 Kiln 10-Cell Baghouse Inlet

The inlet test location was shown in Figures 2-2 and 2-3. Monarch Cement Company personnel noted an accumulation of material in the bottom of the rectangular horizontal duct during installation of the two sampling ports. The unobstructed region of the duct was determined and the sampling ports installed according to IP protocol.

Only the inlet duct to the 10-cell baghouse on No. 5 kiln was tested. The bypass inlet duct to the 3-cell baghouse on No. 5 kiln was not tested for inhalable particulate emissions. However, EPA Methods 2 and 3 measurements were obtained from the bypass system to the 3-cell baghouse. These data, together with data collected at the inlet to the 10-cell baghouse and the common outlet from both baghouses, were used to calculate the percentage of kiln gases controlled by the 3-cell baghouse. Appendix G contains the raw field data sheets and the computer printout results of these measurements at the three locations.

The flow rate at the inlet to the 10-cell baghouse was 48,500 dscfm (dry standard cubic feet per minute). At the bypass inlet to the 3-cell baghouse, the flow was 8,600 dscfm. The sum of these flow rates is 57,000 dscfm, and represents the total flow exiting No. 5 kiln. The 10-cell baghouse controls 84.9% of the gases exiting the kiln. The total

mass emission rate of the 10-cell baghouse inlet was multiplied by 1.18 to calculate inhalable particulate emission factors representative of the emissions from the kiln.

The calculated inlet test data are summarized in Tables 3-2 and 3-3. Figures 3-1 through 3-5 graphically present the results.

3.4.2 Common Outlet Stack from No. 5 Kiln 10-Cell and 3-Cell Baghouses

The outlet test location was shown in Figures 2-2 and 2-4. This testing location is the common outlet from both the 10-cell and 3-cell baghouses on No. 5 kiln.

Table 3-4 summarizes the particle size test sampling data from the common outlet stack. Table 3-5 presents the calculated emission factors and Figures 3-6 through 3-8 graphically show the results of the controlled emissions from No. 5 kiln.

3.5 SUMMARY OF RESULTS

Inhalable particulate matter emission factors were calculated for emissions on No. 5 kiln at the Monarch Cement Company's dry process cement plant located in Humboldt, Kansas. The inhalable emission factors were calculated for the particle diameters of 2.5, 10.0, and 15.0 μm.

Inhalable emission factors calculated for the inlets to the baghouses averaged 45 lb/ton (pounds per ton of product) at 2.5 μm, and 104 and 110 lb/ton at 10.0 and 15.0 μm, respectively.

The outlet sampling site is the combined exhaust location for both the 10-cell and 3-cell baghouses associated with No. 5 kiln. The inhalable particulate emission factors which were calculated for the outlet are representative of the kiln gases controlled by both the 10-cell and 3-cell baghouses. The inhalable emission factors for the outlet averaged 0.30 lb/ton at 2.5 μm, 0.69 lb/ton at 10.0 μm, and 0.72 lb/ton at 15.0 μm.

TABLE 3-2. NO. 5 KILN 10-CELL BAGHOUSE INLET IMPACTOR PARTICLE SIZE TEST SAMPLING DATA

Particle size run number	15 μm Cyclone			Stage 1			Stage 2			Cyclone			Filter	
	Mass (mg)[a]	D_{50} size (μm)[b]	Cum. % than[c]	Mass (mg)	D_{50} size (μm)	Cum. % than	Mass (mg)	D_{50} size (μm)	Cum. % than	Mass (mg)	D_{50} size (μm)	Cum. % than	Mass (mg)	D_{50} size (μm)
I-1-1	731.6	15.29	62.31	40.8	11.04	60.21	60.7	5.98	57.08	526.6	2.03	29.95	581.4	< 2.03
I-2-1	3,744.2	14.97	30.84	71.0	10.99	29.53	277.1	6.05	24.41	1,030.0	1.77	5.38	291.5	< 1.77
I-3-1	3,003.5	15.38	42.24	82.1	11.02	40.66	394.6	5.97	33.08	986.0	2.12	14.12	734.1	< 2.12
I-4-1	2,905.4	14.72	41.95	81.6	10.73	40.32	266.3	5.81	35.00	918.0	2.03	16.66	834.0	< 2.03
I-1-2	2,086.8	15.83	45.69	82.2	11.35	43.56	309.5	6.21	35.50	1,019.6	2.02	8.97	344.6	< 2.02
I-2-2	1,937.0	15.66	42.78	67.3	11.29	40.79	207.0	6.33	34.67	879.6	1.78	8.69	294.0	< 1.78
I-3-2	2,227.4	15.81	40.10	75.0	11.29	38.09	277.5	6.12	30.63	449.5	2.15	18.54	689.4	< 2.15
I-4-2	2,358.3	15.81	39.51	71.7	11.34	37.67	244.8	6.15	31.39	891.2	2.13	8.53	332.7	< 2.13
I-1-3	3,659.5	15.34	33.95	97.4	11.14	32.19	383.0	6.04	25.28	1,112.4	1.99	5.20	288.3	< 1.99
I-2-3	2,699.9	15.62	45.67	135.9	11.27	42.93	414.2	6.24	34.60	1,067.6	1.87	13.11	651.7	< 1.87
I-3-3	2,099.7	15.59	49.68	79.9	11.24	47.77	341.6	6.20	39.58	442.7	1.89	28.97	1,209.0	< 1.89
I-4-3	797.8	15.84	59.17	34.8	11.35	57.39	61.9	6.20	54.22	671.4	2.03	19.85	387.9	< 2.03
I-1-4	2,087.2	17.56	47.41	81.4	12.05	45.36	367.3	6.74	36.11	982.4	2.19	11.36	450.8	< 2.19
I-2-4	1,404.3	16.13	48.65	59.0	11.44	46.50	150.1	6.37	41.01	785.2	1.92	12.30	336.3	< 1.92
I-3-4	1,948.0	15.27	47.00	70.1	11.13	45.09	245.6	6.07	38.41	684.5	1.93	19.79	727.2	< 1.93
I-4-4	1,679.6	15.67	49.48	71.5	11.25	47.33	191.7	6.10	41.56	840.8	2.07	16.28	541.1	< 2.07

[a] mg = net weight milligrams.

[b] D_{50} Size (μm) = 50% effective cutoff diameter micrometers.

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

TABLE 3-3. NO. 5 KILN BAGHOUSE INLET EMISSION FACTORS BASED ON TOTAL MASS AND IMPACTOR SIZE DISTRIBUTION

Particle size run number[a]	Total mass emission rate[b] (lb/hr)[c]	Production rate (ton/hr)	Total mass emission factor (lb/ton)[d]	Ratio of particle size train conc. to total mass. conc.	Emission factors for 2.5 μm (lb/ton)[d]	10.0 μm (lb/ton)	15.0 μm (lb/ton)
I-1-1	7,600	34	220		79	131	137
I-2-1	10,300	33	310		30	90	97
I-3-1	9,000	36	250		42	100	106
I-4-1	8,100	35	230		47	92	98
Average	8,800	34	260	1.1	50	103	110
I-1-2	7,600	34	220		28	93	99
I-2-2	10,300	33	310		45	123	131
I-3-2	9,000	36	250		50	92	99
I-4-2	8,100	35	230		26	85	90
Average	8,800	34	260	1.0	37	98	105
I-1-3	8,300	34	240		20	75	81
I-2-3	9,000	33	270		48	112	122
I-3-3	7,400	33	220		68	102	109
I-4-3	7,700	33	230		60	131	135
Average	8,100	33	240	1.1	49	105	112
I-1-4	8,300	34	240		33	103	112
I-2-4	9,000	33	270		48	123	129
I-3-4	7,400	33	220		53	97	103
I-4-4	7,700	33	230		47	107	113
Average	8,100	33	240	1.0	45	108	114
Total Average	8,400	34	250	1.0	45	104	110

[a] Particle size test data obtained with an Andersen HCSS impactor with 15 μm preseparator.

[b] Total mass emission rate data obtained with an EPA Method 5 train.

[c] Emission rate corrected to total emissions from No. 5 kiln, pounds per hour.

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

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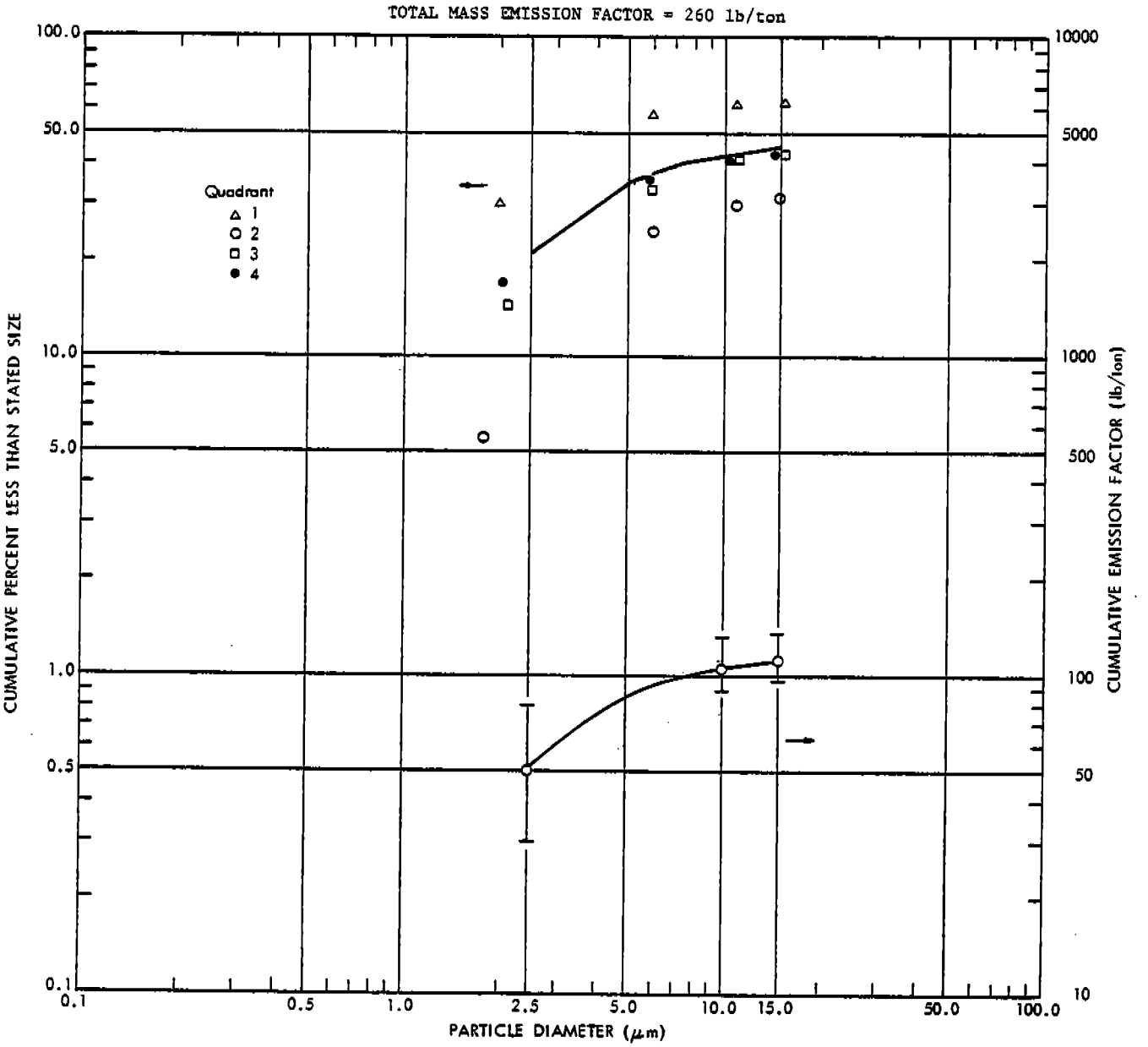

Figure 3-1. No. 5 kiln 10-cell baghouse inlet--test one--cumulative percent less than stated size and cumulative emission factor versus particle diameter.

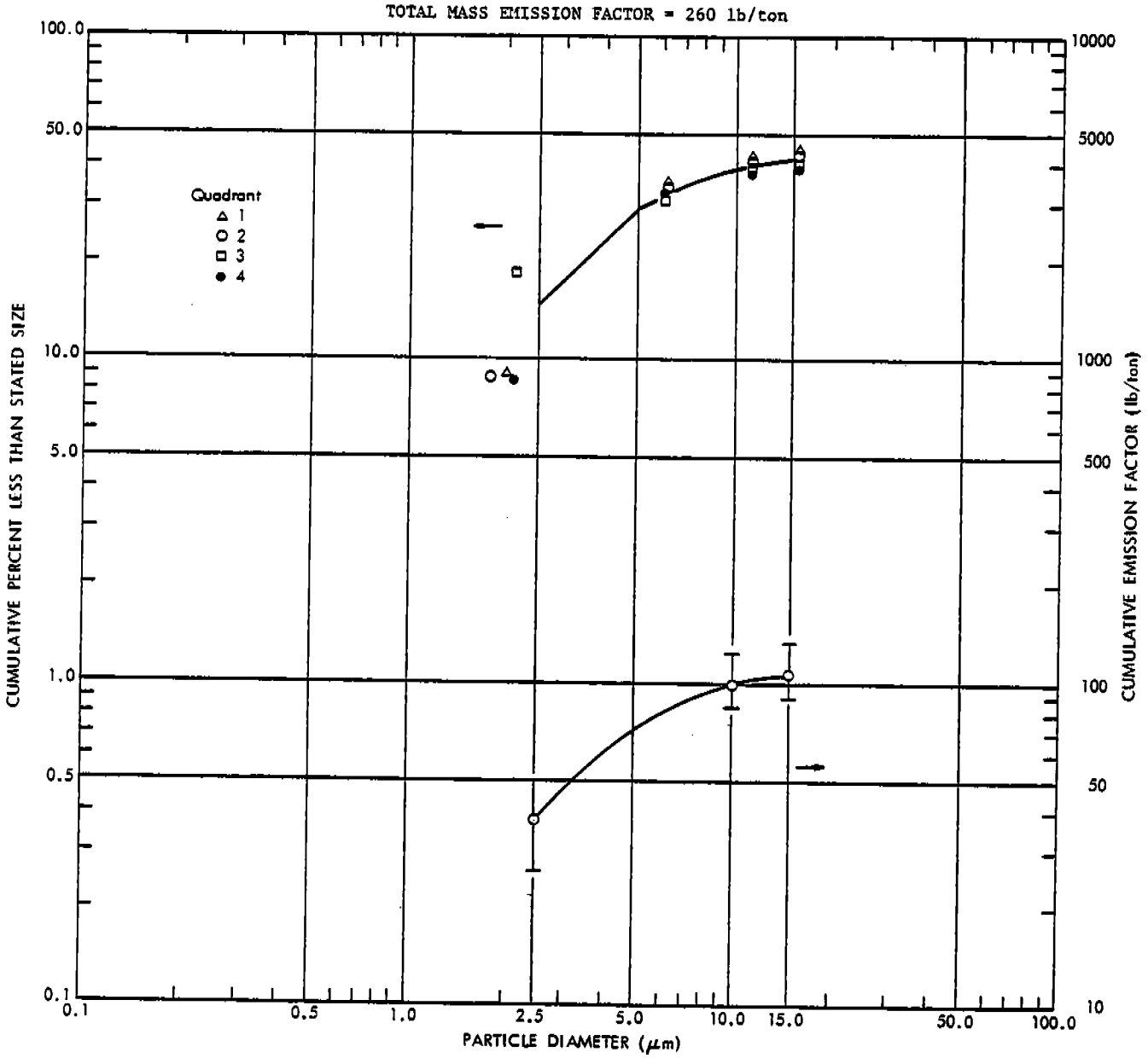

Figure 3-2. No. 5 kiln 10-cell baghouse inlet--test two--cumulative percent less than stated size and cumulative emission factor versus particle diameter.

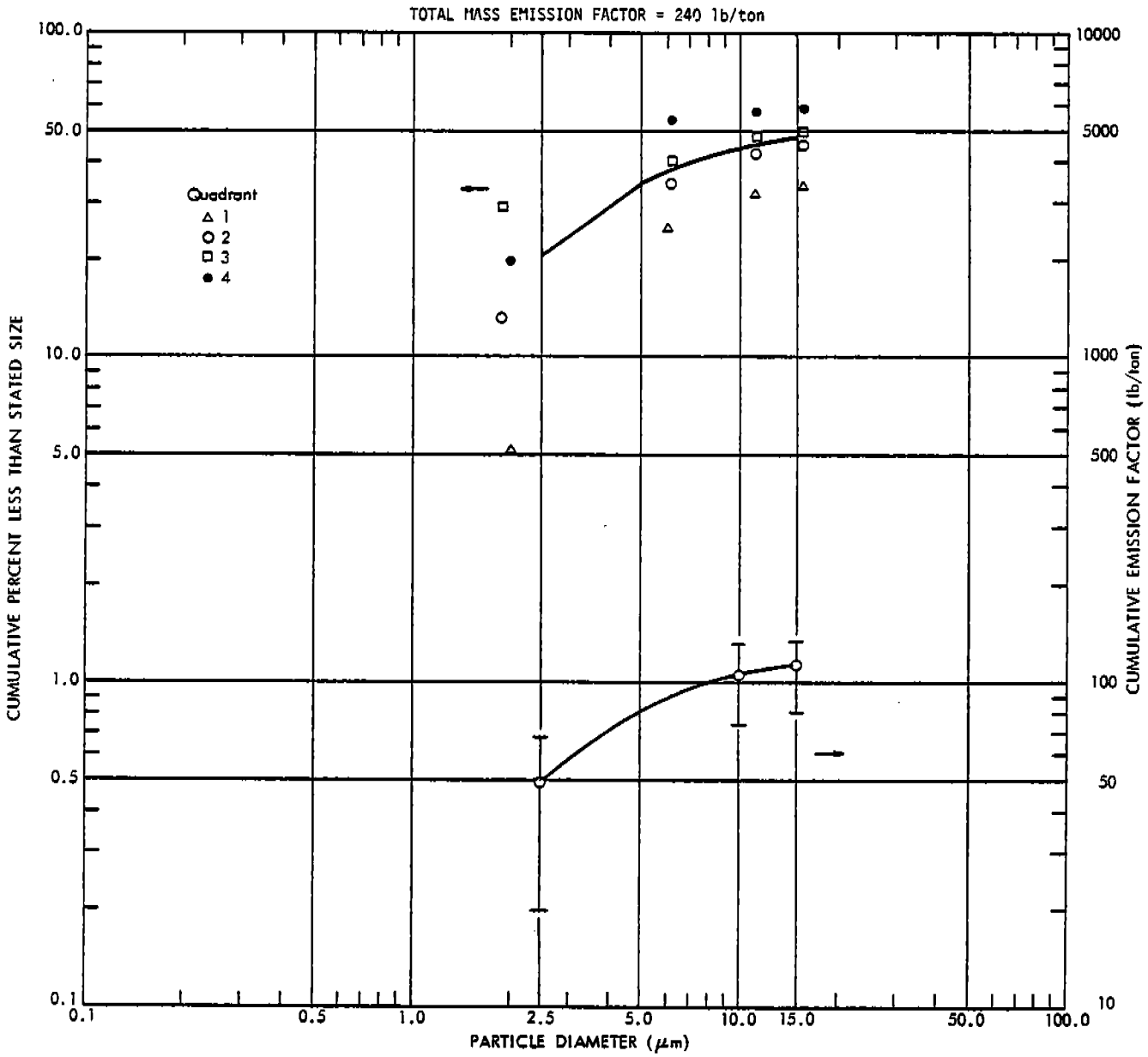

Figure 3-3. No. 5 kiln 10-cell baghouse inlet--test three--cumulative percent less than stated size and cumulative emission factor versus particle diameter.

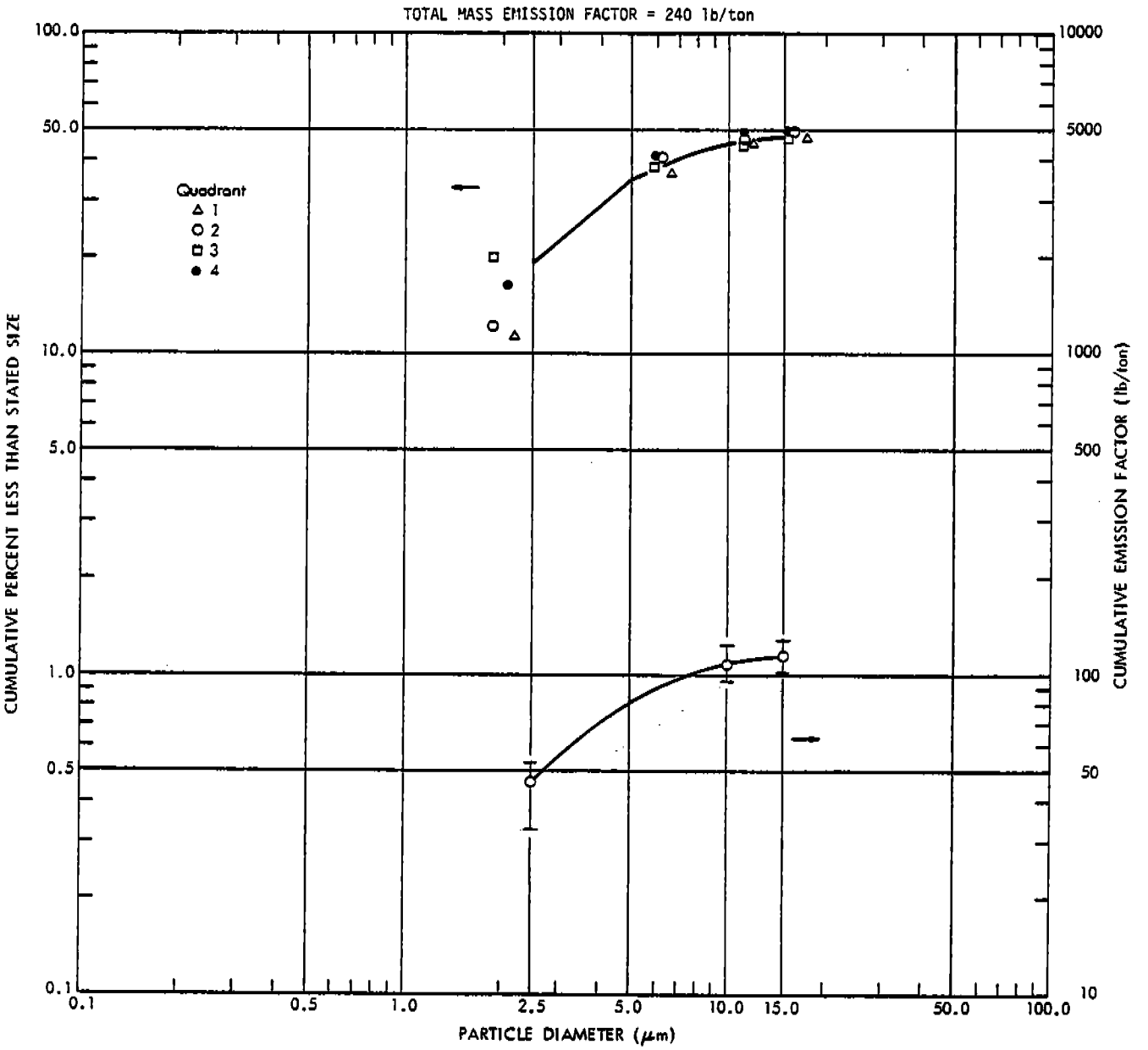

Figure 3-4. No. 5 kiln 10-cell baghouse inlet--test four--cumulative percent less than stated size and cumulative emission factor versus particle diameter.

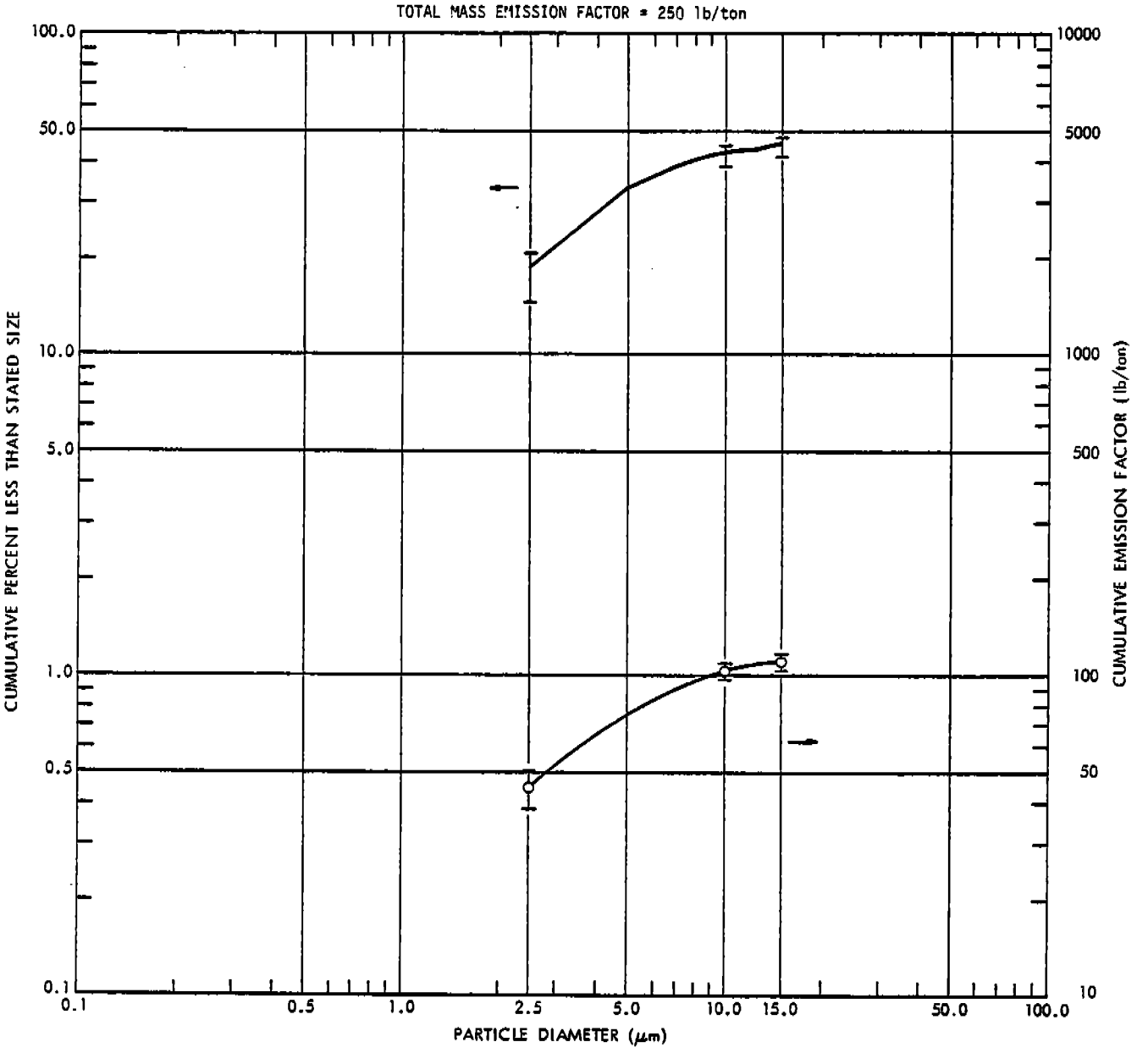

Figure 3-5. No. 5 kiln 10-cell baghouse inlet--total test average--cumulative percent less than stated size and cumulative emission factor versus particle diameter.

TABLE 3-4. NO. 5 KILN COMMON BAGHOUSE OUTLET IMPACTOR PARTICLE TEST SAMPLING DATA

Particle size 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
0-1-1	5.38	15.62	76.40	0.04	14.22	76.23	0.00	8.85	76.23	1.31	5.98	70.48	2.29	4.06	60.44
0-2-1	4.87	15.67	75.43	0.00	14.33	75.43	0.06	8.93	75.13	1.76	6.04	66.25	2.57	4.10	53.28
0-3-1	7.48	15.99	49.25	0.02	14.50	49.12	0.00	9.03	49.12	0.25	6.11	47.42	0.82	4.14	41.86
0-4-1	4.34	16.36	87.69	0.70	14.79	85.71	0.77	9.21	83.53	2.29	6.23	77.03	3.91	4.23	65.95
0-1-2	4.61	16.08	84.74	0.00	14.56	84.74	0.19	9.07	84.11	4.43	6.13	69.44	4.90	4.16	53.21
0-2-2	3.78	15.54	84.43	0.00	14.17	84.43	0.00	8.82	84.43	1.70	5.96	77.42	3.68	4.05	62.26
0-3-2	5.97	15.81	81.83	0.27	14.37	81.01	0.00	8.95	81.01	1.60	6.05	76.14	2.40	4.10	68.84
0-4-2	6.58	15.63	82.23	0.00	14.27	82.23	0.00	8.89	82.23	2.56	6.01	75.32	11.92	4.08	43.13

Particle size 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)
0-1-1	5.74	2.59	35.26	5.57	1.27	10.83	2.18	0.76	1.27	0.01	0.55	1.23	0.28	< 0.55
0-2-1	4.08	2.61	32.69	3.68	1.28	14.13	0.96	0.77	9.28	0.00	0.56	9.28	1.84	< 0.56
0-3-1	3.24	2.64	19.88	2.53	1.30	2.71	0.37	0.78	0.20	0.00	0.57	0.20	0.03	< 0.57
0-4-1	7.46	2.70	44.80	7.14	1.32	24.55	4.49	0.79	11.82	0.92	0.58	9.21	3.25	< 0.58
0-1-2	7.35	2.65	28.87	6.48	1.30	7.42	2.24	0.78	0.00	0.00	0.57	0.00	0.00	< 0.57
0-2-2	6.36	2.58	36.05	5.92	1.26	11.66	2.83	0.76	0.00	0.00	0.55	0.00	0.00	< 0.55
0-3-2	5.90	2.62	50.88	7.57	1.28	27.85	4.69	0.77	13.57	2.02	0.56	7.43	2.44	< 0.56
0-4-2	6.14	2.60	26.55	7.01	1.27	7.62	2.82	0.76	0.00	0.00	0.56	0.00	0.00	< 0.56

[a] mg = net weight milligrams.

[b] D_{50} Size (µm) = 50% effective cutoff diameter micrometers.

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

TABLE 3-5. NO. 5 KILN 10-CELL BAGHOUSE OUTLET EMISSION FACTORS BASED ON TOTAL MASS AND IMPACTOR SIZE DISTRIBUTION

Particle size run number[a]	Total mass emission rate[b] (lb/hr)[c]	Production rate (ton/hr)	Total mass emission factor (lb/ton)[d]	Ratio of particle size train conc. to total mass. conc.	Emission factors for 2.5 μm (lb/ton)[d]	10.0 μm (lb/ton)	15.0 μm (lb/ton)
0-1-1	26	33	0.79		0.27	0.60	0.62
0-2-1	25	35	0.71		0.22	0.54	0.54
0-3-1	26	36	0.72		0.13	0.35	0.36
0-4-1	25	35	0.71		0.30	0.60	0.62
Average	26	35	0.74	0.60	0.23	0.52	0.54
0-1-2	27	33	0.82		0.23	0.69	0.70
0-2-2	30	33	0.91		0.33	0.77	0.82
0-3-2	41	33	1.24		0.61	1.01	1.02
0-4-2	39	33	1.18		0.31	0.97	1.04
Average	34	33	1.03	0.58	0.37	0.86	0.90
Total Average	30	34	0.88	0.59	0.30	0.69	0.72

[a] Particle size test data obtained with an Andersen Mark III impactor with 15 μm preseparator.

[b] Total mass emission rate data obtained with an EPA Method 17 train.

[c] Total mass emission rate of 10-cell baghouse and 3-cell baghouse, pounds per hour.

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

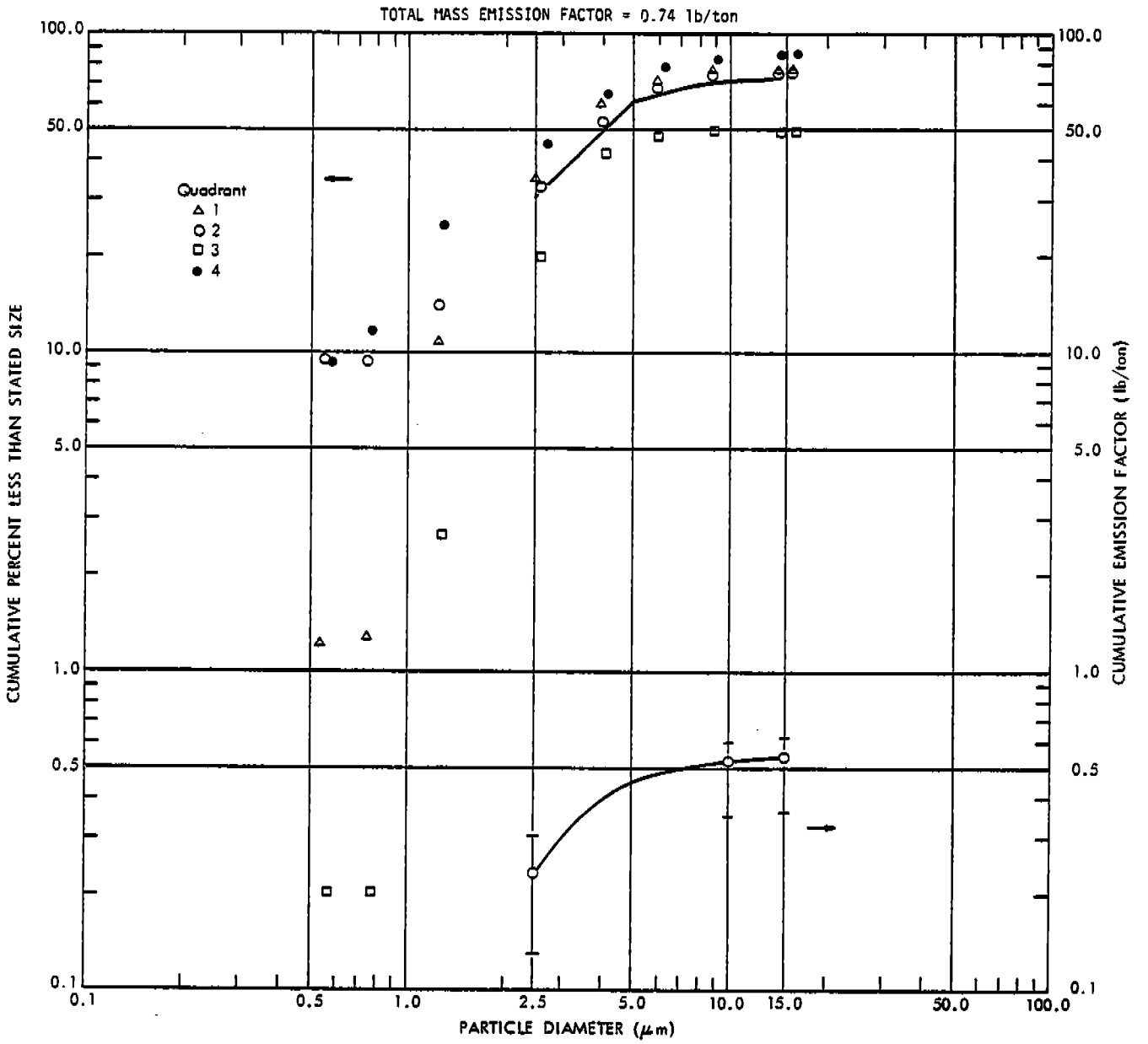

Figure 3-6. No. 5 kiln 10-cell baghouse outlet--test one--cumulative percent less than stated size and cumulative emission factor versus particle diameter.

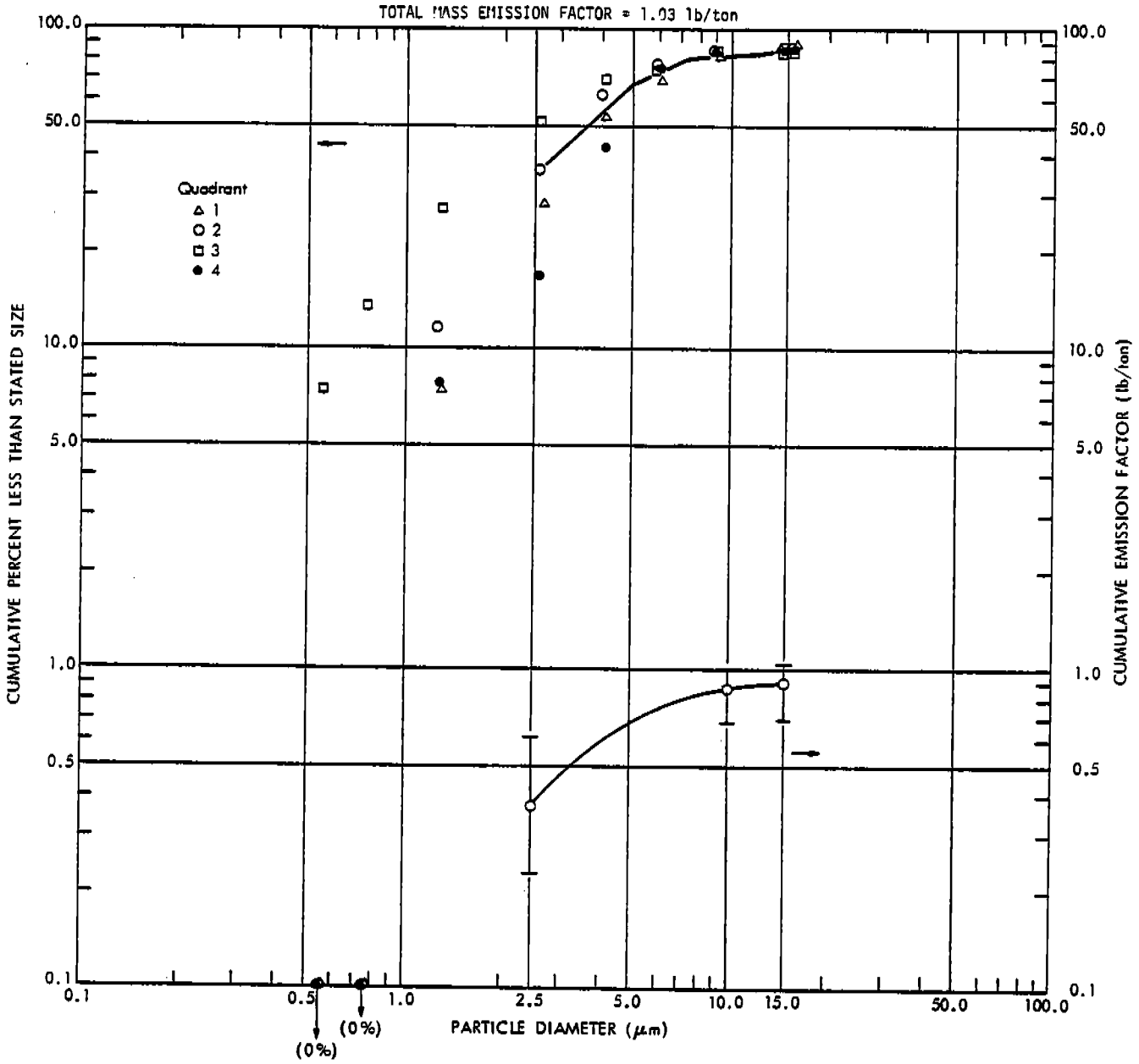

Figure 3-7. No. 5 kiln 10-cell baghouse outlet--test two--cumulative percent less than stated size and cumulative emission factor versus particle diameter.

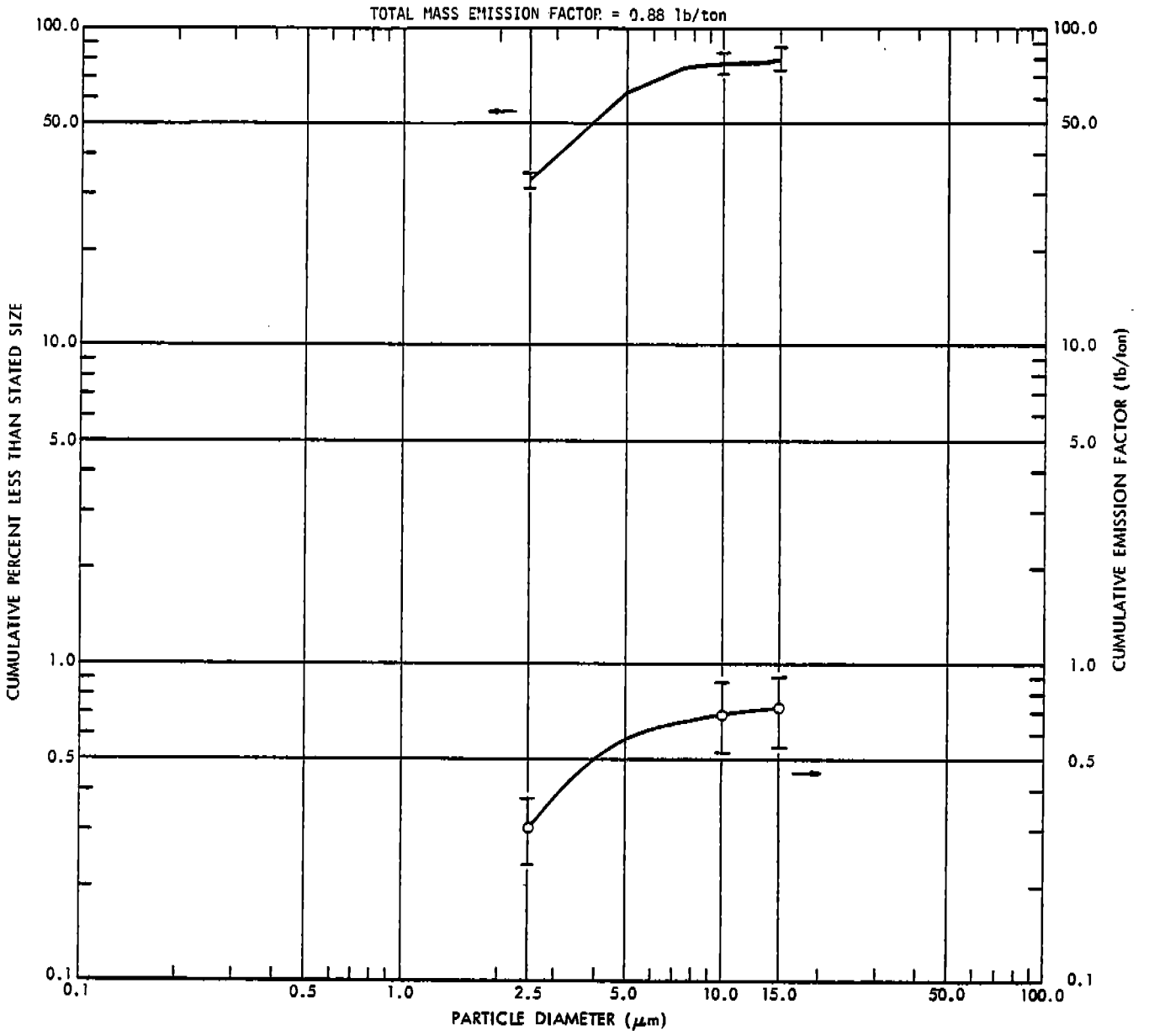

Figure 3-8. No. 5 kiln 10-cell baghouse outlet--total test average--cumulative percent less than stated size and cumulative emission factor versus particle diameter.

Table 3-6 presents the inhalable particulate emission factors calculated for each test. The average inhalable particulate emission factors for all tests conducted at each test location are also presented.

TABLE 3-6. SUMMARY OF EMISSION FACTORS

Sampling location	Test No.	Emission factors for Total (lb/ton)[a]	2.5 μm (lb/ton)	10.0 μm (lb/ton)	15.0 μm (lb/ton)
Baghouse inlets	1	260	50	103	110
	2	260	37	98	105
	3	240	49	105	112
	4	240	45	108	114
	Average	250	45	104	110
Baghouse outlets	1	0.74	0.23	0.52	0.54
	2	1.03	0.37	0.86	0.90
	Average	0.88	0.30	0.69	0.72

[a] (lb/ton) = Pounds per ton of product.