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DEMONSTRATION OF THE USE OF
CHARGED FOG IN CONTROLLING
FUGITIVE DUST FROM
LARGE-SCALE INDUSTRIAL SOURCES

Prepared for

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Prepared by

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

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DEMONSTRATION OF THE USE OF CHARGED FOG IN CONTROLLING FUGITIVE DUST FROM LARGE-SCALE INDUSTRIAL SOURCES

by

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ABSTRACT

Although the charged fog concept has been widely applied to industrial sources of fugitive dust, little data are available regarding fogger control effectiveness on particulate matter. To obtain such data, the Industrial Environmental Research Laboratory of the Environmental Protection Agency contracted TRC Environmental Consultants, Inc. to conduct a full-scale demonstration of a charged fogger on several industrial fugitive emission sources. The sources tested included a primary rock crushing operation, a secondary rock crushing operation, a molten iron spout hole at a blast furnace cast house, and a coke screening operation. The fog device evaluated was the "Fogger IV" manufactured by the Ritten Corporation. This report presents and discusses the results of these four source tests.

This report also presents and discusses the results of three source tests jointly funded by EPA and Armco Inc. The same charged fog devices were used along with a charged fog device developed by AeroVironment, Inc. of Pasadena, California. The sources selected for field testing the two fog devices were a stainless steel slab torch cutting operation, a conveyor transfer operation at a recycle (sinter) plant, and a limestone crusher/conveyor operation.

In general, the testing program showed that (1) the control of emissions by the two types of fog devices are generally comparable, (2) fogger efficiency is dependent on the positions of the foggers in relation to the source, and (3) charging a water spray appears to increase its effectiveness in controlling particulate matter emissions by up to 40 percent.

This report was submitted in fulfillment of Contract No. 68-02-3115, Task 109, by TRC Environmental Consultants, Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from May 1979 to June 1982 and work was completed as of July 1982.

CONTENTS

FIGURES

FIGURES (Continued)

TABLES

TABLES (Continued)

TABLES (Continued)

SECTION 1

INTRODUCTION

A spray of fine water droplets is a well known means of airborne dust removal. Various types of scrubbers rely on water droplets to remove entrained particles from streams and direct water sprays are often used in mining and material handling for dust suppression. Unfortunately, water sprays are not very effective in removing dust from the ambient air.

One method of improving the effectiveness of water sprays is by applying an electrical charge to the spray that is opposite in polarity to the charge on the dust to be suppressed. It has been found that most industrial pollutants and naturally occurring fugitive dusts acquire an electrostatic charge as they are dispersed into the air. If this charged, airborne material is exposed to an oppositely charged water spray, contact between the particulate matter and the water droplets is enhanced. After contact is made, the wetted particulate matter agglomerates rapidly and falls out of the atmosphere.

The effectiveness of these charged sprays can be improved by atomizing the water droplets so that a fog is produced. The fineness of the fog droplets enhances the charge-carrying capability of the spray. Hoenig[1] has demonstrated that the greatest effectiveness is obtained when the water droplets are of a size similar to that of the dust particles to be controlled. There is also the benefit of reduced operating costs since less water is required when fog is used.

A device designed to produce such a fine spray and apply an electrostatic charge to it is known as a charged fogger. The charged fogger is intended primarily for fugitive dust sources that cannot reasonably be controlled by conventional means such as hooding. Such sources include materials-handling operations (transfer points and conveyors), truck and railroad car loading and unloading, front-end loaders, ship loading, grain silos, and mining operations.

Although the charged fog concept has been widely applied to industrial sources of fugitive dust, little quantitative data are available regarding fogger control effectiveness on particulate matter. To obtain such data, the Industrial Environmental Research Laboratory of the Environmental Protection Agency at Research Triangle Park, North Carolina, (IERL/EPA/RTP) contracted TRC Environmental Consultants, Inc. (TRC) to conduct a full-scale demonstration of a charged fogger on several appropriate industrial fugitive emission sources. In particular, IERL/EPA was interested in testing the largest fogger, designated "Fogger IV", manufactured by the Ritten Corporation of Ardmore, Pennsylvania,* on several sources within the iron and steel industry and the sand and gravel industry.

Following numerous visits to iron and steel plants and sand and gravel companies, several sources were selected for Phase I field testing the charged fogger. These sources were:

- Sand and gravel company: primary rock crushing operation;
- Sand and gravel company: secondary rock crushing operation;
- Iron and steel plant: molten iron spout hole at a cast house; and
- Iron and steel plant: coke screening operation.

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* This device is now being manufactured and marketed by the Sonic Development Corporation of Mahwah, New Jersey. (The Ritten Corporation has gone out of business.) However, the device will be referred to as the Ritten fogger throughout this report.

Coincidently with the EPA/IERL fogger test program, Armco, Inc. signed a Consent Decree with EPA Region V under which funds were set aside in a trust fund for the demonstration of the use of electrostatically charged fog on several fugitive dust sources within Armco's plants. TRC was designated as the firm to perform the demonstration program.

To provide Armco with state-of-the-art information on charged fog technology, two types of charged fog devices were to be field tested under the Consent Decree demonstration program. The first of these devices was the Ritten Corporation's Fogger IV. The second device was one developed by AeroVironment, Inc. (AV) of Pasadena, California. AV was subcontracted by TRC to assist in this demonstration program. As compared with the Ritten fogger, the AV fogger uses a different method of charging the fog and a different method of fog dispersal. By testing both fog devices side-by-side, Armco could be provided with a basis for comparison should a decision be made in the future to purchase a charged fog device.

The sources selected for Phase II field testing the two fog devices were located within Armco plants and included:

- A stainless steel slab torch cutting operation;
- A conveyor transfer operation at a recylce plant; and
- A limestone crusher/conveyor transfer operation.

This report presents the results of both Phase I and II charged fogger testing programs in the following manner:

- Section 2 presents a summary and the conclusions of the study.
- Section 3 presents a glossary of acronyms and conversion factors used in the report.
- Section 4 provides general field test information including a discussion of the site selection process, descriptions of the test equipment, and descriptions of the laboratory procedures.

- Section 5 provides specific information on the seven source tests that were performed. This information includes site and source descriptions, equipment locations, test procedures, test conditions, and results.

- Section 6 presents a general discussion of all the test results.

- Section 7 presents the references cited in the text.

SECTION 2

SUMMARY AND CONCLUSIONS

Based on the results of the seven field tests, the following specific conclusions can be drawn regarding the performance, operation, and field installation of the fog devices tested:

Performance

- Charging a water spray appears to increase its effectiveness in controlling particulate matter emissions by up to 40 percent.
- The two Ritten foggers, operating at a combined water flow rate of approximately 160 l/hr, were capable of 60 percent effectiveness in controlling particulate matter emissions. For control efficiencies greater than 90 percent, water flow rates of 300 to 400 l/hr would most likely be required for the sources tested.
- The Ritten and AeroVironment charged fog devices were essentially comparable in terms of baseline emissions reduction and increase in effectiveness due to charging.
- The fog devices tested produced no visual improvement in plume opacity for the following reasons:
  - The fog itself has an opacity associated with it.
  - The fogger water flow rates were insufficient to completely control the quantity of emissions generated.
  - Several of the sources were hot which caused the fog to turn to steam and thus added to the visible plume.

Operation

- The two fog devices are extremely difficult to operate in subfreezing ambient temperatures. This problem might be alleviated by adding glycerin to the water or else by using steam instead of water. Both of these possible solutions have been successfully demonstrated in laboratory work.

- The two fog devices, as presently designed, are not rugged enough to withstand the harsh environments often associated with industrial dust sources (e.g., molten metal, heavy dust plumes, caustic materials.)

- The nose cone and control panel of the Ritten fogger should be redesigned to allow for easier access to the inner workings. As presently designed, the Fogger IV is extremely difficult to work on in the field.

Field Installation

- The fog devices should be run with as low a fan speed as possible to avoid dust reentrainment. The fan speed should be no greater than that necessary to carry the fog to the source.

- Foggers should conceivably be placed above a dust source and aimed down upon it. This should help to isolate the agglomerated particles at the source.

In general, the two types of foggers, as presently designed, both show promise, but have design and operational problems. These problems include dust reentrainment from the fan forced air used to carry the fog to the source; freezeups in cold weather; frequent shorting of electronics; lack of mobility; and water flow limitations. It is recognized that both devices were designed as prototypes and that the test program primarily focused on evaluating the two different concepts. However, the underlying result is that both devices are not ready for use in industry and neither device performed much better than the other.

The future development of the Ritten foggers is no longer with the Ritten Corporation, which terminated their business since the beginning of this study. The Ritten foggers are now being manufactured and sold by the Sonic Development Corporation. Sonic is incorporating their sonic dry-fog nozzles into the Ritten induction ring fog devices. To date, Sonic is developing a prototype Fogger I (the original, small Ritten fogger) using a 15 ℓ/hr (4 gph) water flow nozzle that produces droplets in the 1 to 40 μm range. They are also planning a Fogger IV with a Sonic nozzle. Some of the inherent problems of the Ritten foggers have been addressed by Sonic personnel. They have eliminated waterlines to the gauges and heat traced those leading to the nozzles, thus eliminating freezeups. They are also using a nozzle that produces finer droplets which should increase the charge/droplet ratio and thus the capture efficiency. Sonic has also put the controls into a separate industrial-strength box which reduces maintenance. The product line offered should be a significant improvement over the prototype devices tested during this study.

SECTION 3

GLOSSARY

Acronyms

AV	AeroVironment, Inc.
CFG	Charged Fog Generator
CI	Cascade Impactor
CYC	Cyclone Preseparator
EPA	Environmental Protection Agency
Hi-Vol	High-Volume Air Sampler
SSI	Size Selective Inlet
TRC	TRC Environmental Consultants, Inc.
TSP	Total Suspended Particulate

Conversion Factors

To Convert	Multiply By	To Obtain
^oC	(^oC) (1.8) + 32	^oF
cm	0.3937	in
m^3	35.31	ft^3
g	0.002205	lbs
kg/cm^2	14.22	psi
kW	1.341	hP
ℓ	0.2642	gal
m	3.281	ft

SECTION 4

FIELD TESTS - GENERAL

SITE SELECTION PROCESS

During Phase I, site visits were made to a number of iron and steel plants and sand and gravel companies in order to locate sources that would be acceptable for the first four fogger field tests. Similarly, several Armco plants were visited in Phase II in order to locate three acceptable sites for the Armco testing program.

To determine the acceptability of a proposed source for fogger testing, several criteria were applied to each source examined during the site visits. These criteria were:

- Size. Source emissions should be of a nature that will not overwhelm the spray from two foggers.
- Isolation. The source should be relatively isolated from other dust sources.
- Physical layout. The area around the source must leave room for the foggers, samplers and test personnel.
- Utilities. Suitable power and water supplies must be available at the source.
- Process continuity. The process operation should be fairly continuous for minimal testing time.
- Process consistency. The emissions produced should be similar from test to test.
- Dustiness. A significant amount of dust should be produced so that sampling time is minimized.
- Meteorological influence. The source should be relatively isolated from meteorological influences such as wind and rain.

- Commonality. The source should be one common to other steel mills or sand and gravel companies. Demonstration of the charged-fog technique on a unique source would not result in transferable information.

- Variety. A variety of source and emission particle types should be tested so that a broader spectrum of information regarding fogger effectiveness could be obtained.

While it was not possible to locate any one source that completely satisfied the acceptability criteria, the sources that were selected met enough of these criteria to be judged suitable for the fogger field tests.

TEST EQUIPMENT

The equipment used for the field tests included two charged fog devices manufactured by the Ritten Corporation, two charged fog devices developed by AeroVironment, several high-volume particulate samplers, size selective inlets, a cyclone preseparator, cascade impactors, and a wind measurement system. Each of these items is described below.

Ritten Charged Foggers

Two identical foggers were specially designed and fabricated for the project by the Ritten Corporation of Ardmore, Pennsylvania. Ritten's standard Fogger III was modified and upgraded in order to allow for variations of its operating conditions. The final configuration, designated "Fogger IV", is shown schematically in Figure 1.

In the generation of charged fog by the Fogger IV, water is atomized as it is ejected from a nozzle by a compressed air supply. For the tests, a 1.5 kW compressor was used to supply the required air pressure of 5.6 to 8.8 kg/cm^2 and local water supplies were utilized to provide the required water pressure of 2.1 to 3.5 kg/cm^2. The air flow is variable from 0 to 11.3 m^3/hr and the water flow is variable from 0 to 151 ℓ/hr. As the fog leaves the nozzle, it passes through an induction ring, maintained at 12.5 kV, where either a positive or negative charge, depending on the nature of the dust, is applied to the spray. A power supply of 230 V is required for the fogger operation. A flow of air around the nozzle, provided by a centrifugal fan, projects the fog towards the dust source. The fan is driven by a 3.7 kW motor and operates at a maximum of 79 m^3/min. It is variable from 0 to 100 percent of capacity and produces a maximum output air velocity at the nozzle face of 3048 m/min. A control panel, located on the back of the fogger, allows fogger operation and parameter variability. A schematic representation of the control panel is shown in Figure 2. Additional information regarding the Fogger IV may be found in references 2, 3, and 4.

Flow Spectra--

Two different flow nozzles were used for the tests, both manufactured by the Delavan Manufacturing Company of West Des Moines, Iowa. While both nozzles produced a conical flow of droplets, one nozzle had a slightly higher flow capacity than the other.

To determine the flow spectra of the two nozzles, droplet sizing tests were performed at TRC's laboratory facilities by KLD Associates, Inc. of Huntington Station, New York. The device used to measure the droplet sizes and concentrations was a KLD Model DC-2A Droplet Counter. The Droplet Counter is a hybrid electronic device which uses both analog and digital techniques to measure, count, sort and display liquid droplets. The fundamental technique of this device is to utilize a hot wire anemometer-type probe which is cooled by the impinging droplets. The degree of cooling is droplet size dependent. Further information on this device may be found in reference 5.

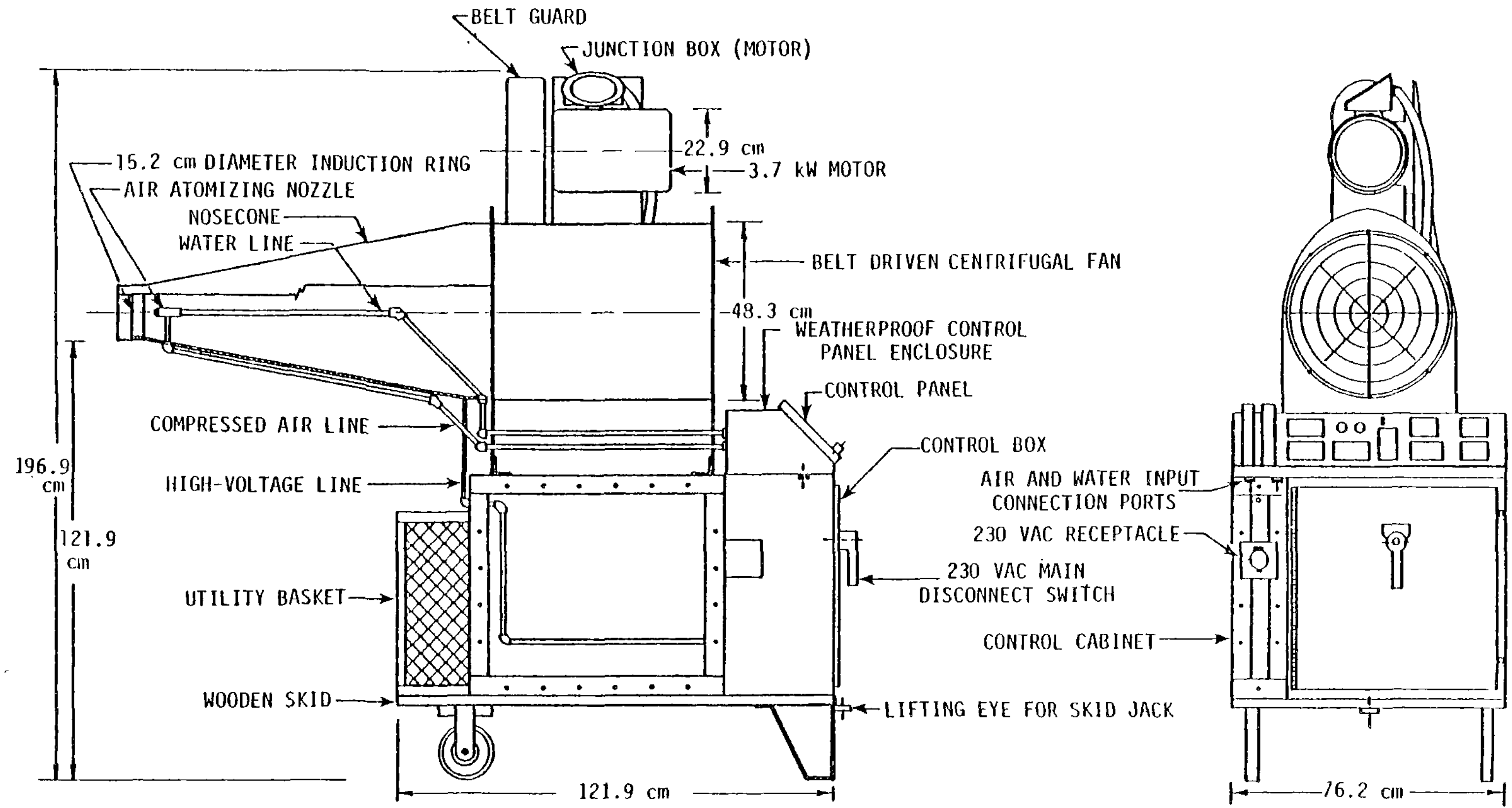


Figure 1. Schematic representation of the Ritten Corporation's Fogger IV.

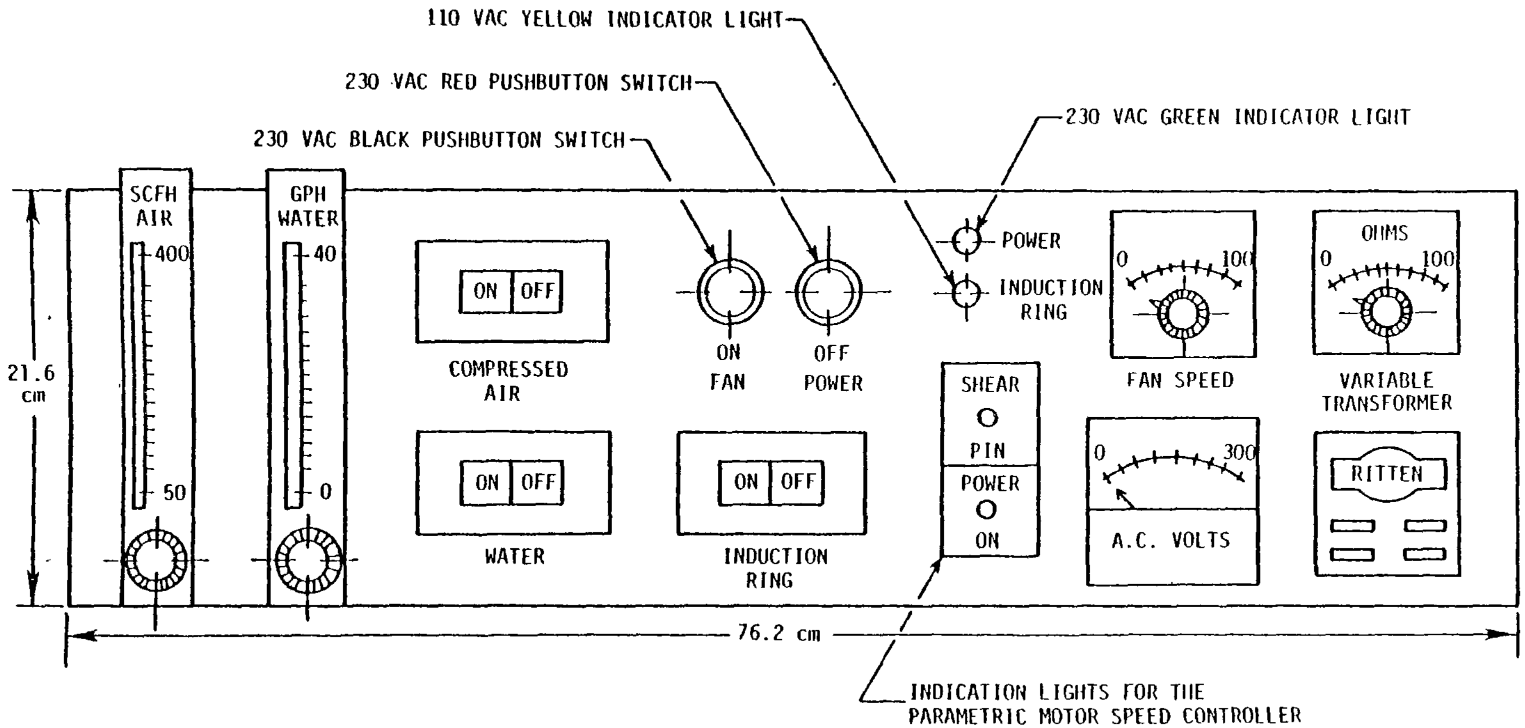


Figure 2. Schematic representation of Fogger IV control panel.

Table 1 presents the operating conditions and results of the droplet sizing tests for the two Delavan nozzles. Each of the runs presented in the table are the average of duplicate tests. From these results, the following observations can be made:

- Charging the spray does not change the mass median diameter of the droplets.
- Increasing the atomizing air flow reduces the mass median diameter while increasing the water flow increases the mass median diameter.
- The mass median diameter of the droplets in the spray varies according to the position in the spray cone.
- The two nozzles produced very similar droplet spectra.

Charge Per Drop--

Tests were performed at TRC's laboratory facilities to determine the charge-to-mass ratio for the water droplets. The charged spray was directed at a fine meshed screen which in turn was connected to an ammeter. The ammeter displayed the charge on the total mass of droplets which could then be converted to a charge per drop using the known water flow rate and droplet spectra.

The results of these tests indicated that the charge-to-mass ratio for a 60 μm diameter drop with 75 ℓ/hr water flow is approximately 0.11 μC/g. This ratio is essentially unaffected by the air flow rate but varies slightly with the water flow rate (0.10 μC/g at 114 ℓ/hr; 0.14 μC/g at 38 ℓ/hr.)

<u>AeroVironment Charged Fog Generators</u>

AeroVironment Inc. of Pasadena, California developed a charged fog generator (CFG) under the sponsorship of EPA/IERL/RTP. This device, which

TABLE 1. RESULTS OF LABORATORY TESTS: DROPLET SIZE

Run No.	Nozzle Type*	Fan Speed (% of Max.)	Water Flow (ℓ/hr)	Air Flow (m^3/hr)	Charge (C)/ No Charge (NC)	Position In Spray Cone: Center(C)/ Outer Edge(OE)	Calculated Mass Median Diameter(μm)
1	D2	40	114	2.5	NC	C	84
2	D2	40	114	2.5	C	C	81
3A	D2	40	57	2.8	NC	C	89
3B	D2	40	57	5.4	NC	C	44
4A	D2	40	57	5.4	C	C	44
4B	D2	40	57	5.4	C	OE	66
5A	D1	40	57	5.4	NC	C	53
5B	D1	40	57	5.4	NC	OE	66
6	D1	40	57	5.4	C	OE	69
7	D1	40	114	5.4	C	OE	91
8	D1	40	114	5.4	NC	OE	90

* D1 - Delavan nozzle, low flow (model 40)
D2 - Delavan nozzle, high flow (model 20)

charges the water by directly connecting the positive terminal of a 15 kV dc power supply to the inflowing water, provides fog with a charge-to-mass ratio of approximately 1.2 μC/g for a 200 μm diameter droplet. Two of these devices were provided for the Armco tests.

The CFG is a modified Ray Oil Burner which consists of only one movable part, a hollow steel shaft upon which are mounted the atomizing cup, the fan, and the motor rotor. Figure 3 schematically represents the CFG. The modifications to the oil burner include replacement of the fuel tube, air cone, and the spinning cup with nonconducting materials. The water inlet tube is attached to the spinning cup and its rear end is connected to the water supply using a rotating seal. Figure 4 is a photograph of the prototype unit used in the Armco study.

Water is introduced into the 3,600 rpm spinning cup whose inside is fabricated to a gradual taper. Because of the centrifugal forces, the water becomes a thin film and moves forward into a high-velocity airstream where it breaks up into fine droplets. These droplets are projected forward by the airstream from the fan. An air butterfly valve is used to set the airflow rate, thus controlling the spray pattern. Figure 5 shows a typical fog pattern obtained with the CFG. The spray pattern covers a volume of 16 to 24 m^3. The water flow rate can be varied from about 8 to 70 ℓ/hr. The total power requirement of this unit is less than 1 kW. The whole unit is mounted on a portable platform for easy transport to a remote location. With the addition of a small generator, the CFG can be operated where commercial electric power is not available.

The medians of the size distribution of the water droplets, measured using a cloud optical array probe for droplets in the range of 30 to 300 μm, are a concentration median droplet diameter of 100 μm and a mass median droplet diameter of ≈200 μm for droplets >30 μm.

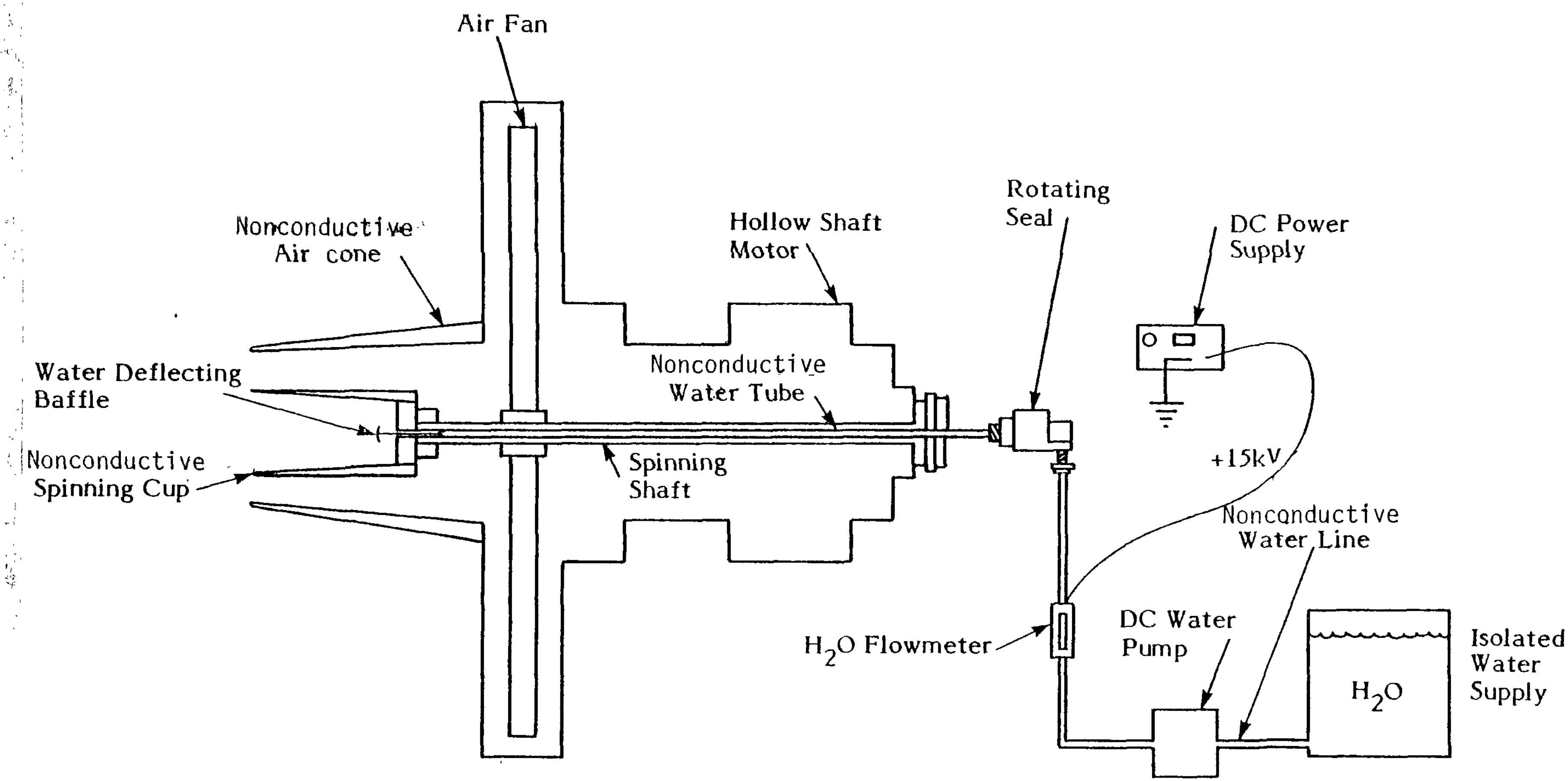


Figure 3. Schematic representation of AeroVironment charged fog generator.

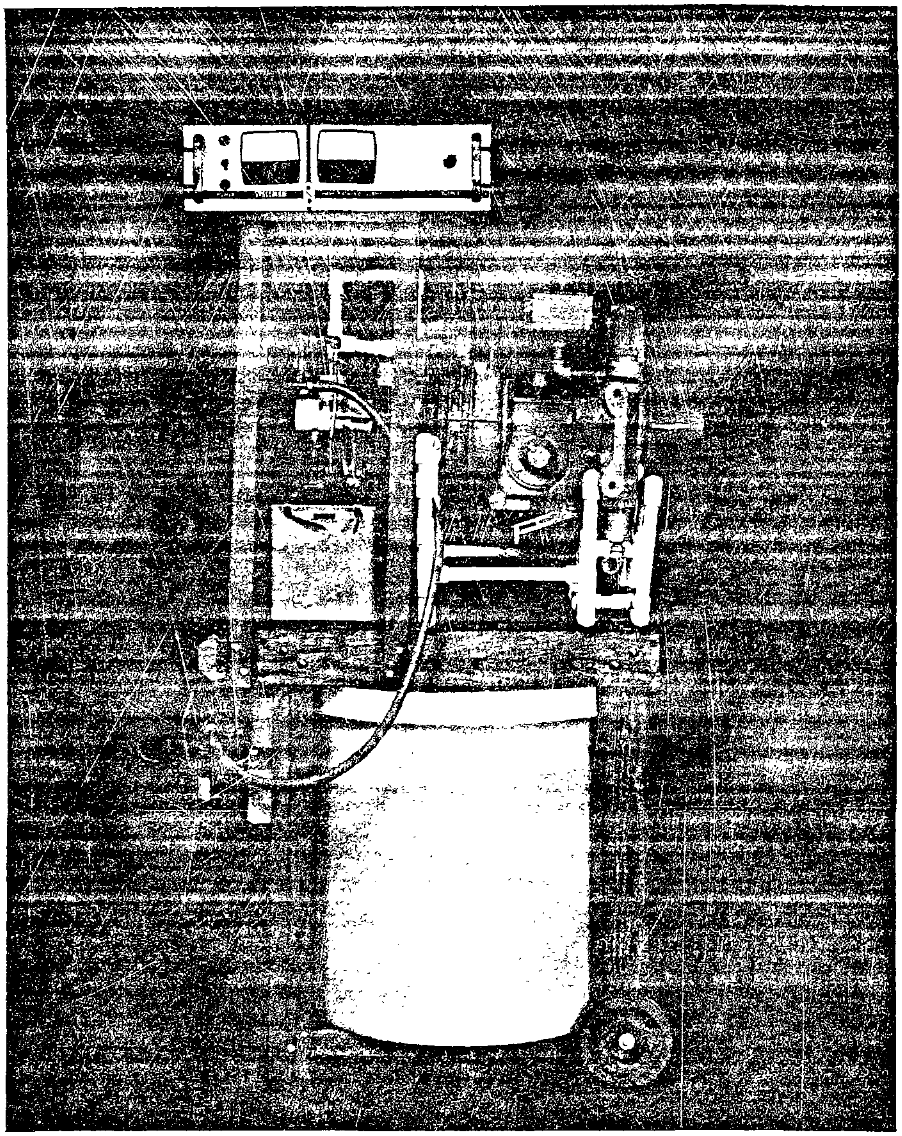


Figure 4. Photograph of AeroVironment charged fog generator.

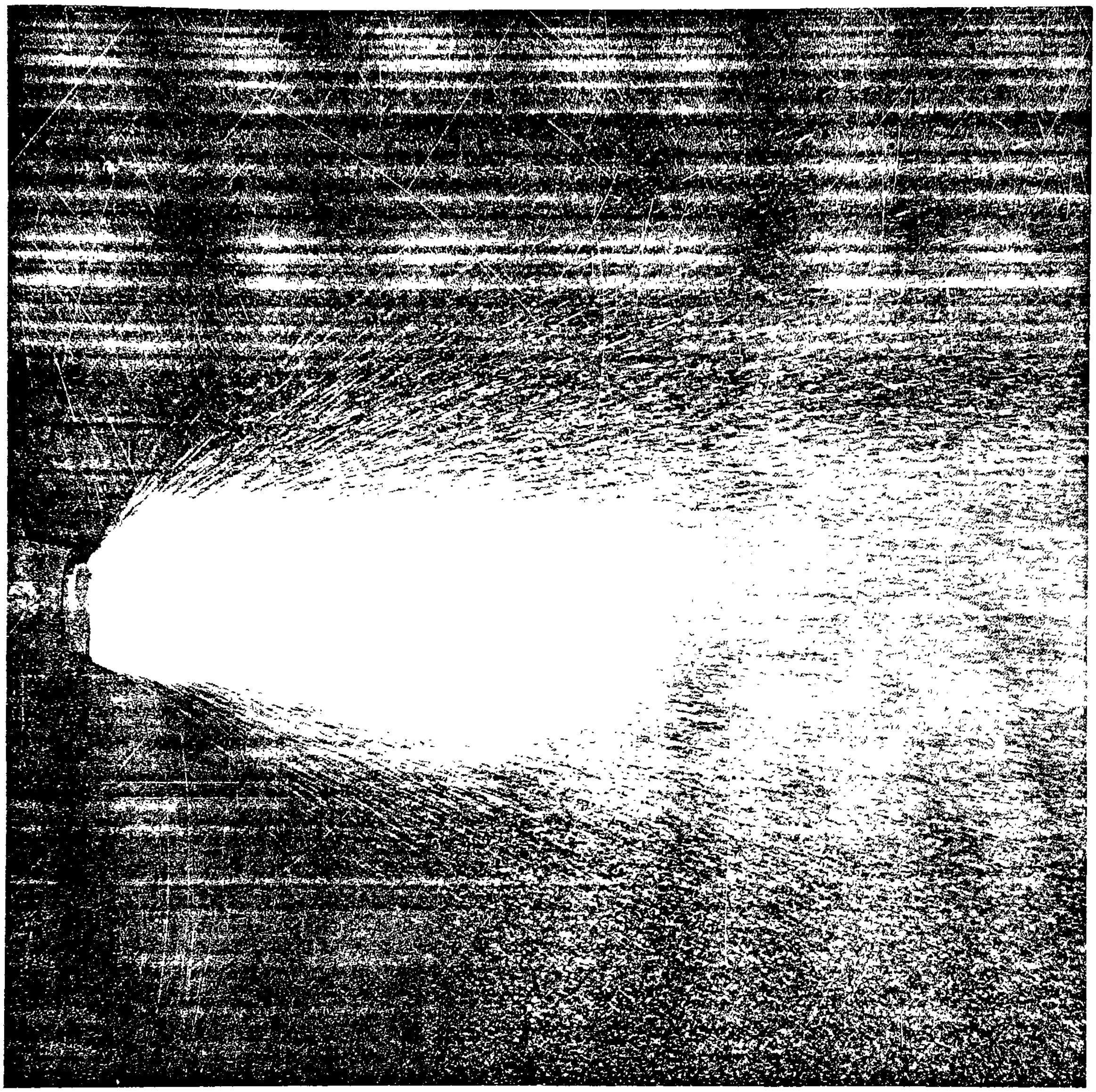


Figure 5. Photograph of typical spray pattern of AeroVironment charged fog generator.

Additional information regarding the AV fogger may be found in references 6 and 7.

<u>Sampling Equipment</u>

High-volume air samplers (hi-vols) were used for the particulate matter measurements. The number of samplers used varied from source to source and, in some cases, from test to test. The exact number used for each test is discussed in the individual source test descriptions.

The hi-vols were manufactured by Misco Scientific of Berkeley, California, and were equipped with automatic flow control. This enabled the mass flow rate to be held constant irrespective of filter loading, atmospheric conditions, or line voltage changes. The hi-vols were operated at a nominal flow of 1.1 m^3/min (40 cfm) which corresponds to a design particulate size cutoff of approximately 30 μm aerodynamic diameter. All hi-vols were calibrated prior to each of the seven source tests.

Several of the hi-vols were fitted with size-selective inlets (SSIs) manufactured by Sierra Instruments of Carmel Valley, California. These inlets, when operated at 1.1 m^3/min, are designed to remove all particles larger than 15 μm aerodynamic diameter from the sampled air before filtering the remaining particulate matter onto a standard hi-vol filter.

For the last two Armco source tests, a hi-vol fitted with a cyclone preseparator (CYC) was also used for data collection. This device, also manufactured by Sierra Instruments, has a particle size cutoff of 5.5 μm aerodynamic diameter when operated at 1.1 m^3/min.

Sierra Instruments Series 230 four-stage cascade impactors (CIs) were used during several of the tests in conjunction with an SSI or cyclone. At a flow rate of 1.1 m^3/min, the four stages separate the collected particles into aerodynamic diameter ranges of: 7.2 to 15 μm (stage 1), 3.0 to 7.2 μm (stage 2), 1.5 to 3.0 μm (stage 3), and 0.95 to 1.5 μm (stage 4) when used with an SSI. The remaining submicron particles are collected on a backup hi-vol filter. For the majority of the tests at the limestone crusher/conveyor, only two of the four stages (numbers 1 and 3) were used in conjunction with the cyclone.

Wind Measurement System

For the first two source tests which were performed outdoors, a Mark III Wind Measuring System manufactured by Climatronics of Bohemia, New York, was used to measure and record the speed and direction of the wind.

Wind speed is measured by a 3-cup anemometer, coupled to a light chopper, which converts the speed of rotation of the cups to a signal with a frequency proportional to the wind speed. The light chopper output is converted to a DC voltage by circuits located in the recorder, and recorded on a strip chart.

Wind direction is measured by a wind vane, coupled to a precision low-torque potentiometer. The wiper voltage of the potentiometer is a measure of wind direction, and is also recorded (after amplification and filtering) on a strip chart.

Both wind speed and direction are filtered with a time constant of approximately 6 seconds. This filtering is used to provide a smooth trace of both wind speed and wind direction.

LABORATORY/DATA ANALYSIS PROCEDURES

Sierra fiberglass filters, Models C-230-GF and C-305-GF, were used as collection substrates for the CI and standard hi-vol measurements, respectively. Prior to installation in the samplers, the filters were inspected for defects, numbered, and stored for 24 hours in a desiccator. Filters were then weighed in a controlled atmosphere where the temperature was between 20°C and 25°C, and the relative humidity was below 50 percent. After an additional 24 hours in a desiccator, 10 percent of the filters, randomly selected, were reweighed. In accordance with procedures of the EPA Quality Assurance Handbook,[8] the entire batch was reweighed when any one of the audited filters differed by more than 2.8 mg from the original weight.

After collection from the samplers, the exposed filters were also desiccated for 24 hours, weighed and audited. In accordance with the above QA procedures, these filters were reweighed when any of the exposed filters differed by more than 5.0 mg from the original weight. The difference between the initial filter weight (WI) and final weight (WF) is the mass loading on the filter. All of the mass loading values were normalized by calculating the concentration using the following equation:

$$X = \frac{(WF - WI) \times 10^6}{f \times t}$$

Where
X = particulate matter concentration ($\mu g/m^3$)
WF - WI = mass loading (gm)
f = average flow rate of sampler (m^3/min)
t = duration of test (min)

The average flow rate was obtained from field data by averaging the recorded starting and final flows of each high-volume sampling unit. Accurate time records were kept for each unit during each test. The resulting values of concentration were used directly to calculate fogger efficiency.

SECTION 5

FIELD TESTS - SPECIFIC

The specifics regarding the seven source tests (four in Phase I, three in Phase II) are presented below in the order in which they were performed.

PHASE I, TEST #1 - SAND AND GRAVEL COMPANY: PRIMARY ROCK CRUSHER

The primary rock crushing operation at a sand and gravel company in Connecticut consists of the unloading of quarry rock into a crushing pit and the subsequent crushing of the rock by a gyratory rock crusher. The unloading of the rock causes dust boil-up at the rear of the pit and the crushing of the rock produces additional fugitive dust. The control of these emissions was the subject of the first fogger field test. The testing was performed during the period from October 2 to 24, 1980, with a total of 32 test runs conducted.

Site and Process Descriptions

As one of the initial steps in the sand and gravel company's operations, quarry rock is brought to a primary rock crusher. Approximately 100 dump trucks per day, each carrying loads of approximately 45 Mg (50 tons) of quarry rock (basically basalt) mixed with dirt, back up to the crushing pit to unload. Unloading times vary from 30 to 60 seconds, depending on conditions in the pit. The pit itself is roughly 8 meters long, 6 meters wide, and 4 meters deep. The crushing is done by a Superior 4265 gyratory rock crusher located in the center of the pit. There is a two-story computer control building to the north side of the crushing pit, a control shed to the east, and a large paved area to the south side. All approach roads and areas around the buildings and pit are paved and kept reasonably clean through frequent sweepings and waterings. Figure 6 is a photograph of the operation and Figure 7 is a plot plan indicating important features and dimensions.

Fugitive dust emissions result from the dumping and crushing operations. The truck unloading is the primary source of dust with the major portion coming from dust boil-up at the rear of the pit. There is also dust at the rear of the truck during the dump. The crushing procedure itself also produces dust, but to a much lesser degree than the unloading process.

Equipment Placement

The locations of the samplers varied from day to day depending on the wind direction. Measurements made at the start of each testing day with the Mark III Wind System were used to insure placement of the samplers within the dust plume. The positions of the foggers were somewhat dependent on the positions of the samplers. Where possible, the foggers were placed so as to blanket the pit with fog while not impinging directly on the samplers. Figure 8 shows the equipment positions for the six days of testing.

The optimum fogger positions appeared to be at the rear of the pit with one fogger aimed across the boil-up area and the other fogger directed at the rear of the unloading truck. This second fogger would help control the boil-up as well as the crushing and truck emissions.

Test Program and Procedure

The test program consisted of 32 runs during 6 days of testing. The test conditions are presented in Table 2. Conditions at the crusher prevented

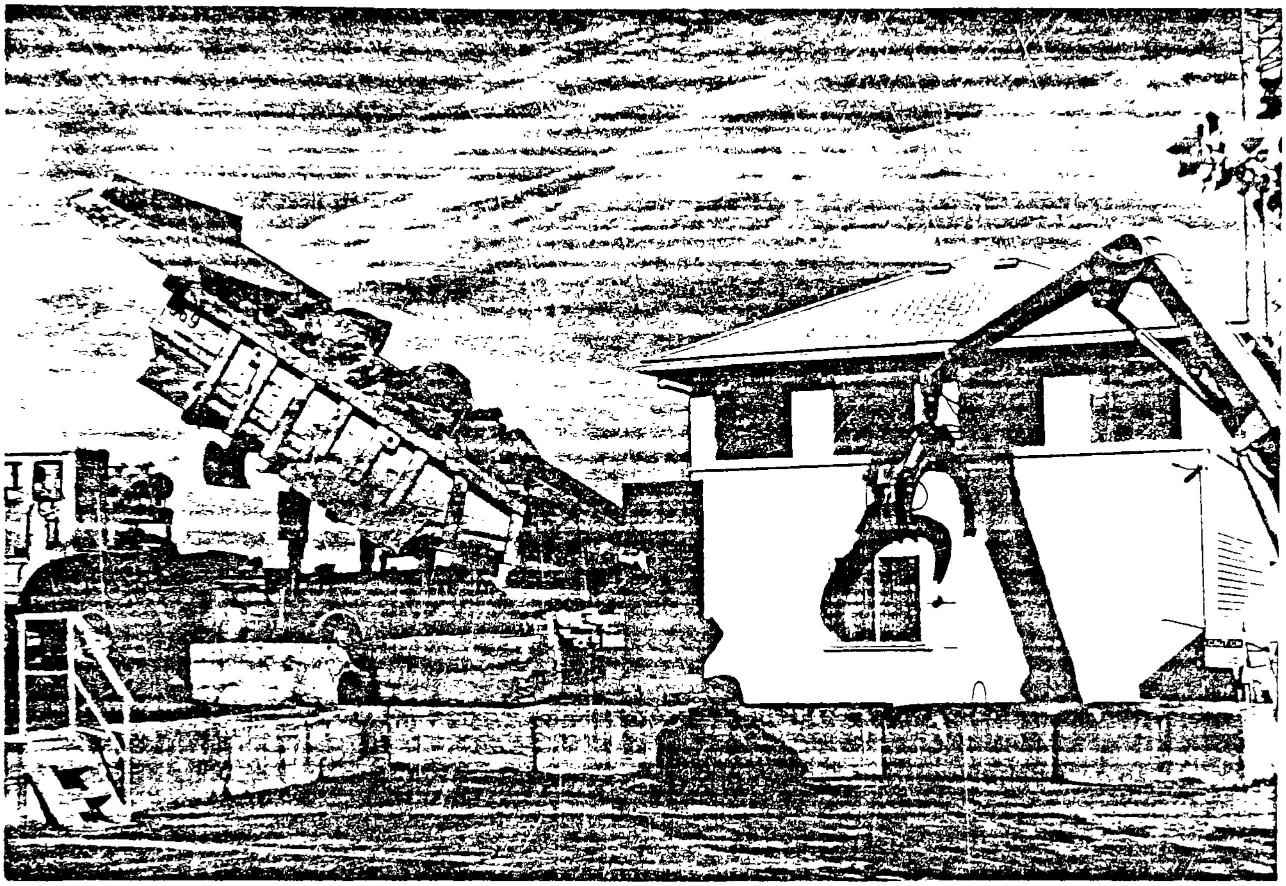


Figure 6. Primary crusher operation.

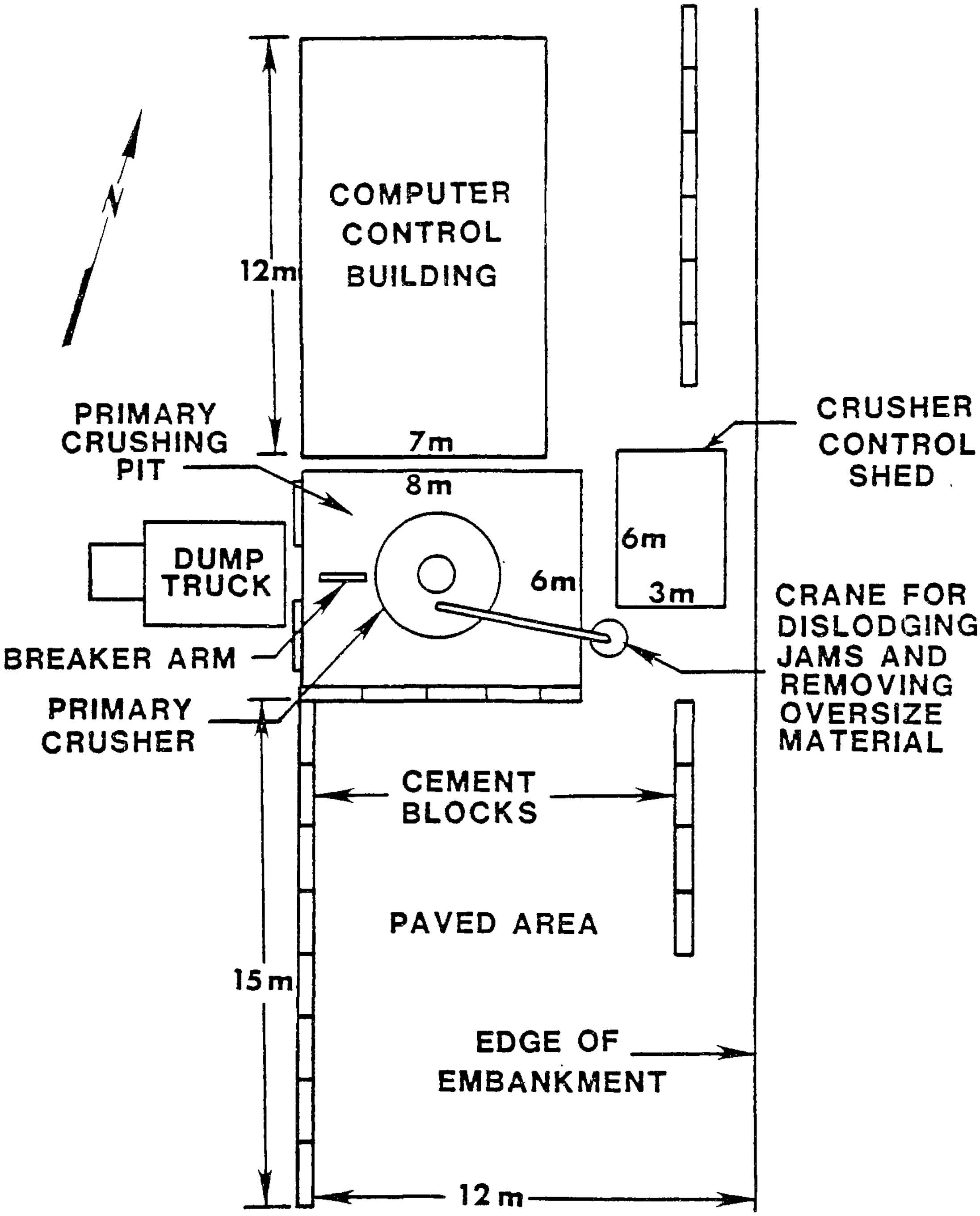


Figure 7. Primary crusher plot plan.

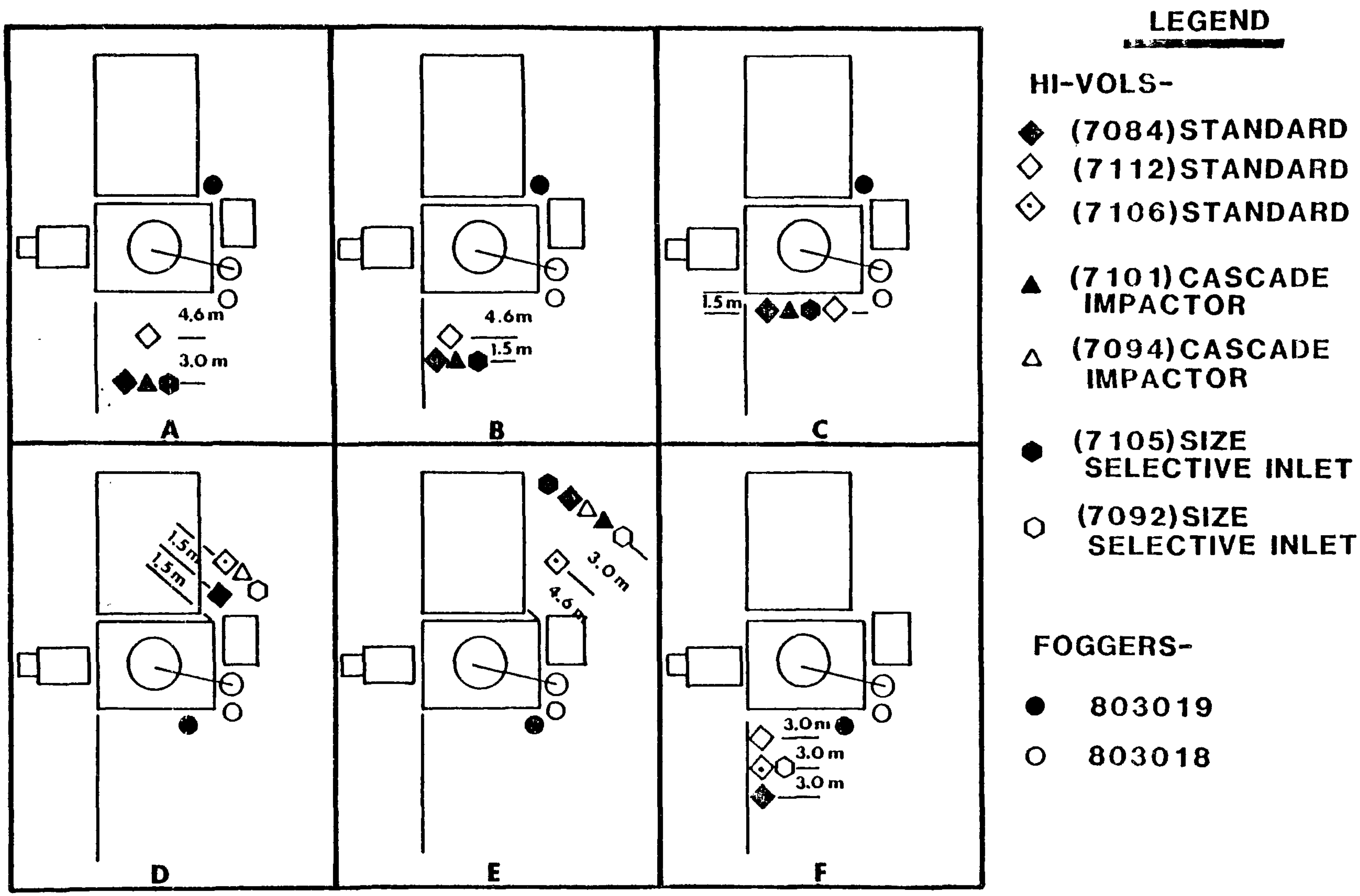


Figure 8. Test equipment positions, types, and serial numbers at the primary rock crusher.

TABLE 2. TEST CONDITIONS - PRIMARY CRUSHER

Run No.	Equipment Positions	Date	Time	Ambient Temp. (C)	Relative Humidity (%)	Wind Direction	Wind Speed (m/sec)	No. of Trucks	Fogger 803018 Water Flow (ℓ/hr)	Fogger 803018 Air Flow (m^3/hr)	Fogger 803018 Fan Speed (%)	Fogger 803018 Sign of Charge	Fogger 803018 Nozzle* Type	Fogger 803019 Water Flow (ℓ/hr)	Fogger 803019 Air Flow (m^3/hr)	Fogger 803019 Fan Speed (%)	Fogger 803019 Sign of Charge	Fogger 803019 Nozzle* Type
7	Fig. 4a	10-13-80	0938-1000	9	77	N-E	2-5	8										
8			1050-1129	10	77	NNW	4	8	61	4.2	80	(0)	1	68	4.2	80	(0)	1
9			1300-1318	13	70			8										
10			1326-1350	13	70			8	68	4.2	80	(-)	1	68	4.2	80	(-)	1
11			1355-1434	13	70			8	72	4.0	80	(+)	1	68	4.0	80	(+)	1
12	Fig. 4b	10-14-80	0833-0915	6	72	WNW	Var.	8										
13			0933-1005	6	72		w/gusts	8	60	2.3	80	(0)	1	68	2.3	80	(0)	1
14			1022-1050	7	72		to 9	8	57	2.3	80	(+)	1	72	1.6	80	(+)	1
15			1059-1125	7	72			8	53	2.7	80	(-)	1	64	1.8	80	(-)	1
16			1245-1305	9	72			8	53	2.4	80	(-)	1	61	1.4	80	(-)	1
17			1313-1346	10	72			8										
18	Fig. 4c	10-15-80	0949-1026	9	36	Calm	Calm	10										
19			1039-1113	9	36			10	68	4.0	50	(-)	2	66	4.0	50	(-)	2
20			1116-1156	11	36			8	76	4.1	50	(0)	2	76	3.6	50	(0)	2
22	Fig. 4d	10-16-80	0940-1003	12	57	Calm	Calm	8										
23			1021-1038	12	57			4	76	2.8	80	(+)	2	76	4.4	80	(+)	2
24			1056-1127	16	57			8	72	2.0	80	(-)	2	76	2.6	80	(-)	2
25			1251-1314	20	52	SSW	2-5	8	72	2.6	80	(+)	2	72	3.1	80	(+)	2
26			1323-1345	20	52			8	77	2.7	80	(0)	2	77	2.8	80	(0)	2
27			1350-1412	20	52			8										
28	Fig. 4e	10-17-80	0850-0927	21	55	Calm	Calm	8										
29			0936-0927	21	55			8	76	3.4	70	(0)	2	76	4.0	70	(0)	2
30			1016-1045	21	55			8	80	2.2	70	(+)	2	80	2.8	70	(+)	2
31			1105-1135	21	55			8	76	3.6	70	(-)	2	76	2.8	70	(-)	2
32	Fig. 4f	10-24-80	0925-0943	4	82	Calm	Calm	6			80					80		
33			0950-1004	4	82			6	76	4.2	80	(0)	2	74	4.2	80	(0)	2
34			1010-1025	5	82	N-E		6			80					80		
35			1027-1040	5	82			6	76	4.7	80	(0)	2	76	4.4	80	(0)	2
36			1045-1112	5	82			6	74	4.8	80	(-)	2	78	4.1	80	(+)	2
37			1120-1138	6	82			6			80					80		
38			1244-1325	11	68	SE-S	1-2	10			80					80		
39			1334-1403	11	68	SE-S	1-2	10	78	4.2	80	(0)	2	78	4.2	80	(0)	2

* Type 1: low flow
Type 2: heavy flow

extensive variations of fogger operating parameters. Water was provided by a tank with a small pump which limited nozzle flow to approximately 80 ℓ/hr. Fan speed was reduced to 80 percent of capacity to help reduce excessive dust reentrainment in the pit.

The sampling procedure was essentially the same for each test. Upon arrival at the test site, the wind measurement system was set up and the wind direction determined. The hi-vol samplers were then positioned in a sampling array downwind of the crushing pit. The foggers were positioned to control the dust cloud while not spraying directly into the samplers. Once the equipment was positioned, the pre-weighed hi-vol filters were placed into the samplers. The samplers were then turned on simultaneously just prior to the first truck dump of a predetermined sequence of trucks (typically, 8 trucks provided sufficient material for sampling purposes). For the runs with the foggers in operation, the foggers were also turned on at this time and adjusted to the predetermined fogger operational parameter conditions. After the last truck of the sequence had dumped into the pit and crushing was completed, the samplers and foggers were all stopped and the filters removed. At the end of the day, all of the filters were returned to TRC's chemistry laboratory where they were subsequently desiccated and weighed.

Test Results

The filter loadings were used in conjunction with the sampler flow rates to calculate particulate matter concentrations. Review of these concentraions indicated that they did not accurately reflect the particulate levels because of the intermittent nature of the truck dumps and the fact that each test did not contain an equal number of these dumps. Since the samplers were not shut off between truck dumps, there was considerable sampling time during which no emissions were emanating from the crushing pit. The data were therefore reduced on a per-truck basis since the durations of the unloading and crush- ing times, the times when the vast majority of the dust was produced, were essentially the same for all dumps. The data, in the form of mg/truck, were also adjusted to account for the slight deviations of the actual sampler flow rates from the design flow of 1.1 m^3/min (40 cfm).

The majority of the tests (runs 7-31) were completed before results were available from the chemistry laboratory. Upon examination of these data, it became evident that a different baseline particulate level would be necessary for comparison of fogger effectiveness. The fans in the foggers that project the fog toward the dust source were powerful enough to redirect the plume, thus causing an "artificial" wind effect. Since the particulate levels recorded with the fog on were always influenced by the fans, the most useful baseline for calculating fogger efficiency would be those levels recorded with just the fans on. This conclusion produced the need for a final series of tests (runs 32-39) wherein particulate matter levels were recorded with the fans on, with and without water addition. The data from these runs would be used for the determination of the efficiency of an uncharged water spray.

Due to the nature of the test, the results are presented separately and then combined to provide overall fogger efficiency information. The data from runs 7-31 provide information about the increase in efficiency as a result of charging the fog. The data from runs 32-39 provide information about fogger efficiency using uncharged fog. Combining the two sets yields fogger efficiency information for charged fog.

The efficiencies were calculated in the following manner. All data were grouped by type of test (fan only, positive fog, negative fog, uncharged fog) into either that measured by standard hi-vols or hi-vols with SSI's. The data were then separated into two groups: the first group included the data from test runs 7-31 and the second group included the data from test runs 32-39. The arithmetic means of each data set were then calculated and these means were used to calculate efficiencies.

Tables 3-6 present the data, means, and efficiencies for the four groups of data: uncharged fog vs. charged fog - standard hi-vols, uncharged fog vs. charged fog - SSI's, fan only vs. uncharged fog - standard hi-vols, and fan only vs. uncharged fog - SSI's. Table 7 summarizes the calculated efficiencies and presents the overall fogger effectiveness.

There was a marked reduction of 20 to 30 percent in particulate matter levels as a result of the application of an uncharged water fog on the dust emissions at the primary crusher. When a charge was applied to this water fog, the levels were reduced an additional 30 to 40 percent. Thus, the charged fog produced by two Fogger IV's reduced the particulate matter levels at the primary crushing pit 45 to 60 percent. This level is consistent with observations which indicated that more than two foggers would be necessary to control the dust emissions from the pit. This reduction could be improved through the use of wind screens (to reduce turbulence and fog deflection) and increased water flow.

A significant result of this test is that the fogger efficiency seems to be consistent regardless of the sign of the charge on the fog. This indicates that the dust is comprised of a combination of particles, some with negative charge and some with positive charge. This is not inconsistent with the laboratory work of Hoenig[1] and the findings of Kunkel[9] that show a charge duality for various types of dust.

TABLE 3. RESULTS OF FOGGER TESTING AT PRIMARY ROCK CRUSHER: UNCHARGED VS. CHARGED FOG - STANDARD HI-VOL

Uncharged Fog			Positive Fog			Negative Fog		
Run No.	Sampler No.*	Particulate Loading (mg/Truck)**	Run No.	Sampler No.*	Particulate Loading (mg/Truck)**	Run No.	Sampler No.*	Particulate Loading (mg/Truck)**
8	7084	23.5	11	7084	8.4	10	7084	7.7
	7101	31.1		7101	14.9		7101	8.4
	7112	30.3		7112	21.4		7112	14.4
13	7084	21.7	14	7084	9.2	15	7084	7.4
	7101	22.8		7101	8.5		7101	9.3
	7112	34.2		7112	12.6		7112	13.8
20	7084	13.9	23	7106	5.0	16	7084	8.7
	7101	20.1		7094	3.4		7101	11.4
	7112	24.0		7084	10.9		7112	17.6
26	7106	25.7	25	7106	32.1	19	7084	8.2
	7094	12.5		7094	11.6		7101	12.0
	7084	18.6		7084	24.1		7112	13.9
29	7084	10.4	30	7084	13.0	24	7106	28.1
	7094	7.5		7094	11.6		7094	14.0
	7106	26.9		7106	27.0		7084	34.2
				7101	7.0			
						31	7084	12.0
							7094	9.1
							7106	21.6
							7101	6.6
ARITHMETIC MEAN	=	21.5	ARITHMETIC MEAN	=	13.8	ARITHMETIC MEAN	=	13.6
			PERCENT REDUCTION FROM UNCHARGED LEVEL	=	36	PERCENT REDUCTION FROM UNCHARGED LEVEL	=	37

NOTE: * Refer to Figure 8 for equipment locations
** Corrected to 40 cfm

TABLE 4. RESULTS OF FOGGER TESTING AT PRIMARY ROCK CRUSHER: UNCHARGED VS. CHARGED FOG - HI-VOL WITH SSI

Uncharged Fog			Positive Fog			Negative Fog		
Run No.	Sampler No.*	Particulate Loading (mg/Truck)**	Run No.	Sampler No.*	Particulate Loading (mg/Truck)**	Run No.	Sampler No.*	Particulate Loading (mg/Truck)**
8	7105	6.9	11	7105	6.0	10	7105	3.9
13	7105	9.9	14	7105	4.2	15	7105	5.3
20	7105	13.6	23	7092	2.6	16	7105	5.5
26	7092	2.7	25	7092	2.4	19	7105	7.9
29	7092	3.5	30	7092	2.4	24	7092	3.1
↓	7105	7.7	↓	7105	8.8	31	7092	2.0
						↓	7105	7.0
	ARITHMETIC MEAN	= 7.4		ARITHMETIC MEAN	= 4.4		ARITHMETIC MEAN	= 5.0
				PERCENT REDUCTION FROM UNCHARGED LEVEL	= 41		PERCENT REDUCTION FROM UNCHARGED LEVEL	= 32

NOTE: * Refer to Figure 8 for equipment locations
** Corrected to 40 cfm

TABLE 5. RESULTS OF FOGGER TESTING AT PRIMARY ROCK CRUSHER: FAN ONLY VS. UNCHARGED FOG - STANDARD HI-VOL

Fan Only			Uncharged Fog		
Run No.	Sampler No.*	Particulate Loading (mg/Truck)**	Run No.	Sampler No.	Particulate Loading (mg/Truck)**
32	7084	6.0	33	7084	3.7
↓	7106	9.2	↓	7106	7.5
	7112	14.8		7112	9.3
34	7084	1.3	35	7084	1.2
↓	7106	2.1	↓	7106	2.9
	7112	3.0		7112	4.0
37	7084	4.8	39	7084	1.2
↓	7106	9.0	↓	7106	2.0
	7112	11.5		7112	2.3
38	7084	1.6			
↓	7106	2.5			
	7112	2.9			
	ARITHMETIC MEAN	= 5.7		ARITHMETIC MEAN	= 3.8
				PERCENT REDUCTION FROM FAN ONLY LEVEL	= 33

Note: * Refer to Figure 8 for equipment locations.
** Corrected to 40 cfm.

TABLE 6. RESULTS OF FOGGER TESTING AT PRIMARY ROCK CRUSHER:
FAN ONLY VS. UNCHARGED FOG - HI-VOL WITH SSI

Fan Only			Uncharged Fog		
Run No.	Sampler No.*	Particulate Loading (mg/Truck)**	Run No.	Sampler No.	Particulate Loading (mg/Truck)**
32	7092	2.7	33	7092	2.1
34	7092	0.8	35	7092	0.7
37	7092	1.4	39	7092	0.4
38	7092	0.7			
	ARITHMETIC MEAN	= 1.4		ARITHMETIC MEAN	= 1.1
				PERCENT REDUCTION FROM FAN ONLY LEVEL	= 21

Note: * Refer to Figure 8 for equipment locations.
** Corrected to 40 cfm.

TABLE 7. RESULTS OF FOGGER TESTING AT PRIMARY ROCK CRUSHER: FOGGER EFFICIENCIES (%)

Formula Used In Calculation*	Percent Reduction: Standard Hi-Vols	Percent Reduction: Hi-Vols with SSI's
$\frac{\text{Fan Only - Uncharged}}{\text{Fan Only}} \times 100$	33	21
$\frac{\text{Uncharged - Positive Fog}}{\text{Uncharged}} \times 100$	36	41
$\frac{\text{Uncharged - Negative Fog}}{\text{Uncharged}} \times 100$	37	32
$\frac{\text{Fan Only - Positive Fog}}{\text{Fan Only}} \times 100$	57	53
$\frac{\text{Fan Only - Negative Fog}}{\text{Fan Only}} \times 100$	58	46

*NOTE: Input to formulae are the arithmetic mean particulate matter levels.

Another significant result is that the efficiency seems to be consistent regardless of particle size range. The particulate matter reductions measured by the standard hi-vols (particles $\leq$ 30 μm) and by the hi-vols with SSI's (particles $\leq$ 15 μm) are very similar. It was hoped that the use of the cascade impactors would provide additional information on efficiency versus particle size, but the results proved unuseable for this purpose. Almost all of the material collected by the hi-vols fitted with the impactors was collected on the back-up filter. This indicated that there was severe particle bounce between the stages. The total mass loadings determined with these samplers were used as additional data points in the standard hi-vol group.

Attempts were made at obtaining information in visibility improvement via EPA Method 9 (visual determination of opacity). It was found that the opacity of the fog was similar to the opacity of the uncontrolled dust plume so that no real visibility improvement was noted.

PHASE I, TEST #2 - SAND AND GRAVEL COMPANY: SECONDARY ROCK CRUSHER

The transfer of crushed stone onto a conveyor belt results in the generation of fugitive dust emissions. The control of such emissions was the subject of the second charged fogger field test. The source chosen for the tests was a secondary rock crusher operation at a sand and gravel plant in Connecticut. The field testing was performed during the period of October 28 to November 4, 1980.

Due to some minor equipment problems and the unexpected shutting down of the operation for the winter, only a limited amount of data was collected. The source test consisted of nine individual runs conducted over a period of three days.

Site and Process Descriptions

The secondary rock crusher operation is a continuous process in which rock is received from a primary jaw crusher and further broken down in size. The rock enters the crusher from a bin which is fed by an elevated conveyor. The crushed rock then falls onto another conveyor which transfers it to the next step of the process. Fugitive dust emissions result from the crushing process and the falling of the rock onto the conveyor. A photograph of the operation is presented in Figure 9.

The area around the crushing operation to the northeast is paved and washed daily. Heavy accumulations of dust and grit occur due to the numerous, uncovered conveyors in the area. A lightly traveled paved road, which is occasionally watered, is located to the southeast of the crusher alongside a steep hill. Storage piles of crushed stone and dirt are located to the south and east, respectively. Railroad tracks and railcars used for transporting crushed stone are located to the northwest. A plot plan of the area is provided in Figure 10.

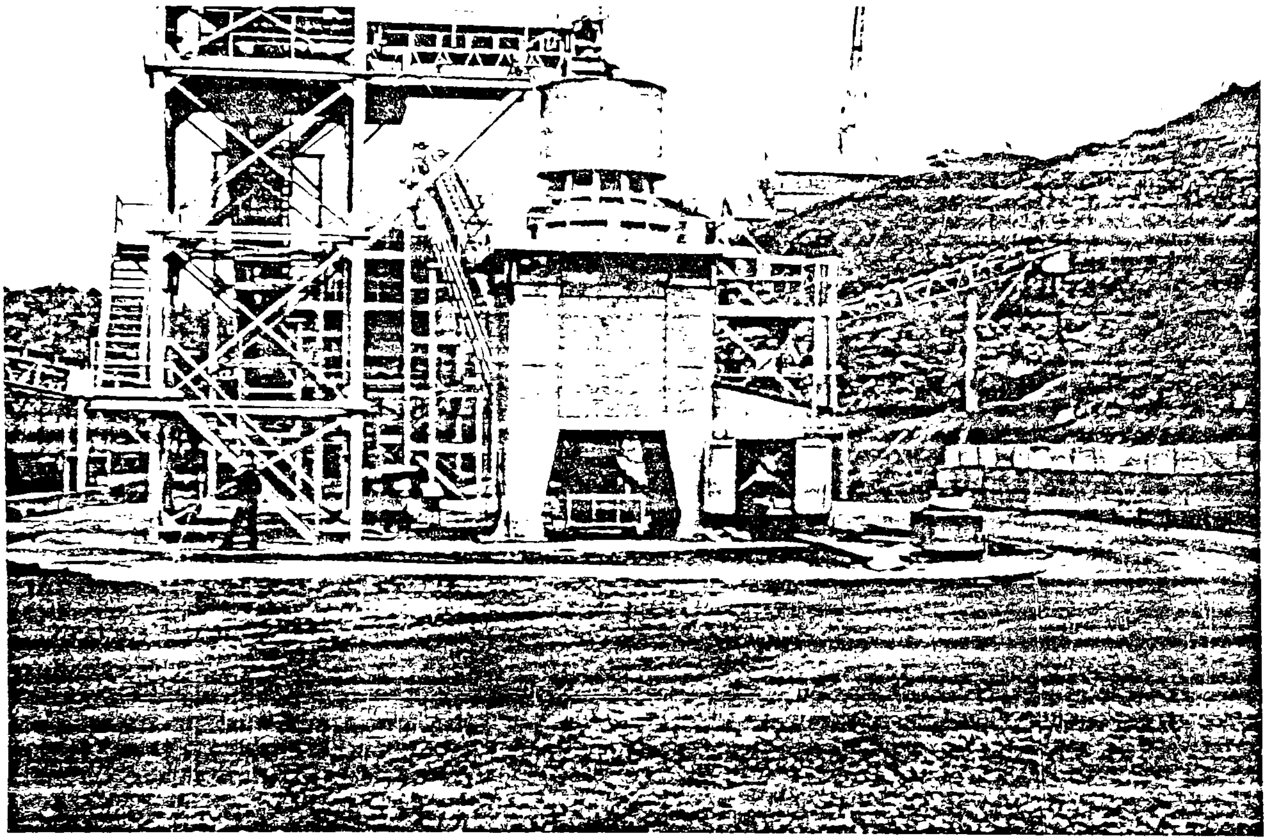


Figure 9. Secondary rock crusher operation.

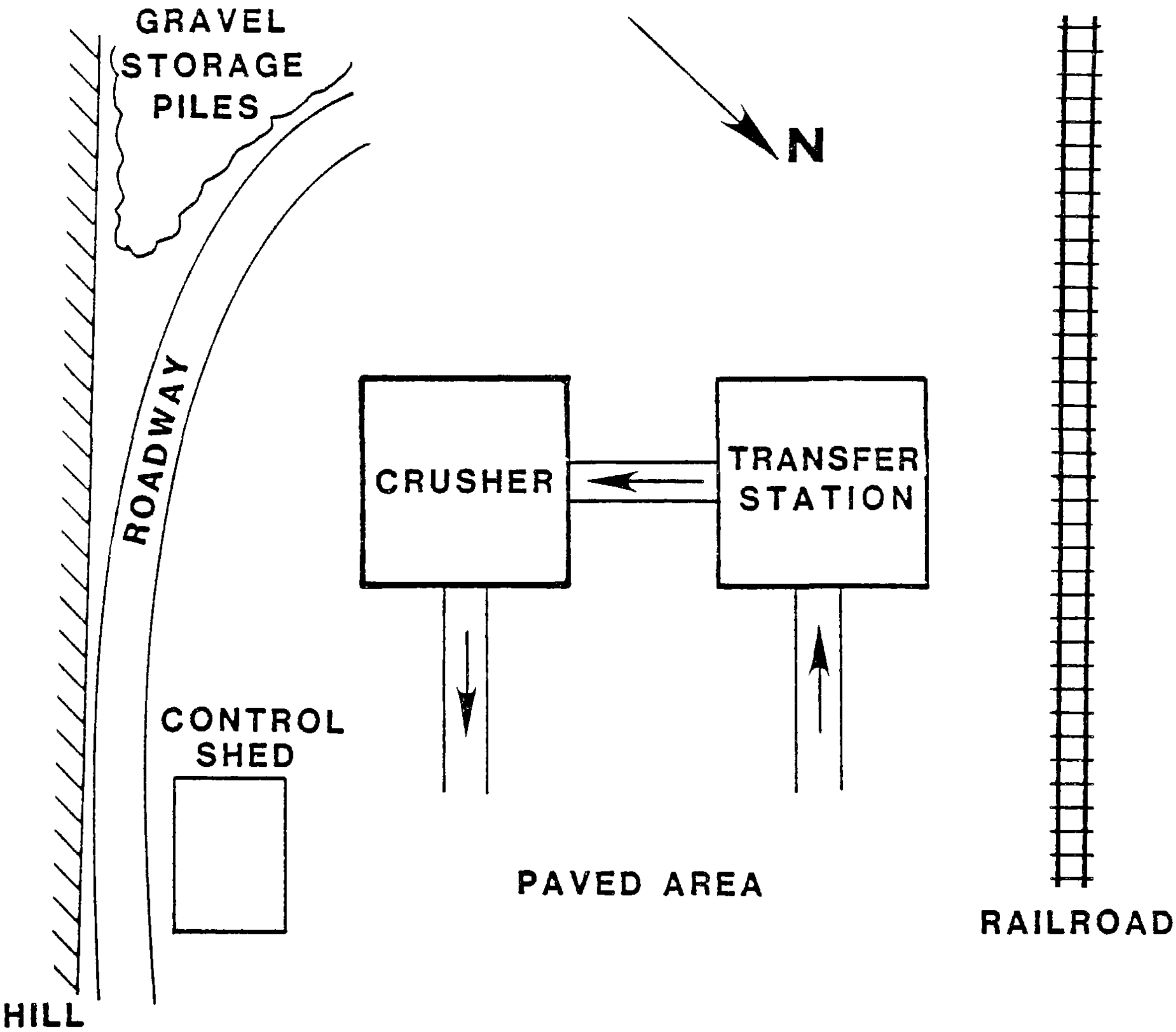


Figure 10. Plot plan of secondary crusher operation.

While the majority of the dust in the area was being generated by the secondary crusher, other operations also generated emissions sporadically which resulted in a less-than-ideal sampling environment. These emission sources included: the loading of crushed stone from the adjacent storage piles into railcars via front-end loaders, traffic on the paved road, the overhead conveyors, and the loading of dirt onto a storage pile.

Equipment Placement

During the first few days of utility hook-up, the Mark III wind system was operated in order to provide input for optimum equipment locations. The recorded results, along with worker observations, indicated that the prevailing wind direction for that time of year was from the southwest. The samplers were thus positioned on the northeast side of the operation.

The foggers were placed on either side of the conveyor that transported the crushed stone from the base of the secondary crusher. They were aimed slightly upwards so as to more completely envelop the transfer area in fog. Figure 11 depicts the positions of the equipment during the test runs.

Problems Encountered

Two main problems arose that restricted the amount of data obtained. The first problem was water line freeze-up and the second problem was the shutting down of the operation for the winter.

Although daytime temperatures were well above freezing, night-time temperatures fell below the freezing point on several different occasions. Despite precautions, residual water that was present in the various pieces of pipe and tubing in the foggers became frozen. This caused failure in some of

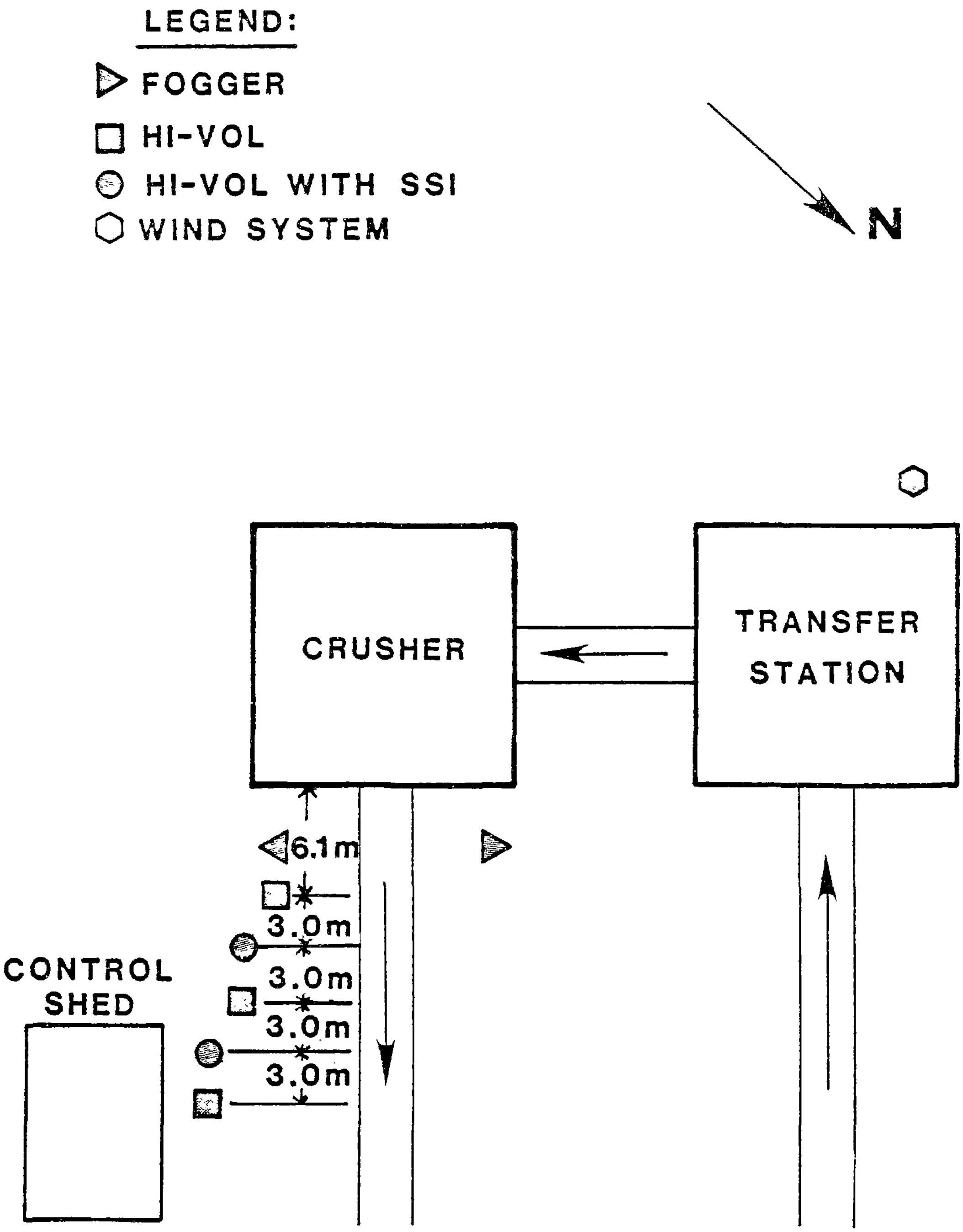


Figure 11. Equipment positions for secondary crusher test.

the joints of the rigid plastic tubing. These pieces of tubing had to be replaced with more flexible materials and this caused delays in the test schedule.

When testing was initiated at the secondary crusher, the plant operators indicated that there might be an operational shutdown in several weeks. This still allowed adequate time for the source test. However, the operation was shut down for the winter after only one week of testing was completed. This shutdown, coupled with the delays due to the ice problems, resulted in the limited data acquisition.

A third problem that further limited the usefulness of the data that were obtained was extraneous dust in the crusher area. It was not possible to completely isolate the dust produced by the crushing operation from the dust being produced by the overhead conveyors and traffic in the area. Dust was also periodically generated by the loading of crushed stone into railroad cars upwind of the operation.

Test Results

The test conditions are presented in Table 8. The test results are summarized in Table 9.

While it visually appeared that the two foggers succeeded in reducing the dust emissions generated by the secondary crusher, an inadequate amount of data was collected to verify the amount of reduction.

TABLE 8. TEST CONDITIONS - SECONDARY CRUSHER

					Fogger 803018					Fogger 803019				
Run No.	Date	Time	Wind Direction	Wind Speed (m/sec)	Water Flow (ℓ/hr)	Air Flow (m^3/hr)	Fan Speed (%)	Sign of Charge	Nozzle* Type	Water Flow (ℓ/hr)	Air Flow (m^3/hr)	Fan Speed (%)	Sign of Charge	Nozzle* Type
1	10-30-80	1246-1306	S-W	0-2										
2	10-30-80	1315-1335	S-W	0-2	114	5.4	80	(-)	2	114	5.4	80	(-)	2
3	10-30-80	1351-1411	S-W	0-2	114	5.1	80	(0)	2	114	5.1	80	(0)	2
4	10-30-80	1407-1427	S-W	0-2			80					80		
5	10-30-80	1433-1453	S-W	0-2	114	5.1	80	(+)	2	114	5.0	80	(+)	2
6	10-31-80	0920-0940	S-W	0-2			80					80		
7	11-4-80	0948-1008	SSW	1-4	102	4.2	100	(+)	2	95	4.8	100	(+)	2
8	11-4-80	1055-1111	SSW	1-4			100					100		
9	11-4-80	1120-1130	SSW	1-4	110	5.1	100	(-)	2	110	4.2	100	(-)	2

*Type 2: heavy flow

TABLE 9. RESULTS OF FOGGER TESTING AT SECONDARY ROCK CRUSHER

Run No.	Date	Un-Controlled	Fan Only	Uncharged Fog	Positive Fog	Negative Fog	Sampler Type	Distance From Source (m)	Measured Concentration ($\mu g/m^3$)
1	10-30-80	X					Standard	6.1	17826
		X					SSI	9.1	1516
		X					Standard	12.2	7312
		X					SSI	15.2	414
		X					Standard	18.3	1075
2	10-30-80					X	Standard	6.1	27954
						X	SSI	9.1	2435
						X	Standard	12.2	8264
						X	SSI	15.2	556
						X	Standard	18.3	1477
3	10-30-80			X			Standard	6.1	13813
				X			SSI	9.1	1414
				X			Standard	12.2	4351
				X			SSI	15.2	446
				X			Standard	18.3	664
4	10-30-80		X				Standard	6.1	37390
			X				SSI	9.1	3609
			X				Standard	12.2	9694
			X				SSI	15.2	860
			X				Standard	18.3	1577
5	10-30-80				X		Standard	6.1	22917
					X		SSI	9.1	4441
					X		Standard	12.2	8102
					X		SSI	15.2	1181
					X		Standard	18.3	1342
6	10-31-80		X				Standard	6.1	31321
			X				SSI	9.1	3883
			X				Standard	12.2	11267
			X				SSI	15.2	1047
			X				Standard	18.3	2176

(continued)

TABLE 9. RESULTS OF FOGGER TESTING AT SECONDARY ROCK CRUSHER (Continued)

Run No.	Date	Un-Controlled	Fan Only	Uncharged Fog	Positive Fog	Negative Fog	Sampler Type	Distance From Source (m)	Measured Concentration ($\mu g/m^3$)
7	11-4-80		X				Standard	6.1	16539
			X				SSI	9.1	2962
			X				Standard	12.2	10894
			X				SSI	15.2	1138
			X				Standard	18.3	2992
8	11-4-80				X		Standard	6.1	22319
					X		SSI	9.1	2851
					X		Standard	12.2	12452
					X		SSI	15.2	1083
					X		Standard	18.3	3593
9	11-4-80					X	Standard	6.1	24345
						X	SSI	9.1	3515
						X	Standard	12.2	12879
						X	SSI	15.2	1126
						X	Standard	18.3	3524

PHASE I, TEST #3 - IRON AND STEEL PLANT: CAST HOUSE SPOUT HOLE

The casting of molten iron from a blast furnace into a ladle car results in emissions of hot fume. The control of such emissions was the subject of the third charged fogger field test. The field testing was performed during two separate visits: December 9 to 18, 1980, and January 26 to February 3, 1981. The second visit was necessitated by the sampling and equipment problems encountered during the initial visit.

Site and Process Descriptions

As part of the overall steel-making process, blast furnaces are utilized to produce molten iron and slag from iron ore, limestone, coke and other materials. The blast furnaces are periodically tapped to release this molten iron and the slag that has formed. The molten iron travels down runners and pours through spout holes into torpedoshaped transport cars, known as ladle cars, which are positioned underneath the cast house floor. The molten iron is then transported to the next step in the process. The tapping and pouring process is known as a cast.

At the subject blast furnace, approximately twelve casts occur each day over three work shifts. Two ladle cars are generally filled during each cast. The length of each cast varies from 45 to 90 minutes depending upon process variables such as the condition of the tap hole and quantity of iron and slag to be cast.

While the molten iron is being cast, fugitive dust emissions, in the form of hot fume, rise up into the blast furnace cast house. The fume is created by the burning of the runner material as well as the reaction of the molten iron with atmospheric oxygen as it falls through the spout holes into the ladles below.

The essential floor plan features of the furnace cast house include the blast furnace, runners, four spout holes, an enclosed control room, two bunker areas for material storage, a crane loading and unloading area, a sand storage bin, and a workman's lounge. A sketch of these features is presented in Figure 12. A photograph of the site is presented in Figure 13.

Test Description: December 9 to 18, 1980

During this initial visit to the blast furnace, a number of sampling and equipment problems were encountered. As a result, only seven tests were performed and only a limited amount of data was obtained.

Equipment Placement--

Due to safety considerations, it was suggested by plant personnel that the foggers be placed in one of the bunkers near the control room. This meant only one fogger could be used since there was a limited amount of room in the bunker. This also meant that the spout hole nearest the blast furnace (spout hole A in Figure 12), the first one utilized during a cast, would be the source to control since the fogger could not effectively control the second spout hole (spout hole C in Figure 12) from the bunker position. This was the fogger position for five of the seven tests. For the other two tests, the fogger was moved out from the bunker because the spout hole on the opposite side of the runner (spout hole B in Figure 12) was scheduled for use and the fogger needed to be moved closer to the source.

The nearest water supply was located on the far side of the control room which necessitated the fogger water supply hose being routed around the outside of the furnace area and into the back of the bunker with the resultant exposure of the waterline to the ambient temperature.

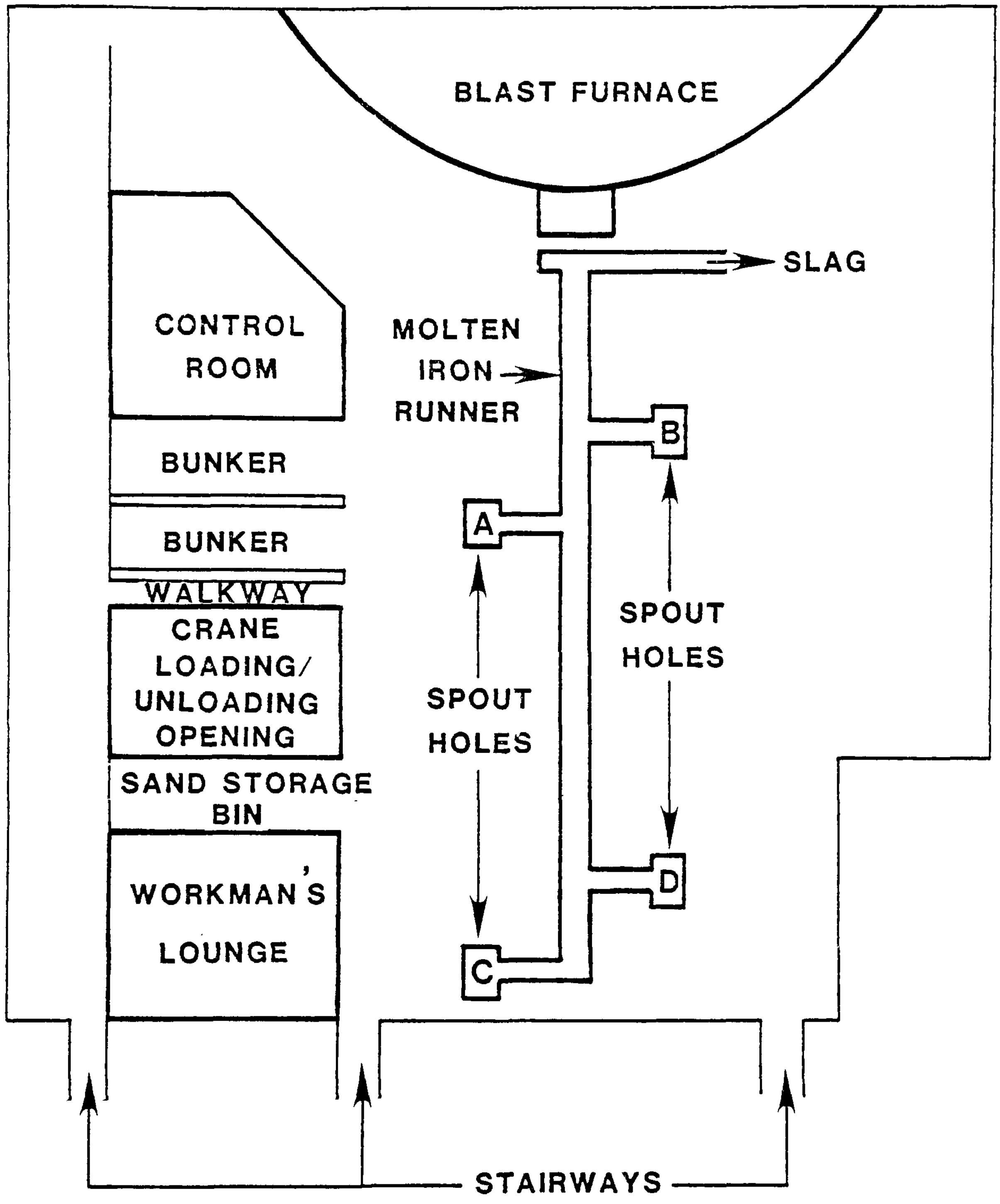


Figure 12. Floor plan of cast house.

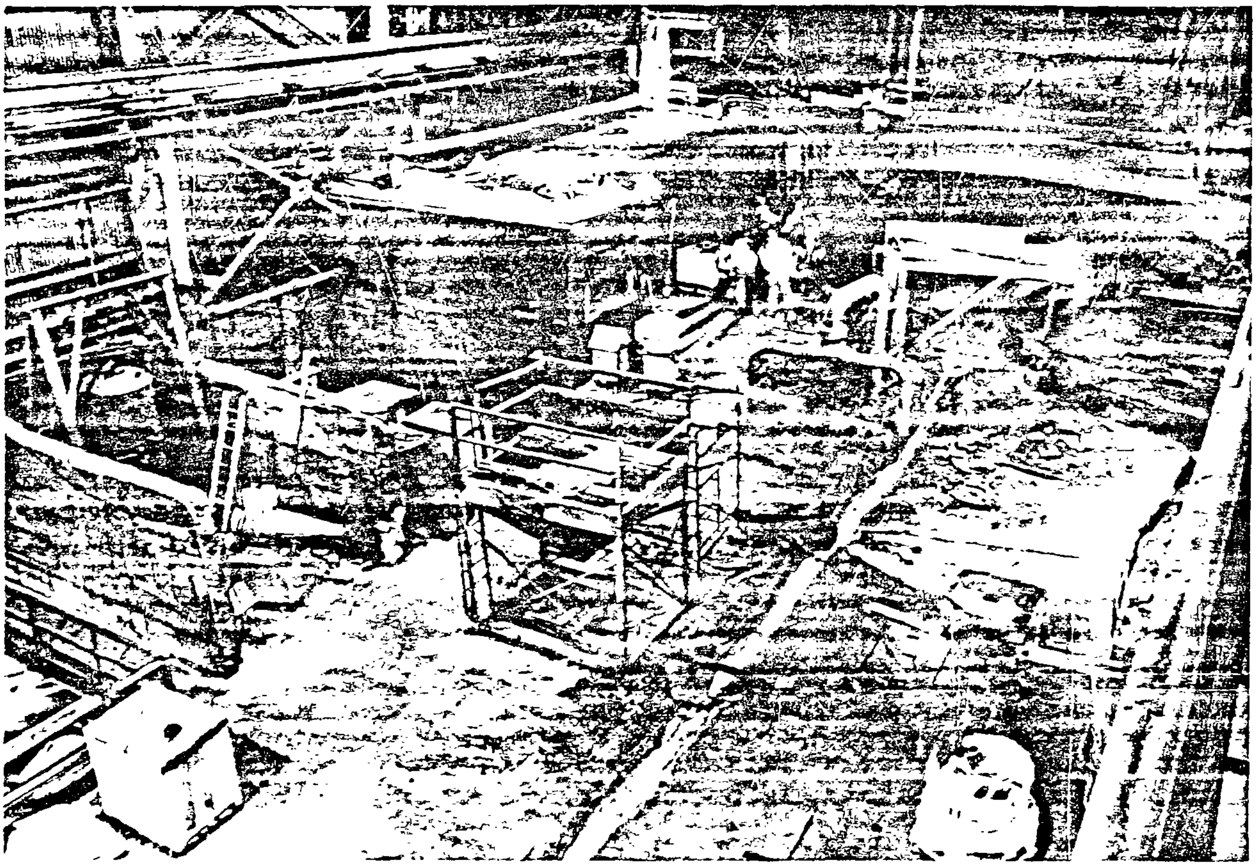


Figure 13. Photograph of cast house.

It was initially decided to use two pairs of hi-vol samplers to measure the TSP levels, with each pair consisting of a standard hi-vol and a standard hi-vol fitted with an SSI. The samplers were located on the floor between the spout hole and the furnace since it appeared the plume was drawn via natural draft back towards the furnace. This initial equipment arrangement is depicted in Figure 14a.

During the first set of tests (runs 1-3), it became apparent that the majority of the fume entering the samplers was from the runners and not from the spout hole. Since the fume emitted from the spout hole tended to rise rather than travel across the floor, it was decided to raise the samplers to obtain more representative results. This elevating of the samplers would also help to eliminate two other problems that were occurring: the fume was so heavy that the hi-vol filters were plugging within three to four minutes and the heat and sparks from the runners and initial furnace tapping were so intense that some damage to the samplers was being sustained.

During the next two sets of runs (numbers 4-5 and 6-7) only one pair of samplers was used and this pair was elevated on 2.4 meter high staging with a heavy metal grating as a platform. The equipment arrangements for these two sets of runs are presented in Figures 14b and 14c. The elevation of the samplers allowed test runs of fifteen minutes before filter plugging occurred and eliminated damage to the samplers.

Problems Encountered--

While the elevation of the samplers eliminated some of the test problems, several others were encountered which eventually resulted in the suspension of testing during this first visit. The problems were principally concerned with the nature of the casting process and the hostile environment during the cast.

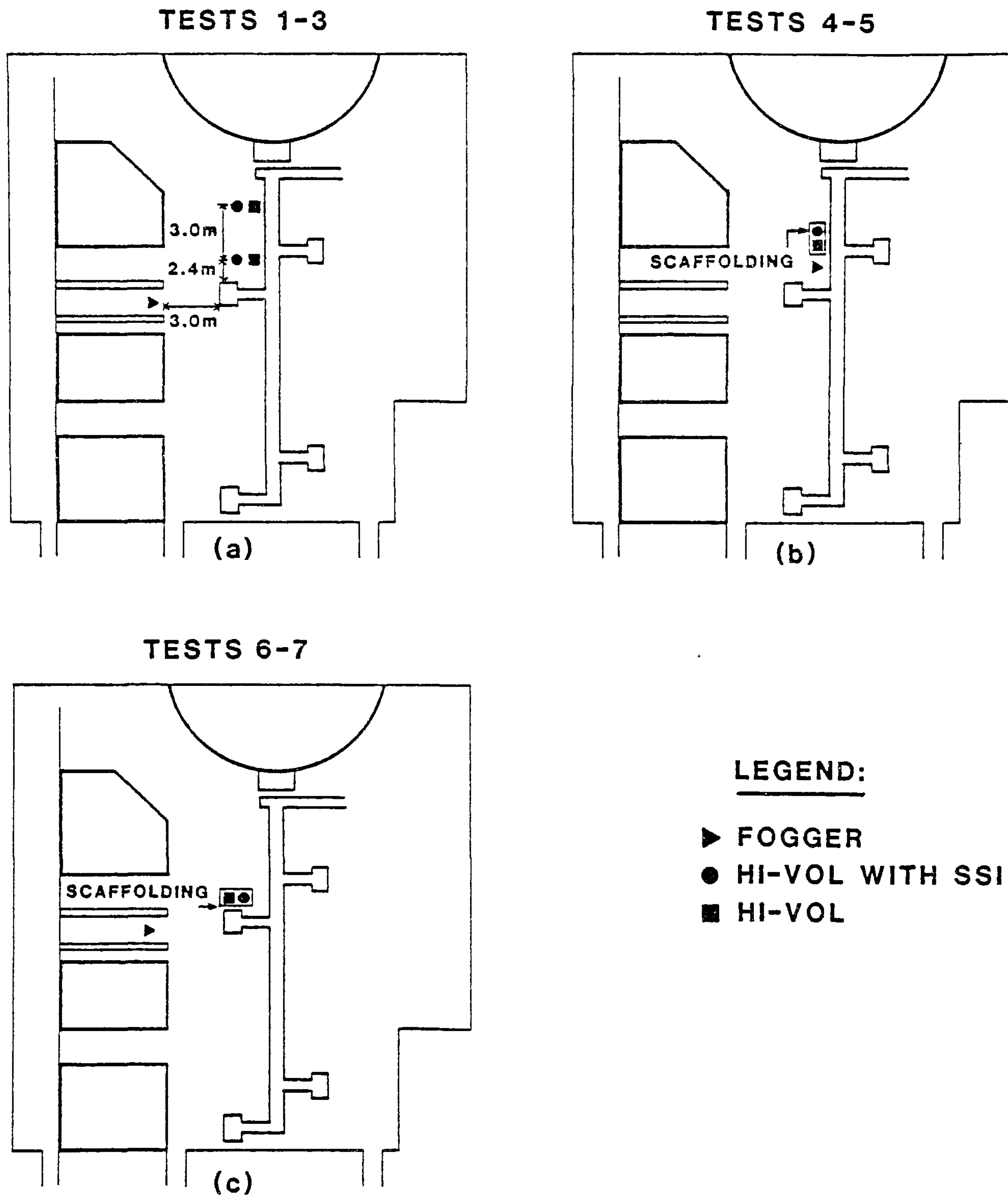


Figure 14. Equipment positions for cast house tests: December 9 to 18, 1980.

Due to safety regulations and the intense heat generated in the test area at the time of a cast, the pre-weighed hi-vol filters had to be placed into the samplers and the flow rates set prior to the start of each cast. This was often done as much as one hour before the furnace was tapped. This caused an indeterminate sampling error by allowing particulate matter to settle onto the filter before the samplers were turned on.

Once the furnace was tapped and the molten iron began to pour into the ladle cars, the samplers and, where applicable, the fogger were turned on. The delay was necessary since the ladle cars, positioned below the holes prior to the cast, cannot tolerate water before the molten iron enters them. When the filters began to plug up, which was indicated by rapidly fluctuating flow control lights on the hi-vols, the samplers were turned off. Since it was not possible to reach the hi-vols and remove the filters until the entire cast was complete and the tap hole plugged, a heavy layer of metal flake material was deposited on the hi-vol filters, further biasing the test results.

The hostile environment in and around the cast house also caused problems throughout the test period. The ambient temperature was below freezing most of the time which resulted in several freeze-ups within the various hoses and tubes associated with the fogger operation. The fogger had to be taken apart several times in order to remove ice blockages. The dusty atmosphere also caused some problems with the fogger electronics which necessitated replacing the originally installed fogger with the other one part way through the test period.

One additional problem encountered, which further complicated the testing, was that ferrosilicon was added to the iron as it entered the ladle during some of the tests. This addition caused its own plume of dust which could not be distinguished from the spout hole fume.

Test Results--

The test conditions are presented in Table 10. The test results are summarized in Table 11.

Observations made during these tests indicated that the fog appeared to be effective in reducing the amount of fume escaping the spout hole. However, the limited quantity of data acquired precludes any reliable efficiency calculations. It also appeared that one fogger is inadequate to control the amount of fume present during a cast.

Test Description: January 26 to February 3, 1981

Due to the inconclusive amount of data obtained during the first set of tests at the blast furnace, a second visit to the site was proposed. After discussions with plant personnel, it was felt that the problems encountered during the first visit could be eliminated if several changes were made in the test set-up. These changes and the results obtained are discussed in the following sections.

Equipment Placement--

To help eliminate the problem of material deposition on the filters, it was decided to use the second spout hole (the one used to fill the second ladle car during a cast) as the test location (spout hole C in Figure 12). It was also decided to use both foggers to control the fume since one fogger

TABLE 10. TEST CONDITIONS - CAST HOUSE: DECEMBER 9 to 18, 1980

Run No.	Date	Time	Fogger Water Flow (ℓ/hr)	Fogger Air Flow (m^3/hr)	Fogger Fan Speed (%)	Fogger Sign of Charge	Nozzle* Type
1	12-13-80	1440-1449	114	7.1	60	(0)	2
2	12-14-80	1000-1010					
3	12-14-80	1640-1645			60		
4	12-16-80	1445-1506	114	7.1	100	(0)	2
5	12-16-80	1755-1807	114	7.1	90	(-)	2
6	12-17-80	1300-1316			80		
7	12-17-80	1445-1500	114	7.1	80	(-)	2

*Type 2: heavy flow

TABLE 11. RESULTS OF FOGGER TESTING AT CAST HOUSE: DECEMBER 9 to 18, 1980

Run No.	Date	Un-Controlled	Fan Only	Uncharged Fog	Positive Fog	Negative Fog	Sampler Type	Measured Concentration ($\mu g/m^3$)	Comments
1	12-13-80			X			Standard - closest to spout	57273	Ferrosilicon added. Fume from runners entering samplers. Test ended when filters clogged.
				X			SSI - closest to spout	19051	
				X			Standard - farthest from spout	46170	
				X			SSI - farthest from spout	11613	
2	12-14-80	X					Standard - closest to spout	347497	Ferrosilicon added. Fume from runners entering samplers. Test ended when filters clogged.
		X					SSI - closest to spout	123496	
		X					Standard - farthest from spout	78756	
		X					SSI - farthest from spout	36005	
3	12-14-80		X				Standard - closest to spout	93803	Ferrosilicon added. Samplers moved ≈ 2 meters further from runner. Less runner fume entering samplers. Test ended when filters clogged.
			X				SSI - closest to spout	44389	
			X				Standard - farthest from spout	97849	
			X				SSI - farthest from spout	25284	
4	12-16-80			X			Standard	18765	Ferrosilicon not added. Samplers on staging. Fume coming off of dam.
				X			SSI	4683	
5	12-16-80					X	Standard	144649	Ferrosilicon not added. Samplers on staging. Fume coming off of dam.
						X	SSI	72031	
6	12-17-80		X				Standard	307191	Ferrosilicon added. Samplers on staging. Fume coming off of dam.
			X				SSI	69874	
7	12-17-80					X	Standard	48586	Ferrosilicon not added. Samplers on staging. Fume coming off of dam.
						X	SSI	27731	

was judged to be inadequate. These two changes resulted in the foggers being located on the cast house floor instead of in bunkers.

To help prevent freeze-ups, the main water line was routed from the workman's lounge instead of from near the control room. This eliminated excessive exposure to the ambient temperature.

The fogger and sampler placements for the second set of tests are shown in Figure 15. One fogger was placed on the blast furnace side of the spout hole while the other was placed on the side of the hole opposite the workman's lounge. This arrangement allowed a cross-flow of fog across the opening. Three samplers were utilized during five of the six tests: two hi-vols (one with an SSI) were secured to staging about two meters high on the blast furnace side of the hole and the other hi-vol was positioned below the staging, on the cast house floor, and protected from runner fume by a metal shield. One additional hi-vol with an SSI was used during the first test (run number 8). This sampler was placed on the floor near the fogger.

In order to operate the foggers in the positions shown in Figure 15, it was necessary to run high voltage power lines and water hoses for distances of up to 25 meters along the metal floor of the cast house. This posed dangers to both personnel and equipment since the lines could be tripped over and the intense heat and sparking and splashing of molten iron near the holes could melt the water hoses or the insulation on the power lines causing them to fail.

Problems Encountered--

Despite the test set-up changes which were designed to help eliminate testing difficulties, a number of problems still occurred which limited the data acquisition.

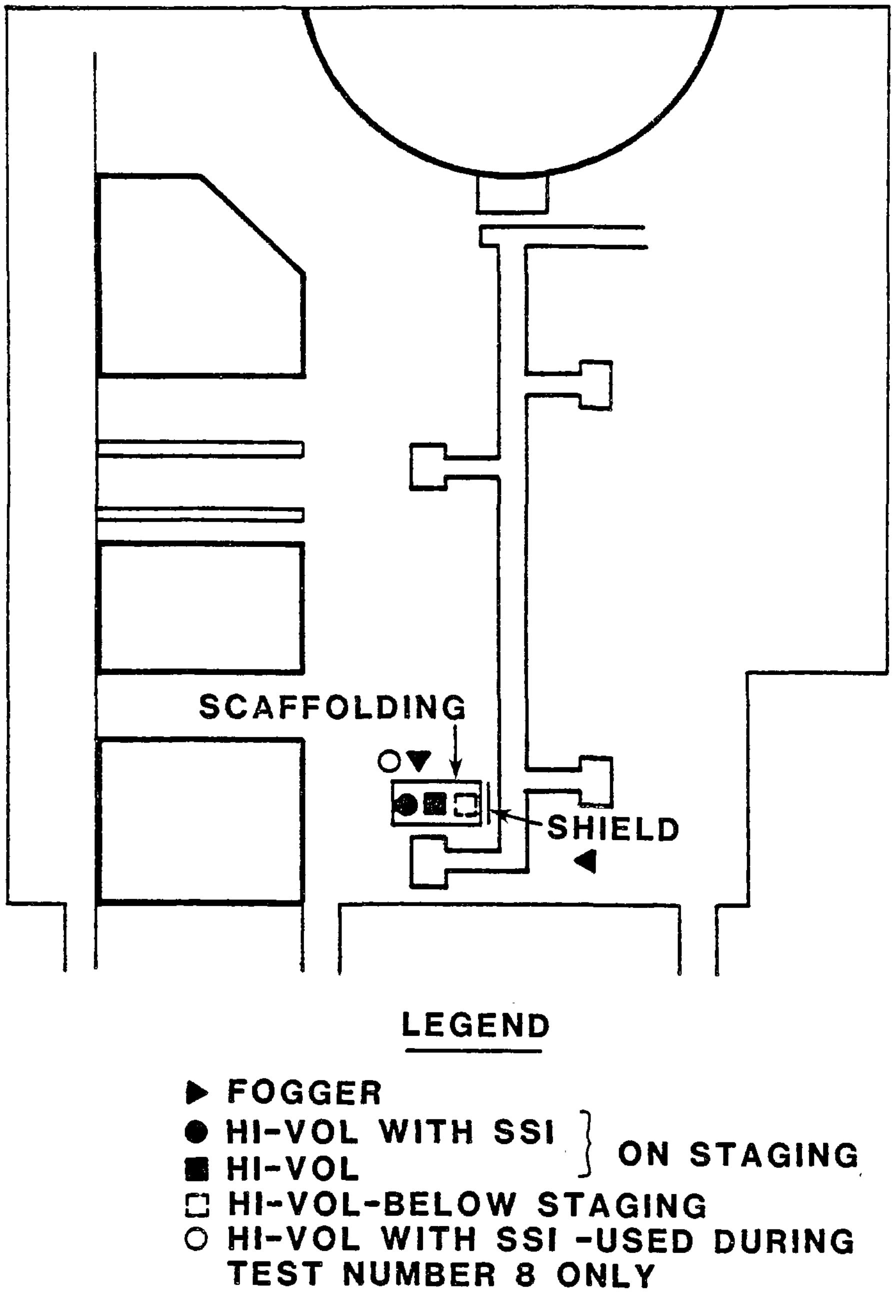


Figure 15. Equipment positions for cast house tests: January 26 to February 3, 1981.

As mentioned above, voltage lines and hoses had to be routed across the floor and were thus, at times, subject to intense heat. Precautions were taken, such as placing boards between the lines and the floor, but some power line protective coverings did sustain damage and a water line burned through during one test which caused water to flow across the floor.

Although the area near the runners and spout hole was extremely hot, there were areas in the cast house that were extremely cold since it was open to the atmosphere. Ambient temperatures during the testing period resulted in operating the foggers in sub-freezing weather. Unfortunately, as presently designed, the foggers are extremely difficult to operate below an ambient temperature of approximately $-4^{\circ}C$. Water freeze-ups were continually experienced in the narrow tubing behind the control panel and rotameter. Freeze-ups also occurred at the nozzle and these were compounded by the wind-chill effect caused by the fan air blowing around the nozzle. Operating the foggers below $-12^{\circ}C$ became virtually impossible even though extensive efforts were made to try to prevent the freeze-up problems. Steps such as heating the external water lines with electrical heating tape and placing a hairdryer behind the control panel and at the nozzle proved to be both time consuming and inadequate to permit the fogger to operate normally.

In addition to the freeze-up problems, one fogger experienced electrical problems which caused it to become unreliable. The fan would not reach the speed necessary to transport the fog to the source. Difficulty was also encountered in keeping the fogger running as the electronic shear pin kept tripping out. The problem was apparently caused by contamination of the electronic controls by dust. This fogger was in a position where it was heavily coated with dust whereas the other fogger was in a less dusty area.

Another problem was the nature of the casting process itself which made it difficult to rely on any set casting schedule. Although plant personnel were cooperative, it was impossible to cast at the test spout hole on a regular basis. Many variables, such as runner condition and the positioning of the ladle cars, affected the schedule. This made it difficult to arrange the tests.

Based upon the difficulty in performing tests in the harsh and hazardous cast house environment in conjunction with the freezing ambient temperatures, it was decided by all parties involved to discontinue testing at this site. The difficulties involved outweighed the questionnable benefits of obtaining further data points.

Test Results--

As a result of the difficulties encountered, only six tests were performed. The test conditions are presented in Table 12. The test results are summarized in Table 13.

As with the first set of tests, the limited quantity of data acquired precludes any reliable efficiency calculations. Furthermore, the fume created by each cast varied drastically as can be seen by comparing runs 8 and 13. The concentrations measured during these two uncontrolled tests differ by a factor of ten. Fume variation is due to several parameters, including iron temperature, ladle temperature, silica content of the iron, and ambient humidity. In fact, the opacity of the fume was seen to vary from 20 to 100 percent during one individual cast. These variations make it very difficult to standardize the tests and, thus, any test program would have to include a considerable number of data points.

TABLE 12. TEST CONDITIONS - CAST HOUSE: JANUARY 26 to FEBRUARY 3, 1981

			Fogger 803018					Fogger 803019				
Run No.	Date	Time	Water Flow (ℓ/hr)	Air Flow (m^3/hr)	Fan Speed (%)	Sign of Charge	Nozzle* Type	Water Flow (ℓ/hr)	Air Flow (m^3/hr)	Fan Speed (%)	Sign of Charge	Nozzle* Type
8	1-28-81	1817-1830										
9	1-30-81	1833-1845	114	7.1	80	(+)	2	114	7.1	100	(+)	2
10	1-31-81	1346-1358			80					80		
11	1-31-81	1552-1556	114	7.1	80	(0)	2	114	7.1	80	(0)	2
12	2-1-81	1421-1432	114	7.1	80	(+)	2	114	7.1	80	(+)	2
13	2-1-81	1816-1822										

*Type 2: heavy flow

TABLE 13. RESULTS OF FOGGER TESTING AT CAST HOUSE: JANUARY 26- FEBRUARY 3, 1981

Run No.	Date	Un-Controlled	Fan Only	Uncharged Fog	Positive Fog	Negative Fog	Sampler Type	Measured Concentration ($\mu g/m^3$)	Comments
8	1-28-81	X					Standard - on staging	10027	
↓	↓	X					SSI - on staging	9089	
		X					Standard - on floor	9477	
		X					SSI - on floor	9295	
9	1-30-81				X		Standard - on staging	16321	
↓	↓				X		SSI - on staging	14204	
					X		Standard - on floor	22107	
10	1-31-81		X				Standard - on staging	53365	
↓	↓		X				SSI - on staging	69725	
			X				Standard - on floor	63831	
11	1-31-81			X			Standard - on staging	8000	
↓	↓			X			SSI - on staging	13610	
				X			Standard - on floor	12289	
12	2-1-81				X		Standard - on staging	14679	
↓	↓				X		SSI - on staging	10762	
					X		Standard - on floor	18394	
13	2-1-81	X					Standard - on staging	102138	Very heavy fume observed
↓	↓	X					SSI - on staging	124111	
		X					Standard - on floor	71787	

PHASE I, TEST #4 - IRON AND STEEL PLANT: COKE SCREEN

The separating of coke into size groups by screening results in fugitive emissions. The objective of the fourth fogger field test was to evaluate the effect of charged fog on such emissions. The site chosen for the test was the coke screening operation located at Stelco's Hilton Works in Hamilton, Ontario, Canada. The field testing was performed during the period of May 1 to 7, 1981 with a total of 51 test runs conducted.

Site and Process Descriptions

As part of the overall steel-making process, coal is converted to coke in order to obtain a fuel which can be used in a blast furnace to provide the high temperatures and reducing atmosphere necessary to smelt the iron out of the ore. As the first step in this process, coal is placed into large ovens and heated to drive off impurities. The resulting product, known as coke, is then removed from the ovens and transferred via railcar to the next step of the process.

One of the subsequent steps in the process is to segregate the still warm coke into two different size categories. The coke is transferred from a conveyor belt onto an inclined vibrating screen. Pieces of coke that are larger than the pore size of the screen travel down its face and are deposited into a hopper at its end. Pieces of coke that are smaller than the pore size pass through the screen into a different hopper. Conveyor belts then transport the separated material to the next steps in the process. The coke arrives at the screen in runs which generally last 2 to 6 minutes. The runs are usually separated by 3 to 10 minutes.

The discharge end of the conveyor belt, the shaker screen, and the hopper inlets are all located within one enclosed room. The screening operation takes place on two different levels within this room. The conveyor belt and top of the screen are on the upper level. The hoppers and bottom of the screen are on the lower level. A catwalk runs around the perimeter of the screen on the upper level. Figure 16 is a sketch of the room which illustrates these features. Figures 17 and 18 are plan view and elevation, respectively, that provide dimensions of the important features.

While the coke is being screened, emissions of coke dust rise up into the room from the screen and the hoppers. The majority of this dust exits the room through a large opening in the wall at the end of the screen on the second level. The rest of the dust either settles out into the room or exits the room via roof monitors or doorways.

Equipment Placement

The equipment used for the majority of the coke screen test runs included five hi-vols (two with SSI's) and the two Ritten foggers. The five hi-vols were placed on the upper level catwalk in front of the doorway since the plume was observed to travel across this area. The two foggers had to be placed on the same side of the screen due to space limitations. One fogger was placed on the upper level and aimed down and across the screen. The other fogger was placed on the lower level about 2.7 m from the hopper. The front end of this fogger was slightly elevated so that it aimed across and above the hopper area. Figure 19 shows the positions and serial numbers of the equipment.

The equipment positions remained constant for all of the test runs; though not all of the samplers were used for every run. All five samplers were used for the first 31 runs. For the next 16 runs, only four samplers were operated (standard hi-vol 7094 was eliminated) in order to allow more

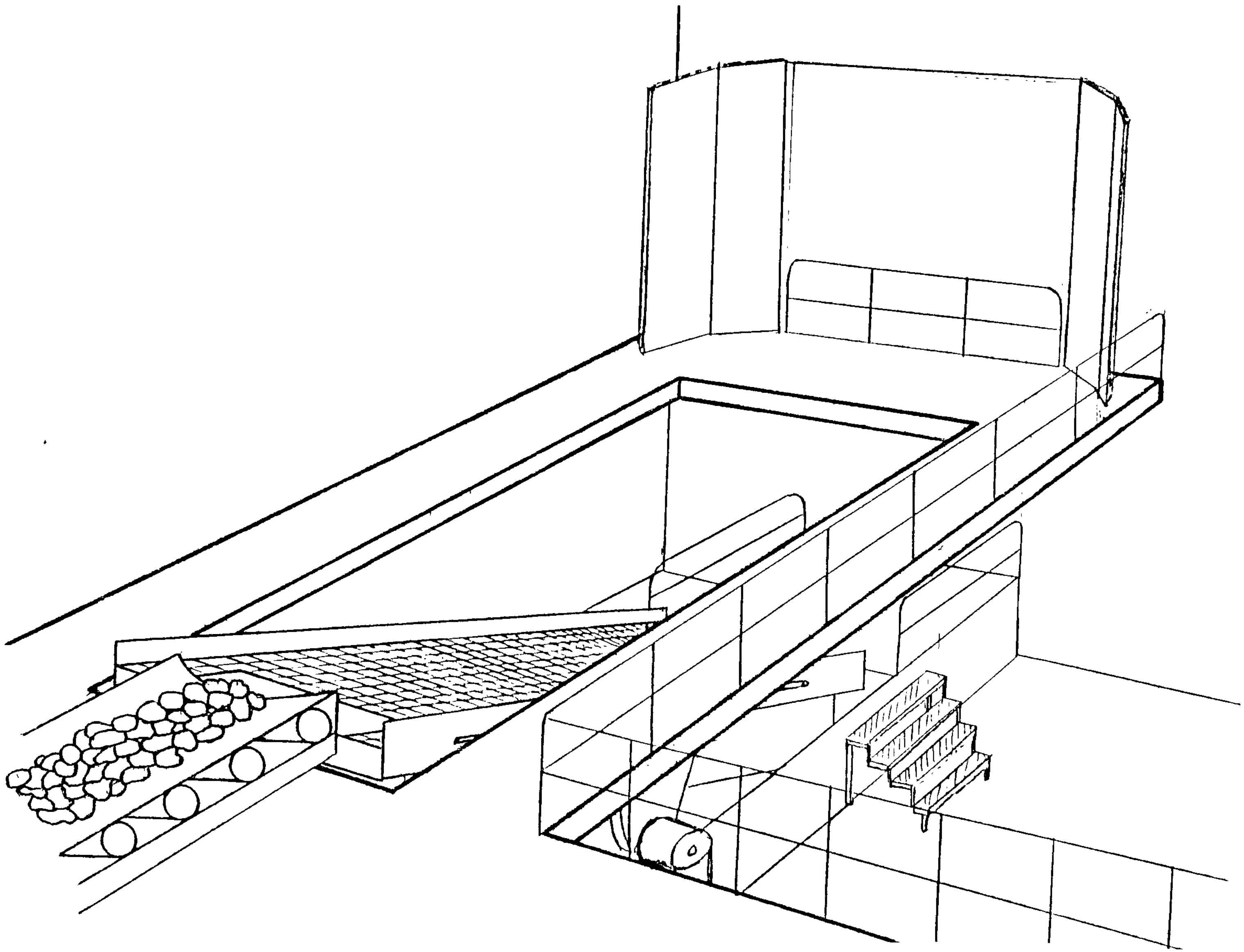


Figure 16. Coke screening operation

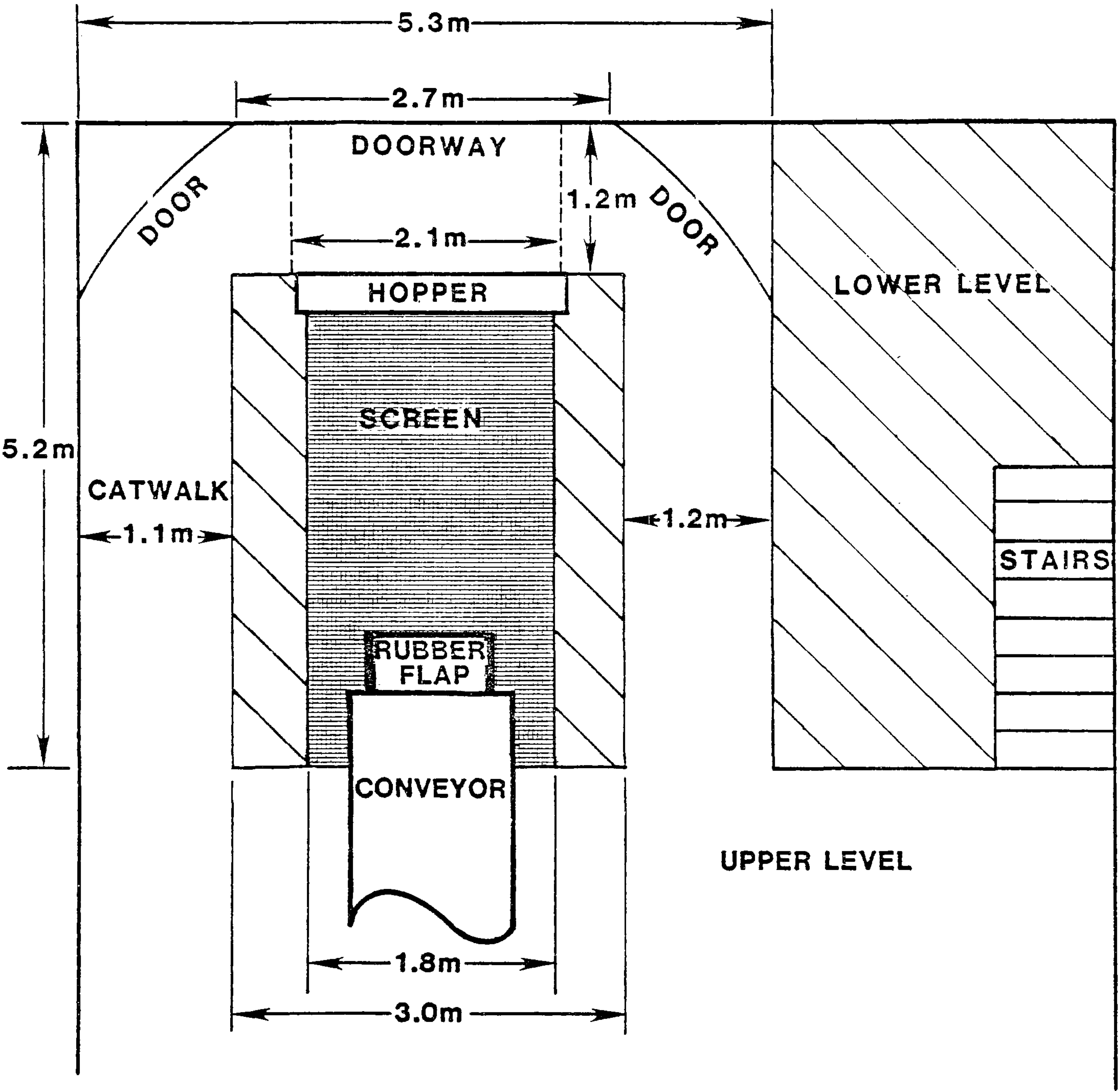


Figure 17. Top view of coke screen operation.

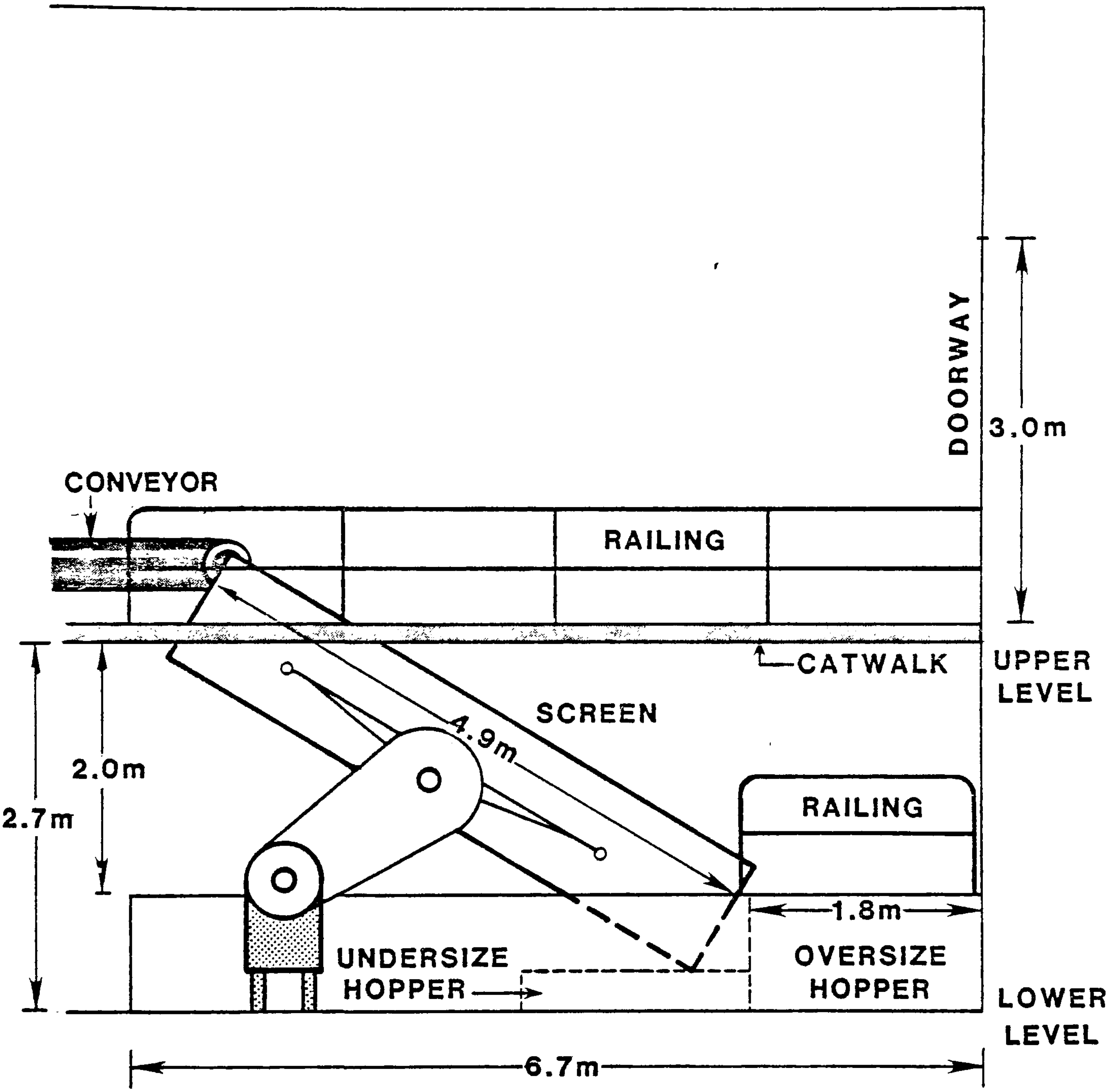


Figure 18. Side view of coke screen operation.

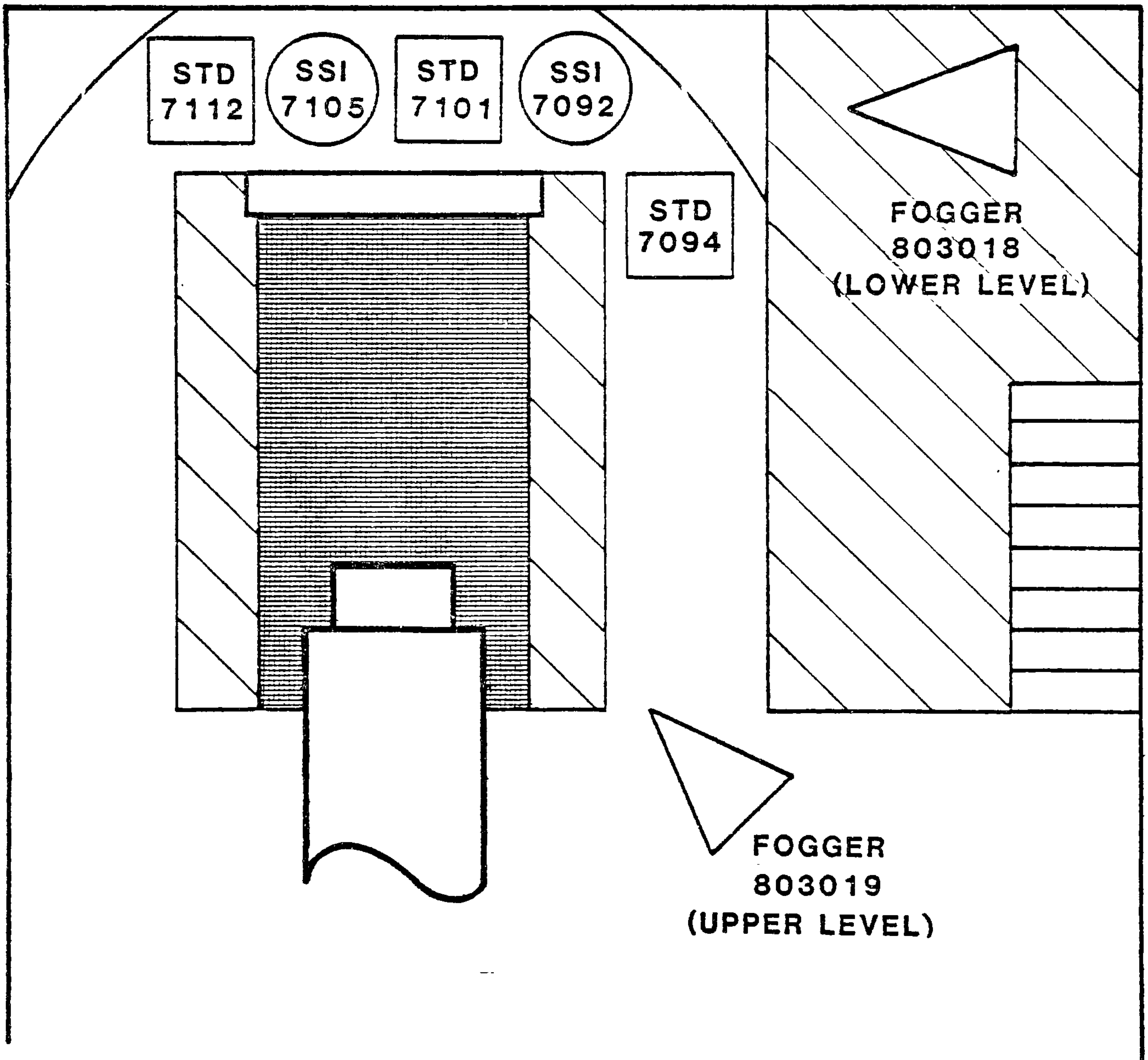


Figure 19. Equipment positions for coke screen.

test runs to be conducted. The last four test runs were conducted using only one hi-vol (number 7092) fitted with both an SSI and a four-stage cascade impactor. The sampler was moved to the center of the doorway for these runs.

Test Program and Procedure

The test program consisted of 51 runs during 6 days of testing. Included in the 51 runs were 13 uncontrolled, 8 fan only, 16 uncharged fog, 7 positive fog and 7 negative fog. The test conditions are presented in Table 14.

The procedure was the same for each of the test runs. Pre-weighed hi-vol filters were placed into the samplers between coke runs. The samplers were simultaneously started once coke began to fall from the conveyor onto the screen and simultaneously turned off at the end of the coke run. During tests in which the foggers were used they were started and adjusted to the proper settings prior to the start of the coke run. The hi-vol filters were immediately removed from the samplers at the end of each run and placed into envelopes.

Test Results

Following completion of all the test runs, the hi-vol filters were returned to the TRC Chemistry Laboratory, desiccated, and weighed. The resulting filter loadings were then used in conjunction with the sampler flow rates to calculate particulate concentrations.

TABLE 14. TEST CONDITIONS - COKE SCREENING OPERATION

Run No.	Date	Start Time	Duration Of Run (min.)	Type of Test	Equipment Positions	Fogger 803018 Water Flow (ℓ/hr)	Fogger 803018 Air Flow (m^3/hr)	Fogger 803018 Fan Speed (%)	Fogger 803019 Water Flow (ℓ/hr)	Fogger 803019 Air Flow (m^3/hr)	Fogger 803019 Fan Speed (%)
1	5-1-81	1040	5.0	Uncontrolled	*						
2	5-1-81	1100	3.5	Uncontrolled	*						
3	5-1-81	1116	4.1	Uncontrolled	*						
4	5-1-81	1210	4.2	Uncharged Fog	*	57	2.5	60	57	2.5	50
5	5-1-81	1230	4.3	Uncharged Fog	*	53	3.1	60	68	2.8	50
6	5-1-81	1247	4.6	Uncontrolled	*						
7	5-1-81	1300	3.7	Uncontrolled	*						
8	5-1-81	1318	3.5	Uncharged Fog	*	91	3.4	50	76	2.8	50
9	5-1-81	1337	4.8	Uncharged Fog	*	83	4.2	50	79	2.5	50
10	5-1-81	1402	5.4	Uncontrolled	*						
11	5-1-81	1414	3.4	Uncontrolled	*						
12	5-4-81	1300	3.2	Uncontrolled	*						
13	5-4-81	1315	6.3	Uncharged Fog	*	61	4.5	50	49	3.1	50
14	5-4-81	1330	3.1	Negative Fog	*	61	4.5	50	49	3.1	50
15	5-4-81	1345	7.3	Uncontrolled	*						
16	5-4-81	1400	2.9	Uncharged Fog	*	83	3.4	50	76	2.1	50
17	5-4-81	1440	5.1	Negative Fog	*	79	3.4	40	72	1.4	40
18	5-4-81	1450	3.8	Uncontrolled	*						
19	5-4-81	1507	3.9	Uncharged Fog	*	61	2.8	40	53	2.8	40
20	5-4-81	1520	4.9	Positive Fog	*	79	2.5	40	53	2.3	40
21	5-4-81	1535	4.4	Uncontrolled	*						
22	5-5-81	1400	3.3	Uncontrolled	*						
23	5-5-81	1422	5.4	Uncharged Fog	*	76	2.8	40	61	2.8	40
24	5-5-81	1443	3.0	Positive Fog	*	76	3.7	40	68	2.4	40
25	5-5-81	1500	4.1	Uncontrolled	*						
26	5-5-81	1511	4.6	Uncharged Fog	*	68	2.8	40	91	2.5	40
27	5-5-81	1522	3.8	Positive Fog	*	79	2.8	40	91	2.3	30
28	5-5-81	1536	4.8	Fan Only	*			40			40
29	5-6-81	0732	1.2	Fan Only	*			40			40
30	5-6-81	0812	2.9	Uncharged Fog	*	83	4.0	40	83	3.5	40
31	5-6-81	0832	2.5	Negative Fog	*	83	3.3	40	76	3.4	40
32	5-6-81	0837	3.1	Fan Only	**			40			40
33	5-6-81	0846	3.6	Uncharged Fog	**	83	3.4	40	79	3.7	40
34	5-6-81	0856	5.8	Negative Fog	**	76	3.1	40	83	3.7	40
35	5-6-81	0905	3.5	Fan Only	**			40			40
36	5-6-81	0915	2.7	Uncharged Fog	**	83	3.7	40	76	3.7	40
37	5-6-81	0925	3.2	Negative Fog	**	83	4.5	40	76	3.7	40
38	5-6-81	1003	3.1	Fan Only	**			40			40
39	5-6-81	1015	3.0	Uncharged Fog	**	76	3.7	40	91	3.1	40
40	5-6-81	1025	3.1	Positive Fog	**	79	4.2	40	87	3.1	40
41	5-6-81	1040	2.4	Fan Only	**			40			40
42	5-6-81	1055	2.6	Uncharged Fog	**	76	3.1	40	91	3.7	40

(continued)

NOTE: Refer to Figure 19
* Five Samplers - 3 standard, 2 SSI

TABLE 14. TEST CONDITIONS - COKE SCREENING OPERATION (Continued)

						Fogger 803018			Fogger 803019		
Run No.	Date	Start Time	Duration Of Run (min.)	Type of Test	Equipment Positions	Water Flow (ℓ/hr)	Air Flow (m^3/hr)	Fan Speed (%)	Water Flow (ℓ/hr)	Air Flow (m^3/hr)	Fan Speed (%)
43	5-6-81	1110	6.4	Positive Fog	**	83	3.7	40	76	3.7	40
44	5-6-81	1225	2.6	Fan Only	**			40			40
45	5-6-81	1238	1.8	Uncharged Fog	**	79	3.7	40	79	5.0	40
46	5-6-81	1255	1.4	Positive Fog	**	76	4.8	40	76	4.5	40
47	5-6-71	1315	4.6	Negative Fog	**	76	4.0	40	87	4.0	40
48	5-7-81	0922	2.7	Fan Only	***			40			40
49	5-7-81	0940	2.7	Uncharged Fog	***	87	3.4	40	83	4.0	40
50	5-7-81	0956	5.6	Negative Fog	***	79	3.1	40	79	3.7	40
51	5-7-81	1015	2.2	Positive Fog	***	79	3.4	40	76	4.2	40

NOTE: Refer to Figure 19

* Five Samplers - 3 standard, 2 SSI

** Four Samplers - 2 standard, 2 SSI (7094 eliminated)

*** One Sampler - SSI and CI

Tables 15 through 19 summarize the calculated concentrations for each of the five test conditions (uncontrolled, fan only, uncharged fog, negative fog, and positive fog). The data set for each hi-vol is presented along with the arithmetic mean of that data set. Also included in the tables are the average concentrations as measured by the standard hi-vols and the hi-vols with SSI's. Hi-vol 7094 was not used in the standard hi-vol averages because it was not operated during all of the test runs and would thus bias some of the results. The arithmetic means of these two data sets are also included in the tables. A comparison of all of the calculated arithmetic means is presented in Table 20.

Table 21 presents the fogger efficiencies that were calculated using the previously described means for the average of the two standard hi-vols and the average of the two hi-vols with SSI's. In calculating the efficiencies, the fan-only particulate matter concentrations were used as the baseline. This was because the fans create an artificial wind effect that is constant for all conditions except the uncontrolled one. The fan air tends to redirect and, to some extent, reentrain some of the dust due to the limitations imposed by the test apparatus positioning. This phenomenon would probably not be present at an actual installation since the fog nozzles would most probably be positioned above the source and aimed down at it. This arrangement is not possible with the experimental test equipment.

As shown in Table 21, there was a slight reduction (12 to 23 percent) in particulate matter concentrations as a result of the application of an uncharged water fog on the dust emissions at the coke screen operation. When a negative charge was applied to this water fog, the concentrations were

TABLE 15. RESULTS OF FOGGER TESTING AT COKE SCREEN OPERATION: UNCONTROLLED PARTICULATE MATTER CONCENTRATIONS (μg/m³)

Run No.	Hi-Vol Designation: Standard 7112	SSI 7105	Standard 7101	SSI 7092	Standard 7094	Avg. of 7112 and 7101	Avg. of 7105 and 7092
1	96743	43248	68655	39587	75068	82699	41417
2	84111	47853	79310	50025	59116	81710	48939
3	37395	18866	31189	16458	44379	34292	17662
6	55996	29278	34040	19097	28646	45018	24187
7	35770	20093	15588	9867	20605	25679	14980
10	158356	69493	88936	42424	54530	123646	55958
11	153497	54752	69804	36262	52203	111650	45507
12	82320	42787	54619	30909	52872	68469	36848
15	57816	34870	36000	34747	43226	46908	34808
18	237970	95672	116134	66004	73282	177052	80838
21	58460	29342	21679	22810	48906	40069	26076
22	55635	24563	37023	18306	52423	46329	21434
25	30758	17647	15294	10665	26004	23026	14156
ARITHMETIC MEAN	88064	40651	51405	30551	48558	69734	35601

TABLE 16. RESULTS OF FOGGER TESTING AT COKE SCREEN OPERATION: FAN ONLY PARTICULATE MATTER CONCENTRATIONS ($\mu g/m^3$)

Run No.	Hi-Vol Designation Standard 7112	SSI 7105	Standard 7101	SSI 7092	Standard 7094	Avg. of 7112 and 7101	Avg. of 7105 and 7092
28	205954	60508	67576	27828	28021	136765	44168
29	229843	91278	225319	75512	136294	227581	83395
32	115205	65149	134932	51626	-	125068	58387
35	149926	74656	115376	41714	-	132651	58185
38	144431	63480	130322	43047	-	137376	53263
41	148014	75411	134221	46886	-	141117	61148
44	181456	118435	304563	91883	-	243009	105159
ARITHMETIC MEAN	167833	78417	158901	54071	82158	163367	66244

TABLE 17. RESULTS OF FOGGER TESTING AT COKE SCREEN OPERATION: UNCHARGED FOG PARTICULATE MATTER CONCENTRATIONS (μg/m³)

Run No.	Hi-Vol Designation Standard 7112	SSI 7105	Standard 7101	SSI 7092	Standard 7094	Avg. of 7112 and 7101	Avg. of 7105 and 7092
4	223620	93586	78518	69921	98704	151069	81753
5	100933	46223	52645	33943	51976	76789	40083
8	72356	31615	23587	19063	31538	47971	25339
9	189098	81921	58080	38274	57340	123589	60097
13	178908	43311	43037	35763	84169	110972	39537
16	168438	160842	130545	39292	89008	149491	100067
19	317657	103506	131790	57152	76526	224723	80329
23	107765	45112	54412	31879	52488	81088	38495
26	107819	36859	44418	23623	27780	76118	30241
30	134123	58875	120544	36058	43519	127333	47466
33	150095	86433	179836	70426	-	164965	78429
36	120065	56096	91624	38542	-	105844	47319
39	144588	64109	94164	34824	-	119376	49466
42	171003	84344	120093	52397	-	145548	68370
45	171168	97534	177972	76210	-	174570	86872
ARITHMETIC MEAN	157176	72691	93418	43824	61305	125296	58258

TABLE 18. RESULTS OF FOGGER TESTING AT COKE SCREEN OPERATION: NEGATIVE FOG PARTICULATE MATTER CONCENTRATIONS ($\mu g/m^3$)

	Hi-Vol Designation						
Run No.	Standard 7112	SSI 7105	Standard 7101	SSI 7092	Standard 7094	Avg. of 7112 and 7101	Avg. of 7105 and 7092
14	190759	60430	41367	35745	50831	116063	48087
17	71705	22332	13553	28486	75668	42629	25409
31	221220	122963	295589	101086	120442	258404	112024
34	85006	46362	79710	34844	-	82358	40603
37	147459	75354	138844	55784	-	143151	65569
47	70055	55538	74286	37218	-	72170	46378
ARITHMETIC MEAN	131034	63830	86392	48861	82314	119129	56345

TABLE 19. RESULTS OF FOGGER TESTING AT COKE SCREEN OPERATION: POSITIVE FOG PARTICULATE MATTER CONCENTRATIONS ($\mu g/m^3$)

	Hi-Vol Designation					Avg. of	Avg. of
Run No.	Standard 7112	SSI 7105	Standard 7101	SSI 7092	Standard 7094	7112 and 7101	7105 and 7092
20	74915	30512	20638	19321	35254	47776	24916
24	124471	42521	42040	20301	41190	83255	31411
27	61084	23356	14349	13451	35749	31261	18403
40	119430	63225	94102	48661	-	106766	55943
43	77963	45944	83510	34150	-	80736	40047
46	189030	114244	187870	75862	-	188450	95053
ARITHMETIC MEAN	107816	53300	73752	35291	37398	89707	44296

TABLE 20. RESULTS OF FOGGER TESTING AT COKE SCREEN OPERATION: ARITHMETIC MEAN PARTICULATE MATTER CONCENTRATIONS (μg/m³)

	Hi-Vol Designation					Avg. of	Avg. of
Run Condition	Standard 7112	SSI 7105	Standard 7101	SSI 7092	Standard 7094	7112 and 7101	7105 and 7092
Uncontrolled	88064	40651	51405	30551	48558	69734	35601
Fan Only	167833	78417	158901	54071	82158	163367	66244
Uncharged Fog	157176	72691	93418	43824	61305	125296	58258
Negative Fog	131034	63830	86392	48861	82314	119129	56345
Positive Fog	107816	53300	73752	35291	37398	89707	44296

TABLE 21. RESULTS OF FOGGER TESTING AT COKE SCREEN OPERATION: FOGGER EFFICIENCIES (%)

Formula Used In Calculation*	Percent Reduction	
	Standard Hi-Vols	Hi-Vols With SSI's
$\frac{\text{Fan Only - Uncharged}}{\text{Fan Only}} \times 100$	23	12
$\frac{\text{Uncharged - Negative Fog}}{\text{Uncharged}} \times 100$	5	3
$\frac{\text{Uncharged - Positive Fog}}{\text{Uncharged}} \times 100$	28	24
$\frac{\text{Fan Only - Negative Fog}}{\text{Fan Only}} \times 100$	27	15
$\frac{\text{Fan Only - Positive Fog}}{\text{Fan Only}} \times 100$	45	33

*NOTE: Input to formulae are the arithmetic mean particulate matter concentrations.

reduced only slightly further (approximately 5 percent). When a positive charge was applied to the water fog, the concentrations were reduced an additional 24 to 28 percent. This indicates that the dust plume was primarily composed of negatively charged particles. The positively charged fog produced by the two Fogger IV's reduced the concentrations at the coke screen operation 33 to 45 percent. This level is consistent with observations which indicated that more than two foggers would be necessary to control the dust emissions from the operation.

The last four test runs (48-51) were conducted using a hi-vol with an SSI and a four-stage cascade impactor operated at 0.6 m^3/min. Additional runs were not conducted due to the considerable length of time necessary to conduct this type of test. The results of these runs are presented in Table 22. While the results are interesting, not enough data were collected to show any firm conclusions.

An attempt to obtain visible emission information was unsuccessful since the addition of the fog to the still-warm coke produced steam which masked any changes to the visibility or opacity of the dust plume.

TABLE 22. RESULTS OF FOGGER TESTING AT COKE SCREEN OPERATION: CASCADE IMPACTOR DATA

Run No.	Test Type	Measured Concentrations ($\mu g/m^3$) Stage 1 (10.2-16μ)	Stage 2 (4.2-10.2μm)	Stage 3 (2.1-4.2μm)	Stage 4 (1.3-2.1μm)	Back-up Filter (0-1.3μm)	Total (0-16μm)
48	Fan Only	12313	20746	6194	4328	16866	60448
49	Uncharged Fog	8424	10727	4545	3394	15333	42424
50	Negative Fog	11036	16022	4268	2381	9496	43193
51	Positive	14088	17737	5766	3431	13066	54088

PHASE II, TEST #5 - IRON AND STEEL PLANT: TORCH CUTTING OPERATION

The cutting of slabs with a torch produces significant amounts of fume. The control of this fume was the subject of the fifth fogger field test. The site chosen for the test was the torch cutting operation located at Armco's Butler Works in Butler, Pennsylvania. The field testing was performed during the period from September 1 to 11, 1981, with a total of 132 test runs conducted.

Site and Process Descriptions

Baseplates for use with the coils of an electric arc furnace are produced by cutting circles measuring approximately 1.2 meters in diameter from slabs of 304 stainless. The cutting machine consists of a template and an oxweld C39 torch which operates using iron powder together with an oxygen and natural gas flame. During the test, the cutting speed of the torch was set to approximately 9.5 cm/min. A typical circle was thus cut in approximately 40 minutes. The cutting resulted in emissions of fume which rise vertically above the operation.

The slabs, which are about 5.5 m long by 1.3 m wide by 0.13 m thick, were positioned by an overhead crane on the cutting surface adjacent to the template table. Four circles were cut out of each slab. After the first two circles are cut, the crane was used to remove the two circles and the scrap material and then to position the remaining half of the slab adjacent to the template table for the cutting of the other two circles.

The entire cutting operation is located inside the Butler Works maintenance building. The area in front and on both sides of the cutting table is a flat concrete floor. The table is positioned approximately 2 meters from the rear wall of the building. The cutting table itself is approximately 1 meter high so that the top of the slab is 1.1 meters from the floor. The maintenance building has several bay doors which are opened and closed frequently for vehicle traffic. Because of these doors and space heater blowers, the air flow shifted directions at times even though the test was performed indoors.

Figure 20 is a photograph of the operation illustrating salient features.

Equipment Placement

The equipment used for all the test runs included four hi-vols, two of which were fitted with SSIs, the two Ritten foggers, and the two AV foggers. In addition, one of the hi-vols with an SSI was fitted with a four-stage cascade impactor during certain test runs. The samplers were located above the cutting operation on a movable platform. The platform was approximately 3 meters high and had a 2-meter by 3-meter metal grating as a surface. After the first seven test runs, the hi-vols were repositioned slightly to the rear of the platform to sample the plume more accurately.

Because of the limited amount of space between the operation and the building wall, all four foggers were located on the same side of the table. Their positions remained constant throughout all the tests. The front-ends of the Ritten foggers were elevated slightly so that the air and water were not directly impinging on the torch. Such impingement was found to disrupt the flow of the iron powder, causing the torch to sputter or go out occasionally.

The equipment positions are shown in Figures 21 and 22.

Test Program and Procedure

The test program consisted of 132 test runs during 7 days of testing. The test conditions are presented in Table 23. To help ensure a valid

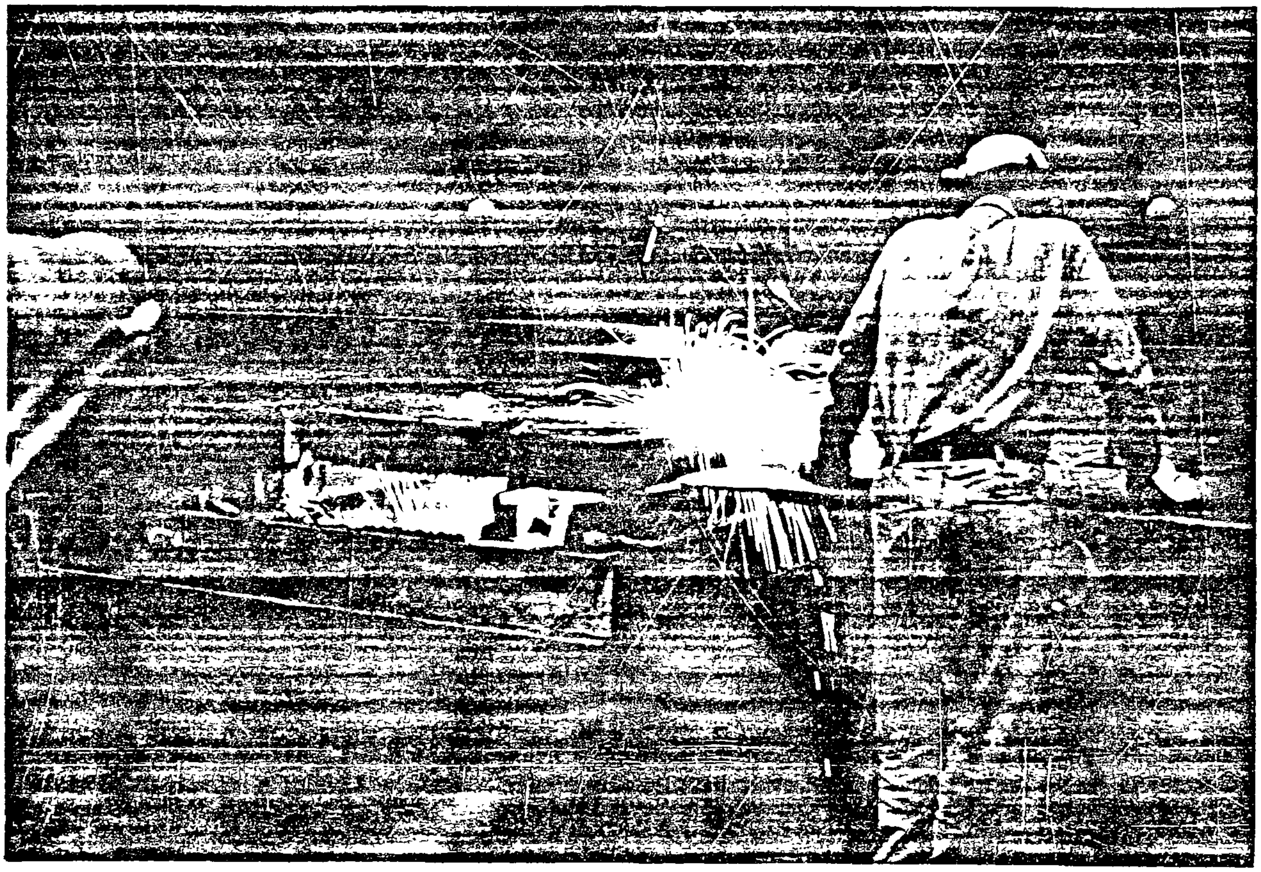


Figure 20. Torch cutting operation.

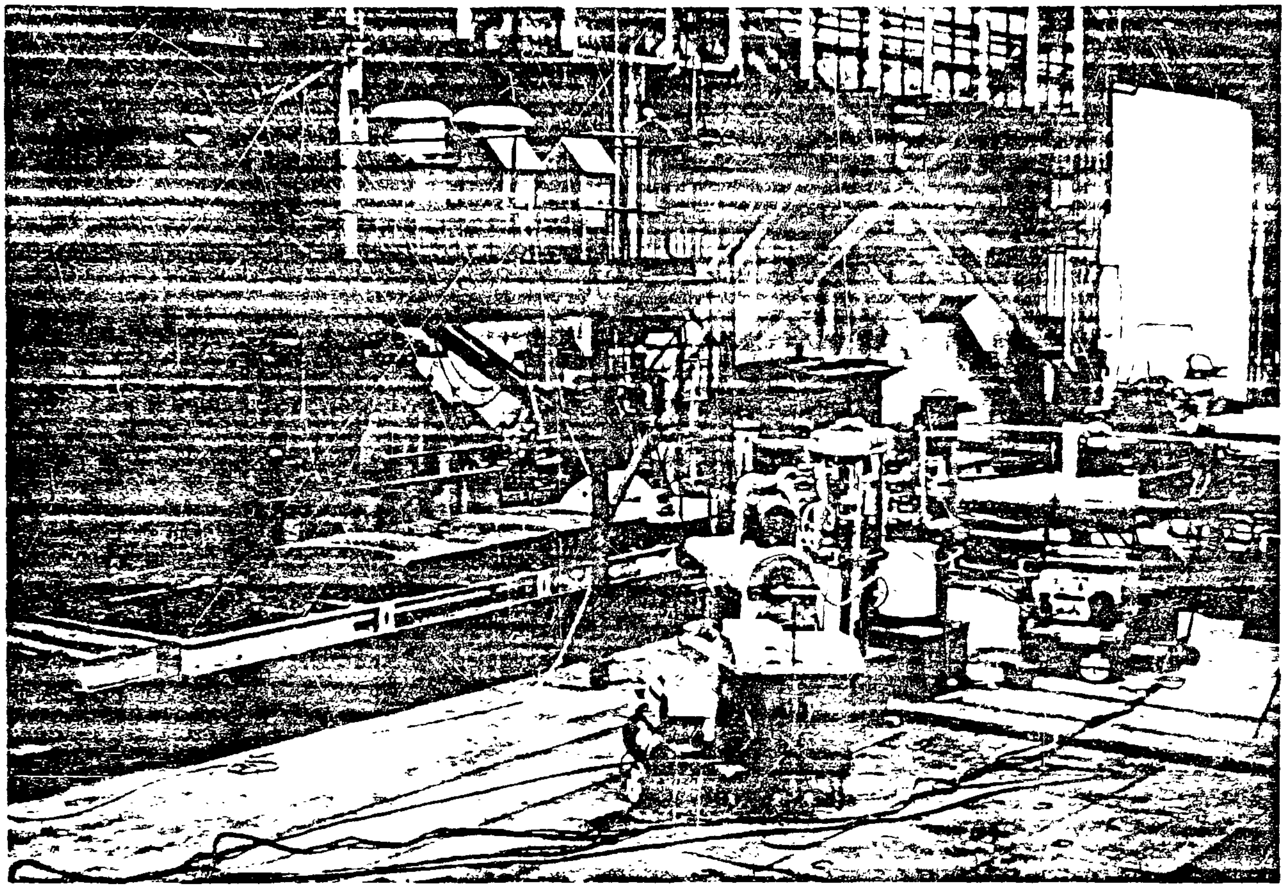
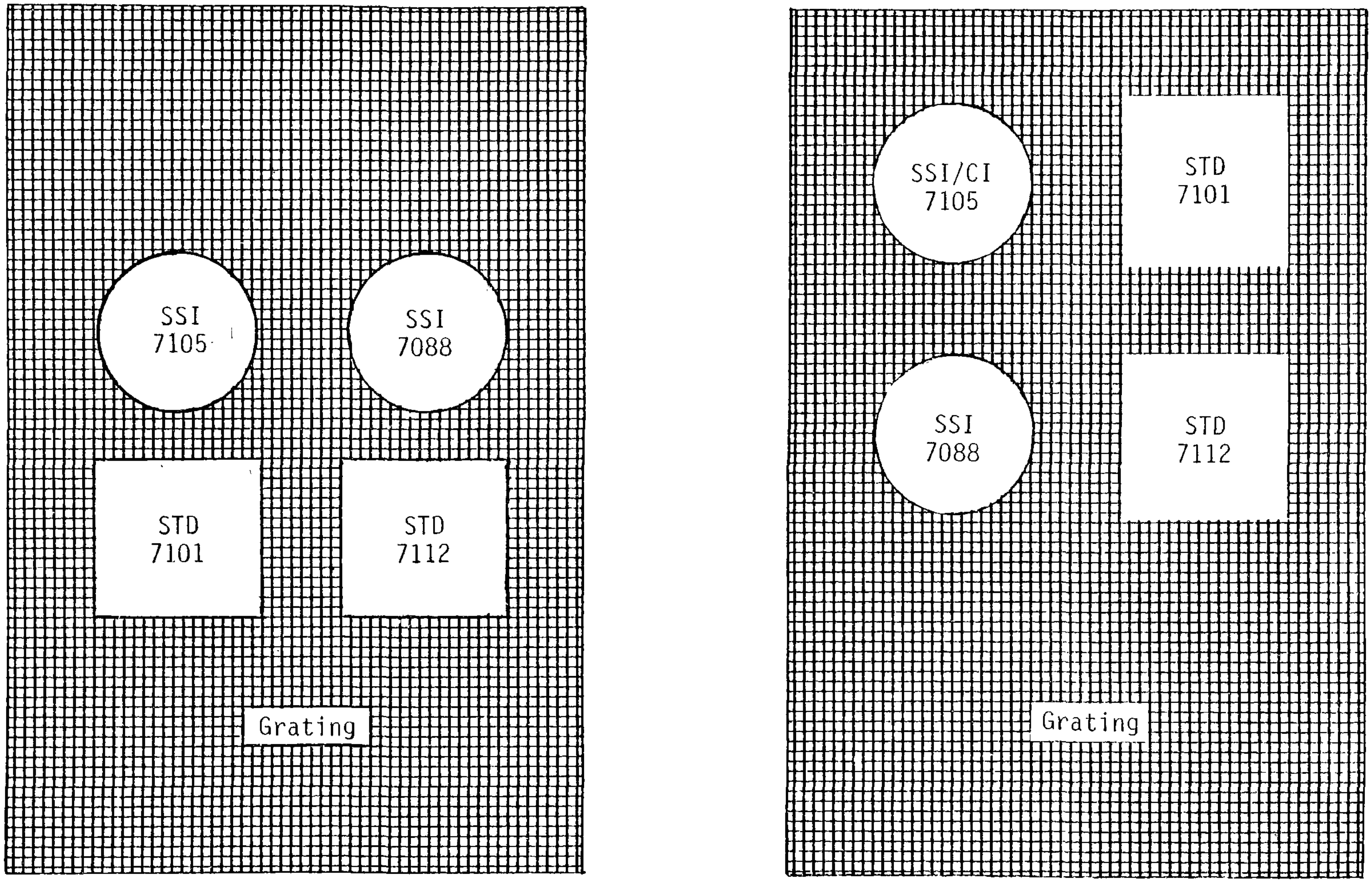


Figure 21. Equipment locations for torch cutting operation test.



Positions for Test Runs 1-7

Positions for Test Runs 8-132

Figure 22. High-volume sampler positions and serial numbers for torch cutting operation.

TABLE 23. TEST CONDITIONS - TORCH CUTTING OPERATION

Run No.	Date	Start Time	Duration of run (min)	Type of Test	Equipment Position*	Ritten Foggers Water Flow (ℓ/hr)†	Ritten Foggers Air-flow (m^3/hr)†	Ritten Foggers Fan Speed (% of max.)	AV Foggers Water Flow (ℓ/hr)†	AV Foggers Fan Speed (% of max.)	Cascade Impactor
1	9-2-81	0830	1.00	Uncontrolled	a						No
2	9-2-81	0835	1.00	Ritten-Fan Only	a			50			No
3	9-2-81	0840	1.00	AV-Fan Only	a					50	No
4	9-2-81	0935	1.28	Ritten-Uncharged	a	56.8	3.6	50			No
5	9-2-81	0950	1.50	Ritten-(+) Fog	a	56.8	3.6	50			No
6	9-2-81	1050	1.50	AV-Uncharged	a				56.8	50	No
7	9-2-81	1100	1.42	AV-(+) Fog	a				56.8	50	No
8	9-2-81	1120	1.25	Uncontrolled	b						No
9	9-2-81	1130	1.00	AV-Fan Only	b					50	No
10	9-2-81	1250	1.00	Ritten-Fan Only	b			50			No
11	9-2-81	1305	1.00	Ritten-Uncharged	b	56.8	3.6	50			No
12	9-2-81	1310	1.00	AV-Uncharged	b				56.8	50	No
13	9-2-81	1315	0.68	Ritten-(-) Fog	b	56.8	3.6	50			No
14	9-2-81	1330	1.00	AV-(+) Fog	b				56.8	50	No
15	9-3-81	0825	1.00	Uncontrolled	b						No
16	9-3-81	0835	1.00	AV-Fan Only	b					50	No
17	9-3-81	0840	1.00	AV-Uncharged	b				75.6	50	No
18	9-3-81	0845	1.00	AV-(+) Fog	b				75.6	50	No
19	9-3-81	0850	1.00	AV-Fan Only	b					50	No
20	9-3-81	0855	1.00	AV-Uncharged	b				75.6	50	No
21	9-3-81	0900	1.00	AV-(+) Fog	b				75.6	50	No
22	9-3-81	0940	1.00	Uncontrolled	b						No
23	9-3-81	0945	1.00	AV-Fan Only	b					50	Yes
24	9-3-81	0950	1.00	AV-Uncharged	b				75.6	50	No
25	9-3-81	0955	1.00	AV-(+) Fog	b				75.6	50	Yes
26	9-3-81	1000	1.00	AV-Fan Only	b					50	No
27	9-3-81	1005	1.00	AV-Uncharged	b				75.6	50	No
28	9-3-81	1010	1.00	AV-(+) Fog	b				75.6	50	No
29	9-3-81	1100	1.00	Uncontrolled	b						No
30	9-3-81	1110	1.00	AV-Fan Only	b					50	Yes
31	9-3-81	1115	1.00	AV-Uncharged	b				75.6	50	No
32	9-3-81	1120	1.00	AV-(+) Fog	b				75.6	50	Yes
33	9-3-81	1125	1.00	AV-Fan Only	b					50	No
34	9-3-81	1130	1.00	AV-Uncharged	b				75.6	50	No
35	9-3-81	1140	1.00	AV-(+) Fog	b				75.6	50	No
36	9-3-81	1310	1.00	Uncontrolled	b						No
37	9-3-81	1320	1.00	AV-Fan Only	b					50	No
38	9-3-81	1322	1.00	AV-Uncharged	b				75.6	50	No

*Refer to Figure 22.

†Values are per individual fogger.

TABLE 23. TEST CONDITIONS - TORCH CUTTING OPERATION (Continued)

Run No.	Date	Start Time	Duration of run (min)	Type of Test	Equipment Position*	Ritten Foggers Water Flow (ℓ/hr)†	Ritten Foggers Air-flow (m^3/hr)†	Ritten Foggers Fan Speed (% of max.)	AV Foggers Water Flow (ℓ/hr)†	AV Foggers Fan Speed (% of max.)	Cascade Impactor
39	9-3-81	1327	1.00	AV-(+) Fog	b				75.6	50	Yes
40	9-3-81	1333	1.00	AV-Fan Only	b					50	Yes
41	9-3-81	1338	1.00	AV-Uncharged	b				75.6	50	No
42	9-3-81	1342	1.00	AV-(+) Fog	b				75.6	50	No
43	9-4-81	0920	1.00	Uncontrolled	b						No
44	9-4-81	0928	1.00	AV-Fan Only	b					50	Yes
45	9-4-81	0940	1.00	AV-Uncharged	b				56.8	50	No
46	9-4-81	0950	1.00	AV-(+) Fog	b				56.8	50	Yes
47	9-4-81	1000	1.00	AV-Uncharged	b				56.8	50	No
48	9-8-81	1238	1.00	Uncontrolled	b						No
49	9-8-81	1245	1.00	AV-Fan Only	b					50	Yes
50	9-8-81	1253	1.00	AV-Uncharged	b				56.8	50	No
51	9-8-81	1300	1.00	AV-(+) Fog	b				56.8	50	Yes
52	9-8-81	1315	1.00	AV-Fan Only	b					50	No
53	9-8-81	1321	1.00	AV-Uncharged	b				56.8	50	No
54	9-8-81	1329	1.00	AV-(+) Fog	b				56.8	50	No
55	9-8-81	1335	1.00	AV-(+) Fog	b				56.8	50	No
56	9-8-81	1433	1.00	AV-Fan Only	b					50	No
57	9-8-81	1439	1.00	AV-Uncharged	b				56.8	50	No
58	9-8-81	1448	1.00	AV-(+) Fog	b				56.8	50	Yes
59	9-8-81	1455	1.00	AV-Fan Only	b					50	Yes
60	9-8-81	1506	0.67	AV-Uncharged	b				56.8	50	No
61	9-9-81	0815	1.00	Ritten-Fan Only	b			40			No
62	9-9-81	0828	1.00	Ritten-Uncharged	b	56.8	3.6	40			No
63	9-9-81	0836	1.00	Ritten-(+) Fog	b	56.8	3.6	40			No
64	9-9-81	0843	1.00	Ritten-Fan Only	b			40			Yes
65	9-9-81	1230	1.00	Ritten-Fan Only	b			40			Yes
66	9-9-81	1236	1.00	Ritten-Uncharged	b	56.8	3.6	40			No
67	9-9-81	1245	1.00	Ritten-(+) Fog	b	56.8	3.6	40			Yes
68	9-9-81	1251	1.00	Ritten-Fan Only	b			40			No
69	9-9-81	1336	1.00	AV-Fan Only	b					50	No
70	9-9-81	1340	1.00	AV-Uncharged	b				56.8	50	No
71	9-9-81	1345	1.00	AV-(+) Fog	b				56.8	50	Yes
72	9-9-81	1351	1.00	AV-Fan Only	b					50	Yes

*Refer to Figure 22.
†Values are per individual fogger.

TABLE 23. TEST CONDITIONS - TORCH CUTTING OPERATION (Continued)

Run No.	Date	Start Time	Duration of run (min)	Type of Test	Equipment Position*	Ritten Foggers Water Flow (ℓ/hr)†	Ritten Foggers Air-flow (m³/hr)†	Ritten Foggers Fan Speed (% of max.)	AV Foggers Water Flow (ℓ/hr)†	AV Foggers Fan Speed (% of max.)	Cascade Impactor
73	9-9-81	1356	1.00	AV-Uncharged	b				56.8	50	No
74	9-9-81	1402	1.00	AV-(+) Fog	b				56.8	50	No
75	9-9-81	1425	1.00	Ritten-Fan Only	b			40			No
76	9-9-81	1441	1.00	Ritten-Uncharged	b	56.8	3.6	40			No
77	9-9-81	1447	1.00	Ritten-(+) Fog	b	56.8	3.6	40			No
78	9-9-81	1453	1.00	Ritten-Fan Only	b			40			No
79	9-9-81	1456	1.00	Ritten-Uncharged	b	56.8	3.6	40			No
80	9-9-81	1502	1.00	Ritten-(+) Fog	b	56.8	3.6	40			No
81	9-10-81	0923	1.00	Ritten-Fan Only	b			40			No
82	9-10-81	0929	1.00	Ritten-Uncharged	b	56.8	3.6	40			No
83	9-10-81	0935	1.00	Ritten-(-) Fog	b	56.8	3.6	40			Yes
84	9-10-81	0940	1.00	Ritten-Fan Only	b			40			Yes
85	9-10-81	0945	1.00	Ritten-(-) Fog	b	56.8	3.6	40			No
86	9-10-81	0951	1.00	Ritten-(-) Fog	b	56.8	3.6	40			No
87	9-10-81	0958	1.00	AV-Fan Only	b					50	No
88	9-10-81	1004	1.00	AV-Uncharged	b				56.8	50	No
89	9-10-81	1010	1.00	AV-(+) Fog	b				56.8	50	No
90	9-10-81	1016	1.00	AV- Fan Only	b					50	No
91	9-10-81	1022	1.00	AV-Uncharged	b						No
92	9-10-81	1030	1.00	AV (+)-Fog	b				56.8	50	No
93	9-10-81	1105	1.00	Ritten-Fan Only	b			40			No
94	9-10-81	1110	1.00	Ritten-Uncharged	b	56.8	3.6	40			No
95	9-10-81	1116	1.00	Ritten-(-) Fog	b	56.8	3.6	40			Yes
96	9-10-81	1122	1.00	Ritten-Fan Only	b			40			Yes
97	9-10-81	1130	1.00	Ritten-Uncharged	b	56.8	3.6	40			No
98	9-10-81	1136	1.00	Ritten-(-) Fog	b	56.8	3.6	40			No
99	9-10-81	1143‡	1.00	Ritten-Fan Only	b			40			No
100	9-10-81		1.00	Ritten-Uncharged	b	56.8	3.6	40			No
101	9-10-81		1.00	Ritten-(-) Fog	b	56.8	3.6	40			Yes
102	9-10-81		1.00	Ritten-Fan Only	b			40			Yes
103	9-10-81		1.00	Ritten-Uncharged	b	56.8	3.6	40			No
104	9-10-81		1.00	Ritten-(-) Fog	b	56.8	3.6	40			No
105	9-10-81		1.00	AV-Fan Only	b					50	No
106	9-10-81		1.00	AV-Uncharged	b				56.8	50	No
107	9-10-81		1.00	AV-(+) Fog	b				56.8	50	Yes
108	9-10-81		1.00	AV-Fan Only	b					50	Yes
109	9-10-81		1.00	AV-Uncharged	b				56.8	50	No
110	9-10-81		1.00	AV-(+) Fog	b				56.8	50	No

*Refer to Figure 22.
†Values are per individual fogger.
‡Times not recorded after this point.

TABLE 23. TEST CONDITIONS - TORCH CUTTING OPERATION (Continued)

						Ritten Foggers			AV Foggers		
Run No.	Date	Start Time	Duration of run (min)	Type of Test	Equipment Position*	Water Flow (ℓ/hr)†	Air-flow (m^3/hr)†	Fan Speed (% of max.)	Water Flow (ℓ/hr)†	Fan Speed (% of max.)	Cascade Impactor
111	9-10-81		1.00	AV-Fan Only	b					50	No
112	9-10-81		1.00	AV-(+) Fog	t				56.8	50	No
113	9-11-81		1.00	Ritten-Fan Only	b			40			No
114	9-11-81		1.00	Ritten-Uncharged	b	56.8	3.6	40			No
115	9-11-81		1.00	Ritten-(+) Fog	b	56.8	3.6	40			Yes
116	9-11-81		1.00	Ritten-Fan Only	t			40			Yes
117	9-11-81		1.00	Ritten-Uncharged	b	56.8	3.6	40			No
118	9-11-81		1.00	Ritten-(+) Fog	t	56.8	3.6	40			No
119	9-11-81		1.00	Ritten-(+) Fog	b	56.8	3.6	40			No
120	9-11-81		1.00	Ritten-Fan Only	b			40			No
121	9-11-81		1.00	Ritten-Uncharged	b	56.8	3.6	40			No
122	9-11-81		1.00	Ritten-(+) Fog	t	56.8	3.6	40			Yes
123	9-11-81		1.00	Ritten-Fan Only	b			40			Yes
124	9-11-81		1.00	Ritten-Uncharged	b	56.8	3.6	40			No
125	9-11-81		1.00	Ritten-(+) Fog	b	56.8	3.6	40			No
126	9-11-81		1.00	Ritten-(+) Fog	t	56.8	3.6	40			No
127	9-11-81		1.00	Both-Fan Only	b			40		50	No
128	9-11-81		1.00	Both-Uncharged	b	56.8	3.6	40	56.8	50	No
129	9-11-81		1.00	Both-(+) Fog	b	56.8	3.6	40	56.8	50	Yes
130	9-11-81		1.00	Both-Fan Only	b			40		50	Yes
131	9-11-81		1.00	Both-Uncharged	b	56.8	3.6	40	56.8	50	No
132	9-11-81		1.00	Both-(+) Fog	b	56.8	3.6	40	56.8	50	No

*Refer to Figure 22.
†Values are per individual fogger.

comparison of results, all of the foggers were operated at the same water flow rate of approximately 56.8 ℓ/hr (15 gph). Fan speed was kept to the minimum required to project the fog to the fume.

The sampling procedure was essentially the same for each test. Prior to each set of tests the hi-vol flow controllers were set to approximately 1.1 m^3/min and preweighed filters were placed into the samplers. After the torch cut had begun and the plume formed, the foggers were adjusted to the desired conditions. The platform was then moved so that the samplers were in the visually thickest part of the plume. The samplers were started simultaneously by a circuit breaker at ground level and allowed to run approximately 1 minute since sufficient material for analysis was collected on the filters during this time period. At the end of the sampling period, the samplers were shut off simultaneously, the platform moved out of the plume, and the filters removed from the hi-vols and placed into envelopes.

Test Results

Following completion of all the test runs, the hi-vol filters were returned to the TRC chemistry laboratory, desiccated, and weighed. The resulting filter loadings were then used in conjunction with the sampler flow rates to calculate particulate matter concentrations.

The next step in the analysis procedure consisted of determining the arithmetic mean particulate matter concentration for each test condition (uncontrolled, Ritten fan only, etc.) for each of the four hi-vols, for the standard hi-vols combined, and for the hi-vols with the SSIs combined. The resulting values are presented in Table 24. The combined sampler data are graphically presented in Figure 23. Included in these mean concentration calculations are the total concentrations from the samplers when a cascade

TABLE 24. BUTLER WORKS TORCH CUTTING OPERATION: ARITHMETIC MEAN PARTICULATE MATTER CONCENTRATIONS UNDER VARIOUS TEST CONDITIONS ($\mu g/m^3$)

Test Condition	Particulate Concentrations As Measured By: Standard Hi-Vol (7112)	Standard Hi-Vol (7101)	Standard Hi-Vols Combined	Hi-Vol With SSI (7088)	Hi-Vol With SSI (7105)*	Hi-Vols With SSIs Combined
Uncontrolled	384913	276300	330606	250178	168584	209381
Ritten-Fan Only	201838	260695	230426	58622	159191	108906
Ritten-Uncharged	130549	210507	170528	73971	190102	132036
Ritten-(+) Fog	148538	213847	181192	92482	167531	130006
Ritten-(-) Fog	92147	182017	140078	59569	112128	85848
AV-Fan Only	79109	190792	133588	31560	111431	71496
AV-Uncharged	79877	129547	104134	22254	78576	50415
AV-(+) Fog	107043	172377	138950	40499	98536	68843
Both-Fan Only†	22955	42422	32688	13067	25471	19269
Both-Uncharged†	27192	56504	36963	43084	34873	40347
Both-(+) Fog†	18673	36198	24514	25427	15185	22013

* Also includes the total concentrations from runs where a cascade impactor was used in this sampler.

† Mean concentrations are based on limited data points.

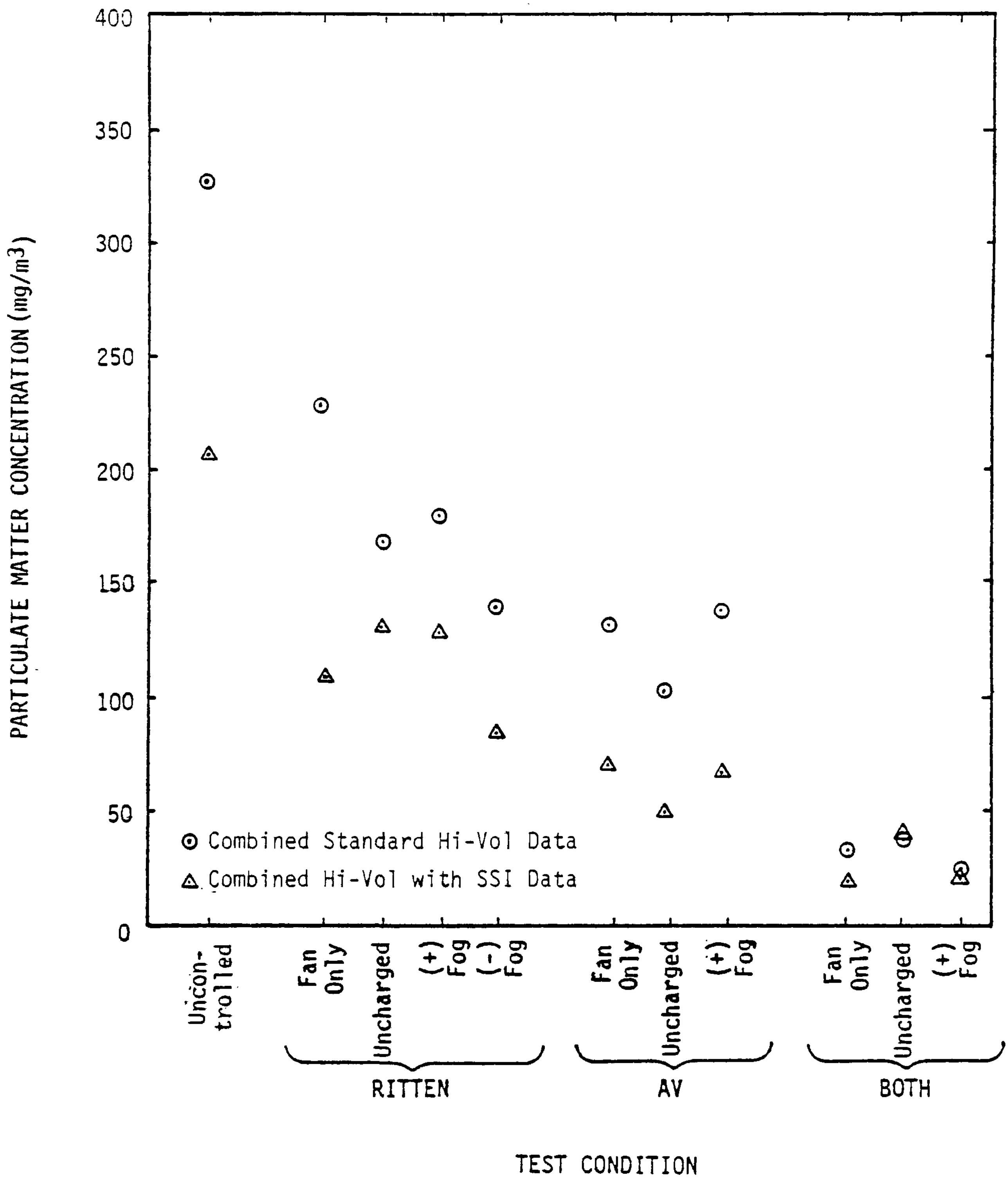


Figure 23. Arithmetic mean particulate matter concentrations under various test conditions (ug/m^3) - torch cutting operation.

impactor was used with an SSI. In the calculation of these values, several data points were omitted when it was obvious that the concentrations were erroneous because either the torch crossed a support strut and thus created excess emissions or because of foreign material falling onto the filter from the hi-vol housing. (The data points that were eliminated from the analysis are denoted by asterisks in Appendix E.)

Before any conclusions may be drawn from these data, the limitations of the test setup must be considered. First, the samplers were placed where the plume visually appeared the thickest. This undoubtably added a degree of uncertainty and inconsistency in the data. Second, the mass recorded by the samplers was dictated by the dispersion characteristics of the plume and whether or not a sampler was in the path of the plume. This, in turn, depended on the air currents in the building. Third, as discussed previously, the four foggers had to be placed on the same side of the cutting operation because of space limitations. As a result, the fan air redirected the emissions from the operation back toward the wall behind the cutting table. Since the samplers were restricted as to how near the wall they could be placed, this redirection by the fan air caused part of the plume to "miss" the samplers. This redirection is evident in the data presented in Figure 23 which show, for the combined standard hi-vol data, a reduction from the background level of 30 percent for the Ritten fan only case, 60 percent for the AV fan only case, and 90 percent for the case where all four fans were operated at the same time. An examination of the hi-vol with SSI data shows a similar trend with even greater percent reductions, which is logical since the fan air would tend to blow the finer material further. Because of this redirection, it would not be correct to relate controlled emission levels to uncontrolled emission levels.

Introduction of water droplets to the fan air reduces the magnitude of the redirection force on the dust since a percentage of the fan air momentum is used in "pushing" the water towards the emission point. This is evident in the data, particularly with the finer material (SSI data) where it can be seen that the measured concentrations actually increase between the fan only and uncharged test condition for the Ritten and both foggers control conditions. The water sprays are probably reducing the dust levels, but this reduction could not be measured owing to limitations of the sampling setup.

The only mean concentrations that are directly comparable are the ones obtained using charged fog and the ones obtained using uncharged fog, since the only difference is the sign of the charge on the water droplets. Aside from the case where all four foggers were used (the data are too limited to draw realistic conclusions), an examination of the mean concentrations (Figure 23) indicates that the emission levels increased when a positive charge was applied to the water spray, indicating that the torch cutting emissions also carry a positive charge. This situation is unusual since Hoenig found that most industrial dusts carry a negative charge.[1] As a result, the positively charged fog repelled the dust rather than attracted it and the fog was rendered less efficient than an uncharged water spray. Examining the results using negatively charged fog indicates that this conclusion is correct. The levels decreased when a negative charge was applied to the water spray. The amount of reduction was 18 percent for the material less than 30 μm (standard hi-vol) and 35 percent for the material less than 15 μm (hi-vol with SSI) using the Ritten foggers. The AV foggers were not operated with a negatively charged fog.

The cascade impactor data were not useful, except from a total concentration standpoint, because they were obtained for only a few types of test conditions: Ritten fan only, Ritten positive charge, Ritten negative charge, AV fan only, and AV positive charge. It was not realized during the tests that the fan only condition could not be realistically used for comparison since this test condition had been used as the baseline in the previous EPA-sponsored test programs. Therefore, to reduce sampling time and data reduction costs, only a few runs were performed with the cascade impactor and none of these runs were conducted under uncharged fog conditions. It may be noted, however, that the levels recorded using negative fog were lower than the levels recorded using positive fog, supporting the positively charged plume hypothesis.

PHASE II, TEST #6 - IRON AND STEEL PLANT: RECYCLE PLANT TRANSFER OPERATION

The transfer of sinter fines from one conveyor belt to another results in fugitive emissions. The objective of the sixth fogger field test was to evaluate the effect of charged fog on such emissions. The site chosen for the test was a transfer point located at the recycle plant of Armco's Middletown Works in Middletown, Ohio. The field testing was performed during the period from October 2 to 14, 1981, with a total of 100 test runs.

Site and Process Descriptions

As part of a material recycling process, iron ore fines are collected from the blast furnace wet scrubbers and the open hearth slag crushing operation, combined with coke dust, and are fed onto a large conveyor. The conveyor moves slowly through a natural gas-fired oven which agglomerates the material into sinter. The sinter is then broken into small pieces and cooled by blowing air though it. Once the sinter is crushed, cooled and sized, it is returned to the blast furnace and used as charging material because of its iron content and fluxing characteristics.

Due to the mechanical agitation of the sinter on the various conveyor belts throughout the recycle plant, small pieces of material are broken off. This fine material is collected from several conveyor areas and combined onto a separate conveyor system. This system transports the fine material back to the beginning of the recycle operation where it is reintroduced as input material.

As part of this fine material conveyor system, the material is transferred several times from one conveyor belt to another. One of these conveyor transfer points was used as the location for the fogger tests. Fugitive dust rises up around the transfer area because of the dropping of the material onto the next conveyor belt. This particular transfer point has a drop height of approximately 1.2 meters.

Equipment Placement

The equipment used for all of the fogger test runs included four hi-vols, two of which were fitted with SSIs, the two Ritten foggers, and the two AV foggers. In addition, a hi-vol fitted with a cyclone preseparator (CYC) and a cascade impactor (CI) was used during the majority of the tests.

The two standard hi-vols and the two hi-vols with SSIs were located on a metal grating directly above the transfer point. The grating was supported by scaffolding and was approximately 2.6 m above the level of the discharge conveyor. The hi-vol with the CYC/CI was placed on the existing platform at the same level as the discharge conveyor. For the fogger tests, one Ritten and one AV fogger were placed under cover in an existing structure adjacent to the transfer point. The second AV fogger was placed opposite the first on the existing platform. Scaffolding was erected adjacent to the existing platform to support the second Ritten fogger so that it too would be positioned opposite the first. All four foggers were on the same level.

The transfer operation, scaffolding and equipment positions are displayed in the photographs presented in Figures 24, 25 and 26. Note in Figures 24 and 25 the wind screen material and tarpaulins that were added to the test set-up to reduce the effects of wind on dust in the region. A sketch of the equipment positions including hi-vol serial numbers is presented in Figure 27.

Test Program and Procedure

The test program consisted of 100 test runs during 8 days of testing. The test conditions are presented in Table 25. To help ensure a valid comparison of results, all of the foggers were operated at the same water flow rate of approximately 56.8 ℓ/hr (15 gph). Fan speed was kept to the minimum required to project the fog to the transfer point.

The sampling procedure was essentially the same for each test. Prior to each test run, preweighed filters were placed into the samplers. For the controlled tests, the foggers were then turned on and adjusted to the desired conditions. The samplers were all started simultaneously through a control box. During the duration of the test, the samplers' flow rates were monitored to ensure that the flow controllers were maintaining the flow at approximately 1.1 m^3/min. Following completion of the test run, the samplers were shut off simultaneously and the filters were removed from the hi-vols and placed into individual envelopes.

Test Results

Following completion of all the test runs, the hi-vol filters were returned to the TRC chemistry laboratory, desiccated and weighed. The resulting filter loadings were then used in conjunction with the sampler flow rates to calculate particulate matter concentrations.

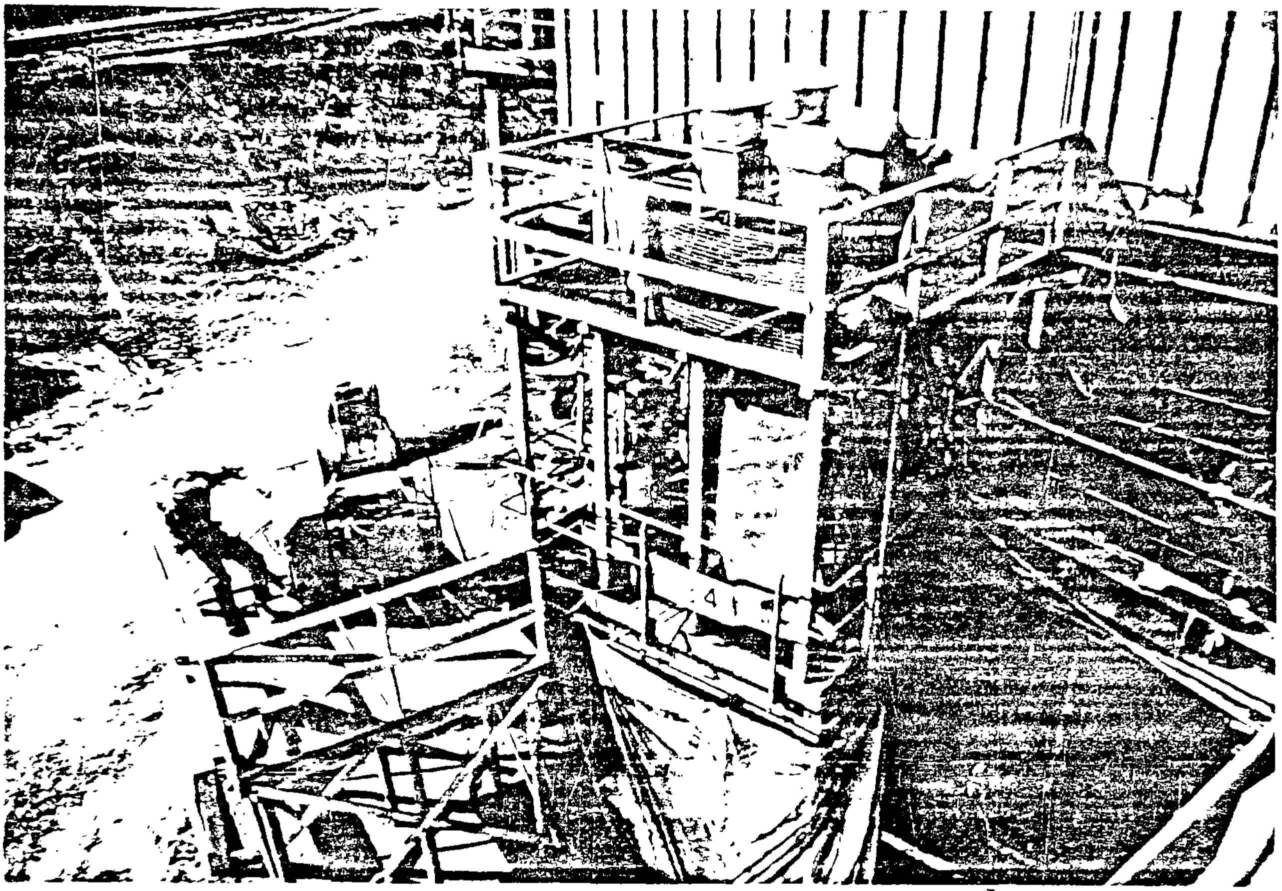


Figure 24. Equipment locations for recycle plant transfer operation test: elevated samplers and outside corner foggers.

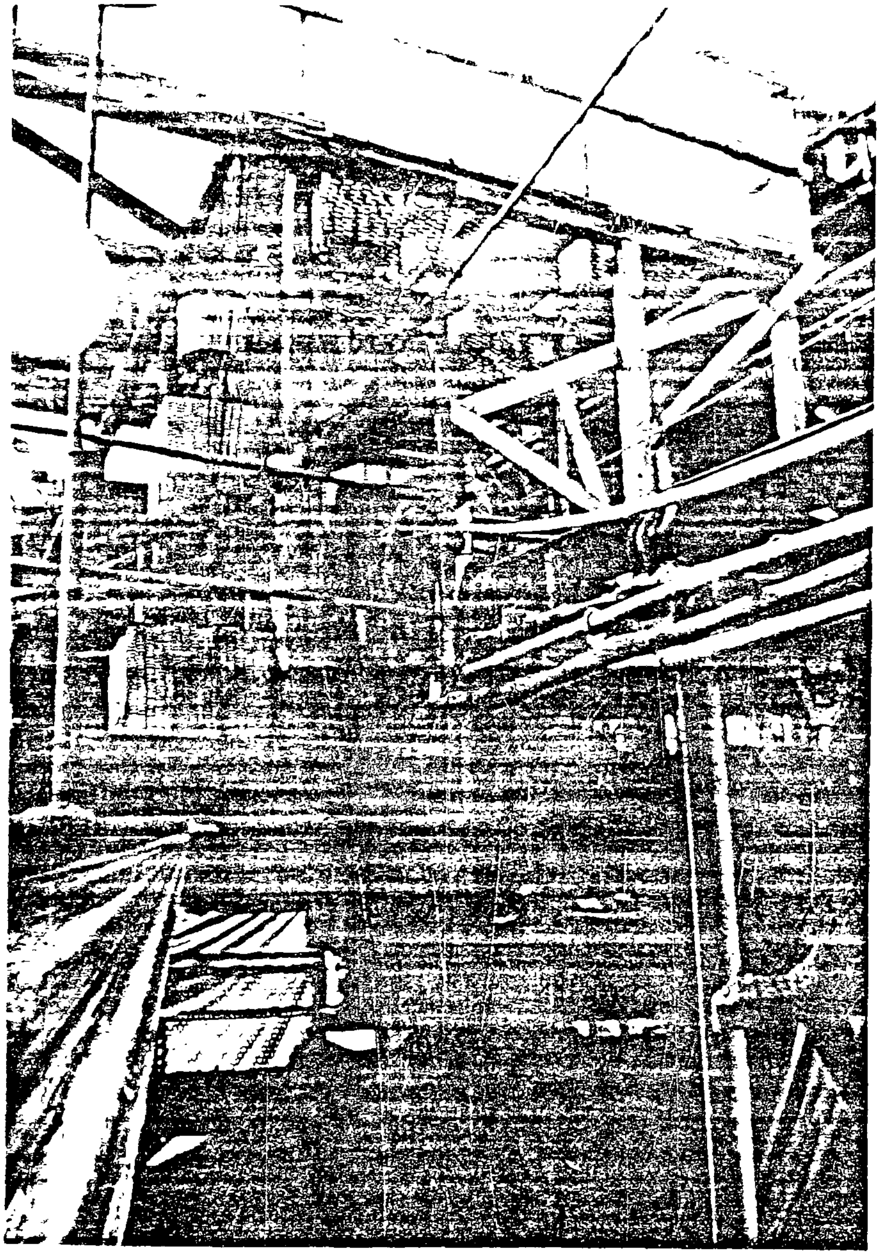


Figure 25. Equipment locations for recycle plant transfer operation test: hi-vol with CYC/CI.

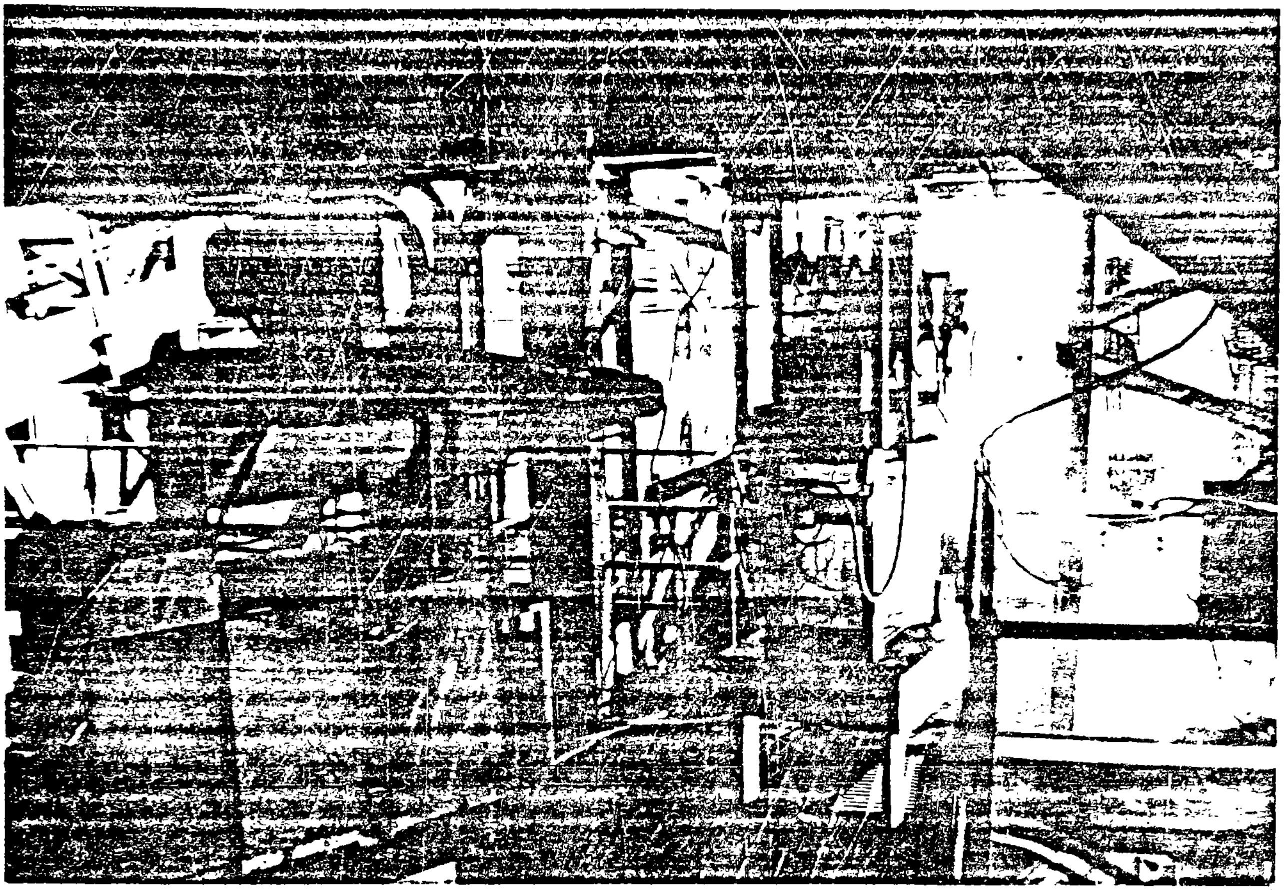


Figure 26. Equipment locations for recycle plant transfer operation test: inside corner foggers.

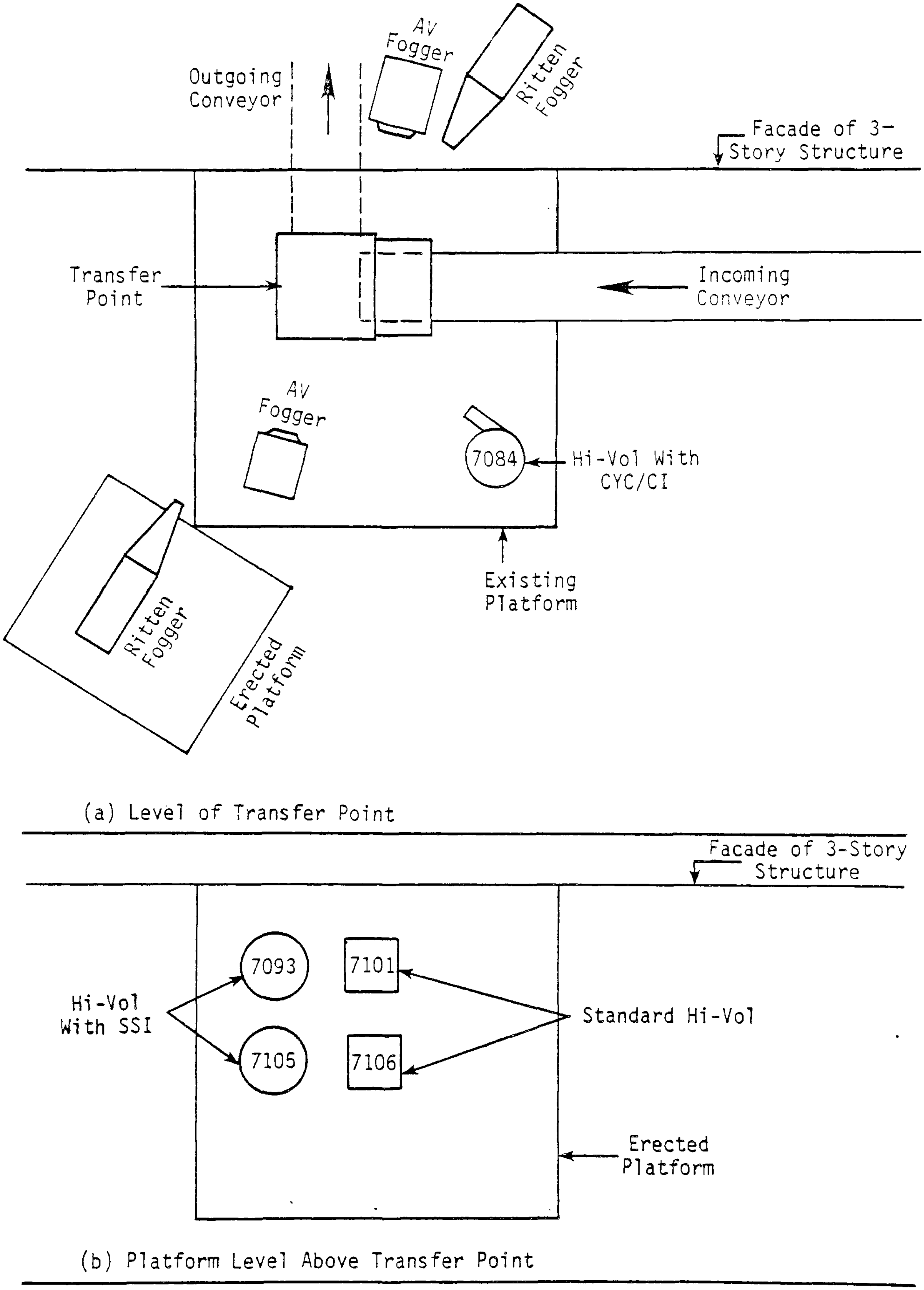


Figure 27. Equipment location sketch for recycle plant transfer operation test

TABLE 25. TEST CONDITIONS - RECYCLE PLANT TRANSFER OPERATION

Run No.	Date	Start Time	Duration of run (min)	Type of Test	Equipment Position*	Ritten Foggers: Water Flow (ℓ/hr)†	Ritten Foggers: Air-flow (m^3/hr)†	Ritten Foggers: Fan Speed (% of max.)	AV Foggers: Water Flow (ℓ/hr)†	AV Foggers: Fan Speed (% of max.)	Cascade Impactor
1	10-2-81	1315	5	Uncontrolled	a						No
2	10-2-81	1343	5	AV-Fan Only	a					50	No
3	10-2-81	1409	5	Ritten-Fan Only	a			30			No
4	10-2-81	1430	5	AV-Uncharged	a				56.8	50	No
5	10-2-81	1523	5	Ritten-Uncharged	a	56.8	3.8	30			No
6	10-2-81	1548	5	AV-(+) Fog	a				56.8	50	No
7	10-2-81	1613	5	Ritten-(+) Fog	a	56.8	3.6	30			No
8	10-2-81	1638	5	Uncontrolled	a						No
9	10-3-81	1000	10	Uncontrolled	a						No
10	10-3-81	1023	5	Uncontrolled	a						No
11	10-3-81	1049	5	AV-Fan Only	a					50	No
12	10-6-81	1340	5	Uncontrolled	a						No
13	10-6-81	1355	5	Uncontrolled	a						No
14	10-6-81	1415	5	Ritten-Fan Only	a			30			No
15	10-6-81	1435	5	AV-Fan Only	a					50	No
16	10-6-81	1500	5	Ritten-Uncharged	a	56.8	3.8	30			No
17	10-6-81	1515	5	Ritten-(+) Fog	a	56.8	3.8	30			No
18	10-6-81	1535	5	Uncontrolled	a						No
19	10-6-81	1615	5	Ritten-(-) Fog	a	56.8	3.8	30			No
20	10-6-81	1640	5	Ritten-Fan Only	a			30			No
21	10-6-81	1700	5	Ritten-Uncharged	a	56.8	3.8	30			No
22	10-6-81	1720	5	Ritten-(-) Fog	a	56.8	3.8	30			No
23	10-7-81	1250	5	Uncontrolled	a						No
24	10-7-81	1325	SSIs-5 others-5.45	Ritten-Fan Only	a			30			No
25	10-7-81	1350	SSIs-5 others-6.12	Ritten-Uncharged	a	56.8	3.8	30			No
26	10-7-81	1420	SSIs-6 others-7.75	Ritten-(-) Fog	a	56.8	3.8	30			No
27	10-7-81	1520	5	AV-(+) Fog	a				56.8	50	No
28	10-7-81	1540	5	AV-Fan Only	a					50	No
29	10-7-81	1600	5	AV-Uncharged	a				56.8	50	No

*Refer to Figure 27.
†Values are per individual fogger.

TABLE 25. TEST CONDITIONS - RECYCLE PLANT TRANSFER OPERATION (Continued)

Run No.	Date	Start Time	Duration of run (min)	Type of Test	Equipment Position*	Ritten Foggers Water Flow (ℓ/hr)†	Ritten Foggers Air-flow (m^3/hr)†	Ritten Foggers Fan Speed (% of max.)	AV Foggers Water Flow (ℓ/hr)†	AV Foggers Fan Speed (% of max.)	Cascade Impactor
30	10-7-81	1655	5	Uncontrolled	a						No
31	10-7-81	1715	5	AV-Fan Only	a					50	No
32	10-7-81	1735	4.75	AV-(+) Fog	a				56.8	50	No
33	10-7-81	1825	SSIs-5 others-5.5	AV-Uncharged	a				56.8	50	No
34	10-8-81	0935	SSIs-4.57 others-5.4	Uncontrolled	a						Yes
35	10-8-81	1012	SSIs-5 others-5.08	AV-Fan Only	a					50	Yes
36	10-8-81	1040	SSIs-5 others-5.18	Ritten-Fan Only	a			30			Yes
37	10-8-81	1115	SSIs-5 others-5.18	AV-(+) Fog	a				56.8	50	Yes
38	10-8-81	1155	SSIs-5 others-5.12	Ritten-(+) Fog	a	56.8	3.8	30			Yes
39	10-8-81	1225	SSIs-4.83 others-4.9	AV-Uncharged	a				56.8	50	Yes
40	10-8-81	1405	SSIs-5 others-5.33	Ritten-Uncharged	a	56.8	3.8	30			Yes
41	10-8-81	1445	SSIs-5 others-5.17	Uncontrolled	a						Yes
42	10-8-81	1520	SSIs-5 others-5.25	Ritten-Fan Only	a			30			Yes
43	10-8-81	1550	SSIs-5 others-5.17	Ritten-Uncharged	a	56.8	3.8	30			Yes
44	10-8-81	1620	5	Ritten-(+) Fog	a	56.8	3.8	30			Yes
45	10-8-81	1645	5	AV-Fan Only	a					50	Yes
46	10-8-81	1710	5	AV-Uncharged	a				56.8	50	Yes
47	10-8-81	1735	5	AV-(+) Fog	a				56.8	50	Yes
48	10-8-81	1805	5	Uncontrolled	a						Yes
49	10-12-81	0920	5	Ritten-Fan Only	a			30			Yes (2)
50	10-12-81	0950	7	Ritten-Uncharged	a	56.8	3.8	30			Yes (2)
51	10-12-81	1020	7	Ritten-(+) Fog	a	56.8	3.8	30			Yes (2)
52	10-12-81	1105	7	Ritten-(-) Fog	a	56.8	3.8	30			Yes (2)
53	10-12-81	1140	7	Uncontrolled	a						Yes (2)
54	10-12-81	1300	7	AV-Fan Only	a					50	Yes (2)

*Refer to Figure 27.
†Values are per individual fogger.

TABLE 25. TEST CONDITIONS - RECYCLE PLANT TRANSFER OPERATION (Continued)

						Ritten Foggers			AV Foggers		
Run No.	Date	Start Time	Duration of run (min)	Type of Test	Equipment Position*	Water Flow (ℓ/hr)†	Air-flow (m^3/hr)†	Fan Speed (% of max.)	Water Flow (ℓ/hr)†	Fan Speed (% of max.)	Cascade Impactor
55	10-12-81	1320	10	AV-Uncharged	a				56.8	50	Yes (2)
56	10-12-81	1410	10	AV-(+) Fog	a				56.8	50	Yes (2)
57	10-12-81	1435	7	Uncontrolled	a						No
58	10-12-81	1505	7	Ritten-Fan Only	a			30			Yes
59	10-12-81	1530	10	Ritten-Uncharged	a	56.8	3.8	30			Yes
60	10-12-81	1615	10	Ritten-(+) Fog	a	56.8	3.8	30			Yes
61	10-13-81	1000	SSIs-9.25 others-10	Ritten-Fan Only	a			30			Yes
62	10-13-81	1025	10	Ritten-Uncharged	a	56.8	3.8	30			Yes
63	10-13-81	1050	10	Ritten-(+) Fog	a	56.8	3.8	30			Yes
64	10-13-81	1110	10.25	Ritten-(-) Fog	a	56.8	3.8	30			Yes
65	10-13-81	1125	10	Uncontrolled	a						Yes
66	10-13-81	1240	15	AV-Fan Only	a					50	Yes
67	10-13-81	1305	15	AV-Uncharged	a				56.8	50	Yes
68	10-13-81	1325	15	AV-(+) Fog	a				56.8	50	Yes
69	10-13-81	1345	15	Ritten-Fan Only	a			30			Yes
70	10-13-81	1405	15	Ritten-Uncharged	a	56.8	3.8	30			Yes
71	10-13-81	1425	12	Ritten-(+) Fog	a	56.8	3.8	30			Yes
72	10-13-81	1450	15	AV-Fan Only	a					50	Yes
73	10-13-81	1515	SSIs-15 others-15.5	AV-Uncharged	a				56.8	50	Yes
74	10-13-81	1545	15.42	AV-(+) Fog	a				56.8	50	Yes
75	10-13-81	1605	15	Uncontrolld	a						Yes
76	10-14-81	0845	15	AV-Fan Only	a					50	Yes
77	10-14-81	0905	15	AV-Uncharged	a				56.8	50	Yes
78	10-14-81	0925	15	AV-(+) Fog	a				56.8	50	Yes
79	10-14-81	0950	15	Ritten-Fan Only	a			30			Yes
80	10-14-81	1010	15	Ritten-Uncharged	a	56.8	3.8	30			Yes
81	10-14-81	1025	15	Ritten-(+) Fog	a	56.8	3.8	30			Yes
82	10-14-81	1050	15	Ritten-(-) Fog	a	56.8	3.8	30			Yes
83	10-14-81	1110	15	Uncontrolled	a						Yes
84	10-14-81	1240	15	AV-Fan Only	a					50	Yes
85	10-14-81	1300	15	AV-Uncharged	a				56.8	50	Yes
86	10-14-81	1320	15	AV-(-) Fog	a				56.8	50	Yes
87	10-14-81	1340	15	Ritten-Fan Only	a			30			Yes
88	10-14-81	1400	15	Ritten-Uncharged	a	56.8	3.8	30			Yes

*Refer to Figure 27.
†Values are per individual fogger.

TABLE 25. TEST CONDITIONS - RECYCLE PLANT TRANSFER OPERATION (Continued)

						Ritten Foggers			AV Foggers		
Run No.	Date	Start Time	Duration of run (min)	Type of Test	Equipment Position*	Water Flow (ℓ/hr)†	Air-flow (m^3/hr)†	Fan Speed (% of max.)	Water Flow (ℓ/hr)†	Fan Speed (% of max.)	Cascade Impactor
89	10-14-81	1420	14.25	Ritten-(+) Fog	a	56.8	3.8	30			Yes
90	10-14-81	1440	15	Ritten-(-) Fog	a	56.8	3.8	30			Yes
91	10-14-81	1500	15	Uncontrolled	a						Yes
92	10-14-81	1525	10	Both-Fan Only	a			30		50	Yes
93	10-14-81	1545	9	Both-Uncharged	a	56.8	3.8	30	56.8	50	Yes
94	10-14-81	1605	12	Both-(+) Fog	a	56.8	3.8	30	56.8	50	Yes
95	10-14-81	1625	10	Both-Fan Only	a			30		50	Yes
96	10-14-81	1645	15	Both-Uncharged	a	56.8	3.8	30	56.8	50	Yes
97	10-14-81	1705	15	Both-(+) Fog	a	56.8	3.8	30	56.8	50	Yes
98	10-14-81	1725	15	Both-Fan Only	a			30		50	Yes
99	10-14-81	1750	15	Both-Uncharged	a	56.8	3.8	30	56.8	50	Yes
100	10-14-81	1810	15	Both-(+) Fog	a	56.8	3.8	30	56.8	50	Yes

*Refer to Figure 27.
†Values are per individual fogger.

The next step in the analysis procedure was to group the concentrations by test day since it was obvious during the testing that some days were much dustier than other days. The quantity of emissions generated at this site was highly dependent on meteorological factors such as wind speed, wind direction, and precipitation and thus all the data could not be grouped together as in the case of the torch cutting operation data. Table 26 presents the arithmetic mean daily concentrations for each test condition for the standard hi-vols combined and the hi-vols with SSIs combined (the samplers located above the operation on the constructed platform). Table 27 presents the arithmetic mean daily concentrations for each test condition for the hi-vol with the cyclone preseparator and cascade impactor (the sampler located adjacent to the transfer point on the existing platform).

Examination of the data presented in Table 26 reveals no definite trends. While a few days appear to display the expected results (i.e., emission levels with fan only greater than emission levels with uncharged fog, greater than emission levels with charged fog), most of the days display highly erratic results. This wide variability in results from the samplers above the operation may be due to the influence of other dust sources near the transfer operation. Dust from the ground surrounding the operation was frequently reentrained by the action of wind and vehicular traffic; this reentrained material could have affected the recorded emission levels. Additionally, downwashed material seemed to be impacting the samplers occasionally from a shaker-screen operation located above the level of the samplers. Because of the uncertainty of the accuracy of the results, further analysis of the data presented in Table 26 does not seem warranted.

The sampler with the CYC/CI located adjacent to the operation was not as subject to the influence of other dust sources and an examination of the data presented in Table 27 reveals some possible trends. However, it should be

TABLE 26. RECYCLE PLANT TRANSFER OPERATION - STANDARD HI-VOL AND SSI DATA: ARITHMETIC MEAN PARTICULATE MATTER CONCENTRATIONS UNDER VARIOUS TEST CONDITIONS ($\mu g/m^3$)

Date	Test Condition	Standard Hi-Vols Combined (7101 and 7106)	Hi-Vols with SSIs Combined (7093 and 7105)	Number of Runs
10-2-81	Uncontrolled	118195	35771	2
	Ritten-Fan Only	55025	26064	1
	Ritten-Uncharged	42038	15319	1
	Ritten-(+) Fog	47431	19792	1
	Ritten-(-) Fog	-	-	0
	AV-Fan Only	344974	113809	1
	AV-Uncharged	53896	18433	1
	AV-(+) Fog	39577	15102	1
10-3-81	Uncontrolled	148445	37238	2
	Ritten-Fan Only	-	-	0
	Ritten-Uncharged	-	-	0
	Ritten-(+) Fog	-	-	0
	Ritten-(-) Fog	-	-	0
	AV-Fan Only	58023	13249	1
	AV-Uncharged	-	-	0
	AV-(+) Fog	-	-	0
10-6-81	Uncontrolled	70265	35958	3
	Ritten-Fan Only	78307	39291	2
	Ritten-Uncharged	108567	43269	2
	Ritten-(+) Fog	101470	42201	2
	Ritten-(-) Fog	85176	42915	1
	AV-Fan Only	161645	48577	1
	AV-Uncharged	-	-	0
	AV-(+) Fog	-	-	0
10-7-81	Uncontrolled	132160	84035	2
	Ritten-Fan Only	107656	54845	1
	Ritten-Uncharged	62154	27015	1
	Ritten-(+) Fog	-	-	0
	Ritten-(-) Fog	102527	36185	1
	AV-Fan Only	257877	78549	2
	AV-Uncharged	158406	58139	2
	AV-(+) Fog	111058	37948	1

TABLE 26. (Continued) RECYCLE PLANT TRANSFER OPERATION - STANDARD HI-VOL AND SSI DATA: ARITHMETIC MEAN PARTICULATE MATTER CONCENTRATIONS UNDER VARIOUS TEST CONDITIONS ($\mu g/m^3$)

Date	Test Condition	Standard Hi-Vols Combined (7101 and 7106)	Hi-Vols with SSIs Combined (7093 and 7105)	Number of Runs
10-8-81	Uncontrolled	141079	46593	3
	Ritten-Fan Only	129856	51820	2
	Ritten-Uncharged	66101	20334	2
	Ritten-(+) Fog	71574	23861	2
	Ritten-(-) Fog	-	-	0
	AV-Fan Only	164129	63684	2
	AV-Uncharged	35726	10880	2
	AV-(+) Fog	104590	46879	2
10-12-81	Uncontrolled	26752	9870	2
	Ritten-Fan Only	32765	8634	2
	Ritten-Uncharged	10893	2942	2
	Ritten-(+) Fog	17037	3448	2
	Ritten-(-) Fog	26120	7526	1
	AV-Fan Only	9003	2410	1
	AV-Uncharged	24734	5194	1
	AV-(+) Fog	14648	3497	1
10-13-81	Uncontrolled	2045	1174	2
	Ritten-Fan Only	2481	1009	2
	Ritten-Uncharged	2109	760	2
	Ritten-(+) Fog	1721	570	2
	Ritten-(-) Fog	870	200	1
	AV-Fan Only	1753	921	2
	AV-Uncharged	1646	766	2
	AV-(+) Fog	1424	678	2
10-14-81	Uncontrolled	1491	334	2
	Ritten-Fan Only	3389	1323	2
	Ritten-Uncharged	4181	1545	2
	Ritten-(+) Fog	3595	2474	2
	Ritten-(-) Fog	4938	1322	2
	AV-Fan Only	5779	2028	2
	AV-Uncharged	1995	973	2
	AV-(+) Fog	2044	1015	2
	Both-Fan Only	1617	938	3
	Both-Uncharged	855	284	3
	Both-(+) Fog	571	242	3

TABLE 27. RECYCLE PLANT TRANSFER OPERATION - CYC/CI DATA: ARITHMETIC MEAN PARTICULATE MATTER CONCENTRATIONS UNDER VARIOUS TEST CONDITIONS (μg/m³)

Date	Test Condition	HI-VOL WITH CYC/CI (7084) Stage 1	Stage 2	Stage 3	Stage 4	Backup	Total	Number of Runs
10-6-81	Uncontrolled						81807	3
	Ritten-Fan Only						92987	2
	Ritten-Uncharged	CYCLONE PRESEPARATOR ONLY					60737	2
	Ritten-(+) Fog	NO CASCADE IMPACTOR					55117	1
	Ritten-(-) Fog						47667	2
	AV-Fan Only						119217	1
	AV-Uncharged						-	0
	AV-(+) Fog						-	0
10-7-81	Uncontrolled						193267	2
	Ritten-Fan Only						229828	1
	Ritten-Uncharged	CYCLONE PRESEPARATOR ONLY					154590	1
	Ritten-(+) Fog	NO CASCADE IMPACTOR					-	0
	Ritten-(-) Fog						87199	1
	AV-Fan Only						186418	2
	AV-Uncharged						158899	2
	Av-(+) Fog						129437	2
10-8-81	Uncontrolled	7366	7530	5430	4405	47705		3
	Ritten-Fan Only	11385	12124	7356	5541	34329		2
	Ritten-Uncharged	5007	6725	3992	2655	12829		2
	Ritten-(+) Fog	5058	8646	3715	2134	7615		2
	Ritten-(-) Fog	-	-	-	-	-		0
	AV-Fan Only	10764	13858	6900	4277	15226		2
	AV-Uncharged	3224	4391	2443	1557	4673		2
	AV-(+) Fog	7961	9713	5571	4748	32973		2
10-12-81	Uncontrolled	1340	785	676	*	5431		1
	Ritten-Fan Only	5163	6099	4982	5312	83489		2
	Ritten-Uncharged	2249	3541	2119	1574	16051		2
	Ritten-(+) Fog	2429	2357	1562	1128	10016		2
	Ritten-(-) Fog	3122	2920	1876	1199	5520		1
	AV-Fan Only	1448	973	914	985	8309		1
	AV-Uncharged	1324	1589	2063	1212	9607		1
	AV-(+) Fog	2023	2544	2785	2954	54160		1

*Mass of material on filter less than sensitivity of balance.

TABLE 27. (Continued) RECYCLE PLANT TRANSFER OPERATION - CYC/CI DATA: ARITHMETIC MEAN PARTICULATE MATTER CONCENTRATIONS UNDER VARIOUS TEST CONDITIONS (μg/m³)

Date	Test Condition	HI-VOL WITH CYC/CI (7084) Stage 1	Stage 2	Stage 3	Stage 4	Backup	Total	Number of Runs
10-13-81	Uncontrolled	*	*	*	*	1886		1
	Ritten-Fan Only	*	*	*	*	1335		1
	Ritten-Uncharged	677	672	*	315	1690		2
	Ritten-(+) Fog	675	679	766	494	2768		2
	Ritten-(-) Fog	*	550	*	*	1980		1
	AV-Fan Only	405	419	264	255	1123		2
	AV-Uncharged	*	*	*	*	991		2
	AV-(+) Fog	*	383	*	*	1667		2
10-14-81	Uncontrolled	707	680	464	439	3522		2
	Ritten-Fan Only	901	1187	843	646	2883		2
	Ritten-Uncharged	1204	1831	1094	758	3414		2
	Ritten-(+) Fog	1014	1627	797	614	2653		2
	Ritten-(-) Fog	924	1029	642	418	2195		2
	AV-Fan Only	1426	2389	1336	909	3788		2
	AV-Uncharged	940	1589	851	573	1733		2
	AV-(+) Fog	801	985	699	421	2188		2
	Both-Fan Only	984	1404	935	720	6471		3
	Both-Uncharged	939	1118	1037	731	5749		3
	Both-(+) Fog	981	780	702	672	5650		3

*Mass of material on filter less than sensitivity of balance.

noted that wide variations still occurred between similar tests. For example, on October 6, three measurements of the background dust levels were made. During the three runs, the CYC/CI recorded values of 24,028 $\mu g/m^3$, 178,302 $\mu g/m^3$ and 43,092 $\mu g/m^3$, respectively. These data show some problems relating to the method of sampling, or to the impact of external parameters, or both. Nonetheless, some possible trends are discussed in the following paragraphs.

The sampling on October 6 and 7 was performed with only the cyclone preseparator and no cascade impactor. Using the fan only and uncharged cases as the baselines, percent reductions in concentration levels were calculated for the 2 days (Table 28). (Uncontrolled levels are not useful for comparison since the uncontrolled dust from the operation rises up and away from the sampler while the controlled dust, theoretically, is kept at the platform level.) Significant reductions were obtained for the particle size range sampled (approximately less than 6 µm) for both fog devices with the Ritten foggers performing slightly better (based on the limited data).

The sampling on October 8, 12, 13 and 14 was performed with a cascade impactor placed inside the sampler with the cyclone preseparator. Table 29 presents the percent reductions from the fan only and uncharged concentration levels for each stage of the impactor for October 8, 12 and 14. The data from October 13 are insufficient to perform this analysis. Perhaps the most important values shown on this table are the reductions from charging the spray. The Ritten foggers performed quite well, particularly on the small particle ranges (the respirable range), with efficiency increases of 20 to 40 percent for positive fog, and 20 to 65 percent for negative fog.

TABLE 28. RESULTS OF FOGGER TEST AT RECYCLE PLANT TRANSFER OPERATION: SAMPLER WITH CYCLONE PRESEPARATOR

Test Condition	October 6, 1981			October 7, 1981		
	Mean Particulate Matter Concentration (μg/m³)	Percent Reduction from Fan Only Condition	Percent Reduction from Uncharged Condition	Mean Particulate Matter Concentration (μg/m³)	Percent Reduction from Fan Only Condition	Percent Reduction from Uncharged Condition
Ritten - Fan Only	92987	-		229828	-	
Ritten - Uncharged	60737	34.7	-	154590	32.7	-
Ritten - (+) Fog	55117	40.7	9.3	*	*	*
Ritten - (-) Fog	47667	48.7	21.5	87199	62.1	43.6
AV - Fan Only				186418	-	
AV - Uncharged				158899	14.8	-
AV - (+) Fog				129437	30.6	18.5

*No data for this test condition.

TABLE 29. RESULTS OF FOGGER TEST AT RECYCLE PLANT TRANSFER OPERATION: SAMPLER WITH CYCLONE PRESEPARATOR AND CASCADE IMPACTOR

		October 8, 1981		October 12, 1981		October 14, 1981	
CI Stage	Test Condition	Percent Reduction from Fan Only Condition	Percent Reduction from Uncharged Condition	Percent Reduction from Fan Only Condition	Percent Reduction from Uncharged Condition	Percent Reduction from Fan Only Condition	Percent Reduction from Uncharged Condition
1	Ritten-Uncharged	56.0	-	56.4	-	-33.6	-
	Ritten-(+) Fog	55.6	-1.0	53.0	-8.0	-12.5	15.8
	Ritten-(-) Fog	*	*	39.5	-38.8	-2.6	23.3
	AV-Uncharged	70.0	-	8.6	-	34.1	-
	AV-(-) Fog	26.0	-146.9	-39.7	-52.8	43.8	14.8
2	Ritten-Uncharged	44.5	-	41.9	-	-54.3	-
	Ritten-(+) Fog	28.7	-28.6	61.4	33.4	-37.1	11.1
	Ritten-(-) Fog	*	*	52.1	17.5	13.3	43.8
	AV-Uncharged	68.3	-	-63.3	-	33.5	-
	AV-(-) Fog	29.9	-121.2	-161.5	-60.1	58.8	38.0
3	Ritten-Uncharged	45.7	-	57.5	-	-29.8	-
	Ritten-(+) Fog	49.5	-6.9	68.6	26.3	5.5	27.1
	Ritten-(-) Fog	*	*	62.3	11.5	23.8	41.3
	AV-Uncharged	64.6	-	-125.7	-	36.3	-
	AV-(-) Fog	19.3	-128.0	-204.7	-35.0	47.7	17.9
4	Ritten-Uncharged	52.1	-	70.4	-	-17.3	-
	Ritten-(+) Fog	61.5	-19.6	78.8	28.3	5.0	19.0
	Ritten-(-) Fog	*	*	77.4	23.8	35.3	44.9
	AV-Uncharged	63.6	-	-23.0	-	37.0	-
	AV-(-) Fog	-11.0	-204.9	-199.9	-143.7	53.7	26.5
Back-up	Ritten-Uncharged	62.6	-	80.8	-	-18.4	-
	Ritten-(+) Fog	77.8	-40.6	88.0	37.6	8.0	22.3
	Ritten-(-) Fog	*	*	93.4	65.6	23.9	35.7
	AV-Uncharged	69.3	-	-15.6	-	54.3	-
	AV-(-) Fog	-116.6	-605.6	-551.8	-463.8	42.2	-26.3

*No data for this test condition.

Data were also obtained on October 14 using all four foggers. An examination of Table 27 indicates that the data do not show any trends.

PHASE II, TEST #7 - CEMENT PLANT: LIMESTONE CRUSHER/CONVEYOR OPERATION

The production of lime from limestone requires the limestone to be crushed. The crushing process is completed in several steps which include sizing and transferring material by conveyor. Throughout the process, significant amounts of dust are produced. The control of this dust at a crusher/conveyor was the subject of the seventh fogger field test. The site chosen for the test was the Black River Lime Company located in Butler, Kentucky. The field testing was performed during the period from November 16 to December 3, 1981, with a total of 134 test runs.

Site and Process Descriptions

During the lime-making process at Black River Lime, limestone is crushed, transferred, and screened numerous times. The process begins at an underground limestone mine. The material is removed from the mine by conveyor and deposited into a hopper from where it is fed by gravity into a crusher. The crushed limestone is then transferred by conveyor to the top of a structure which houses various sorting and screening operations. The largest pieces of material pass to a crusher located below ground level at the base of the structure. The crushed pieces of approximately 10 cm in diameter are transferred to the next step in the process by a conveyor that begins underground and ends up several stories above ground. The underground portion of the conveyor is contained in a corrugated tunnel of steel approximately 3 meters in diameter. All of the dust generated by the crushing/conveying process passes through the tunnel and exits at its mouth. Figure 28 is a photograph of the tunnel exit.

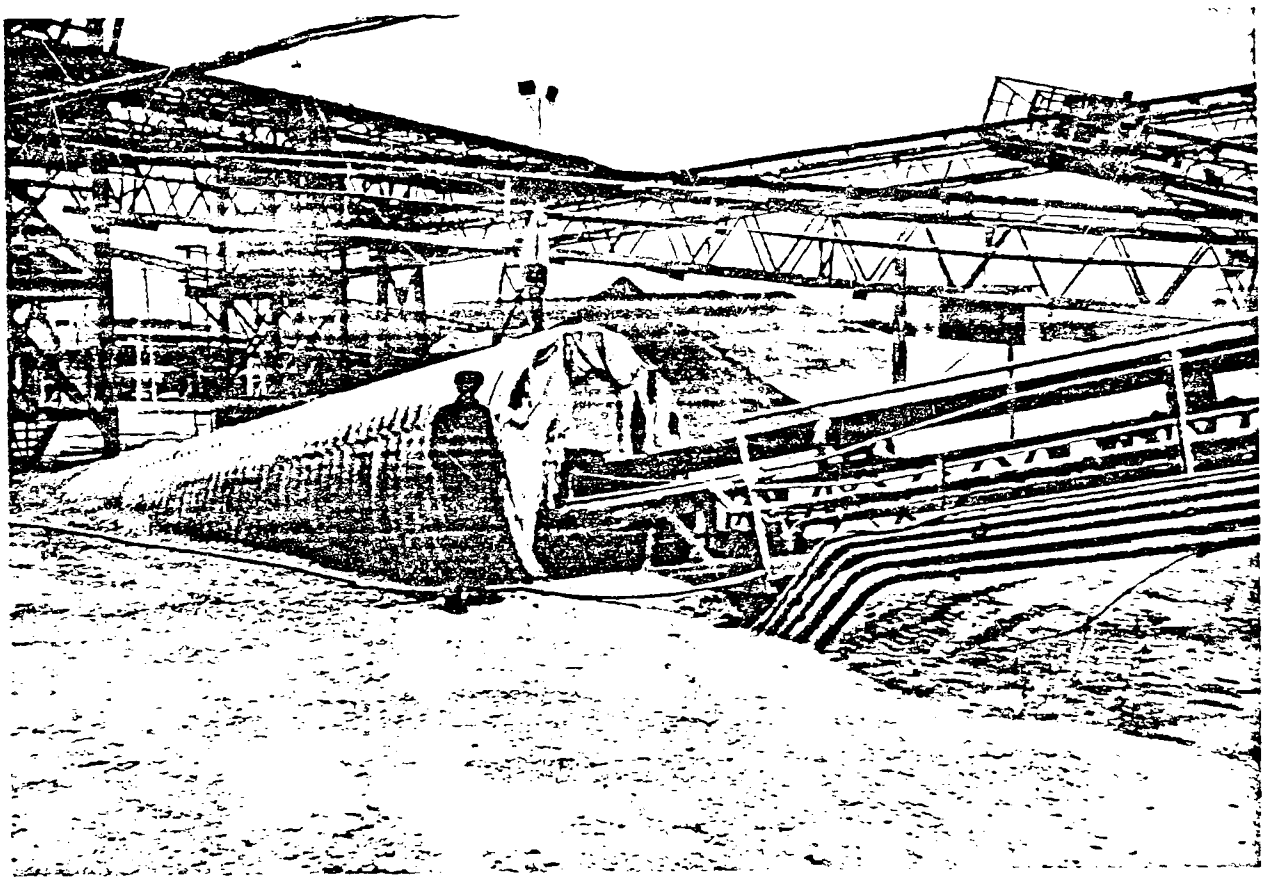


Figure 28. Limestone crusher/conveyor operation.

Equipment Placement

The equipment used for most of the test runs included four hi-vols, one of which was fitted with an SSI and another fitted with a cyclone preseparator and a cascade impactor, one Ritten fogger, and the two AV foggers. Two of the samplers (one standard hi-vol and one with an SSI) were located on a platform over the conveyor belt at the mouth of the tunnel. The other two samplers (one standard and one with a CYC/CI) were located immediately inside the mouth of the tunnel on a walkway next to the conveyor. The foggers were located outside the tunnel, aimed slightly downward and back toward the crusher. Two holes (approximately 0.6 m square) were cut in the sides of the tunnel to accommodate the sprays. These holes were staggered (by about 6 m) so that the sprays from the opposing foggers would not impinge on each other which might possibly reduce their effectiveness. Only one Ritten fogger was used owing to an electronic malfunction in the other fogger. To provide for a reasonable comparison between the Ritten and AV foggers, the Ritten fogger was operated at twice the flow rate of one AV fogger. Figures 29 and 30 are photographs of the equipment and Figure 31 is a sketch of the locations indicating sampler serial numbers.

Test Program and Procedure

The test program consisted of 134 test runs during 8 days of testing. The test conditions are presented in Table 30. To ensure a valid comparison of results, each of the AV foggers were operated at a water flow rate of 56.8 ℓ/hr (15 gph) while the Ritten fogger was operated at a water flow rate of

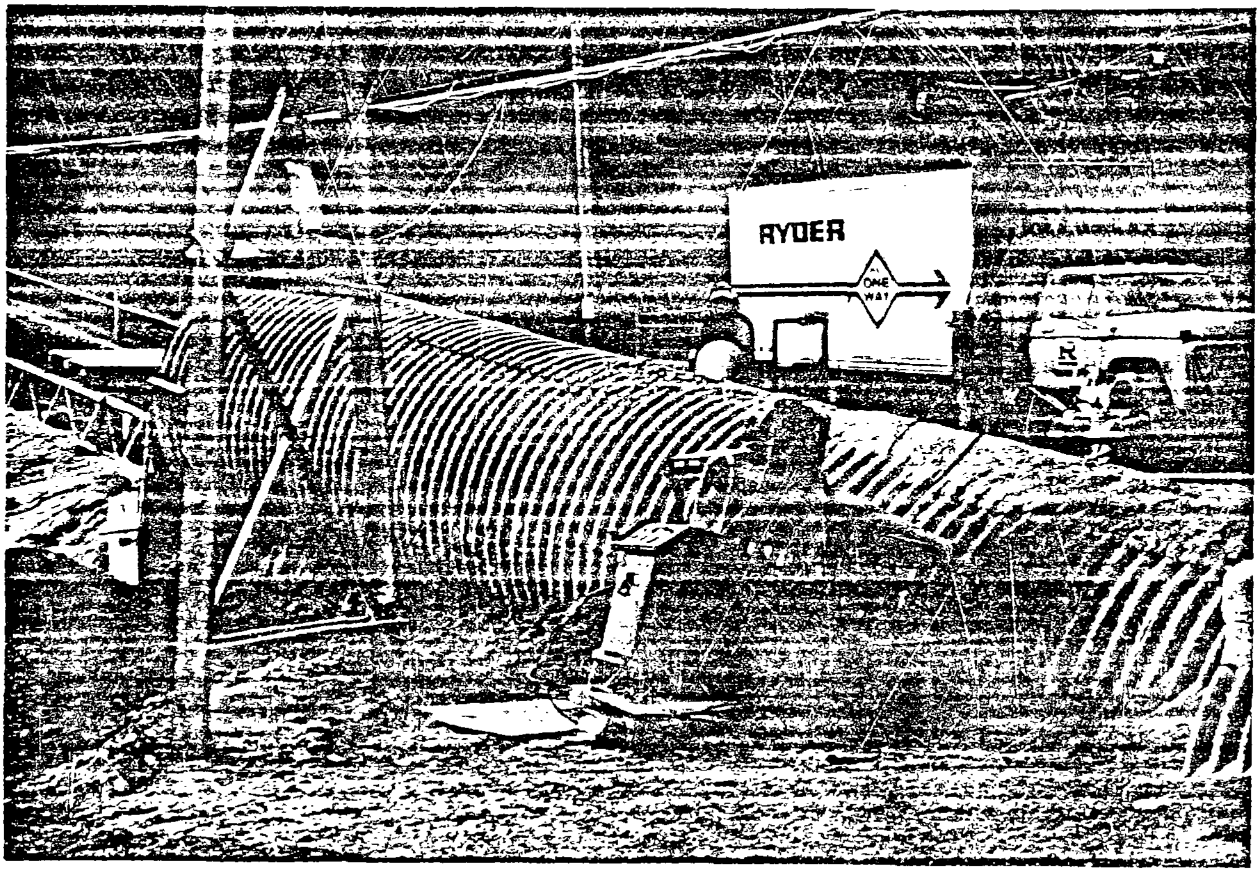


Figure 29. Equipment locations for crusher/conveyor test: foggers.

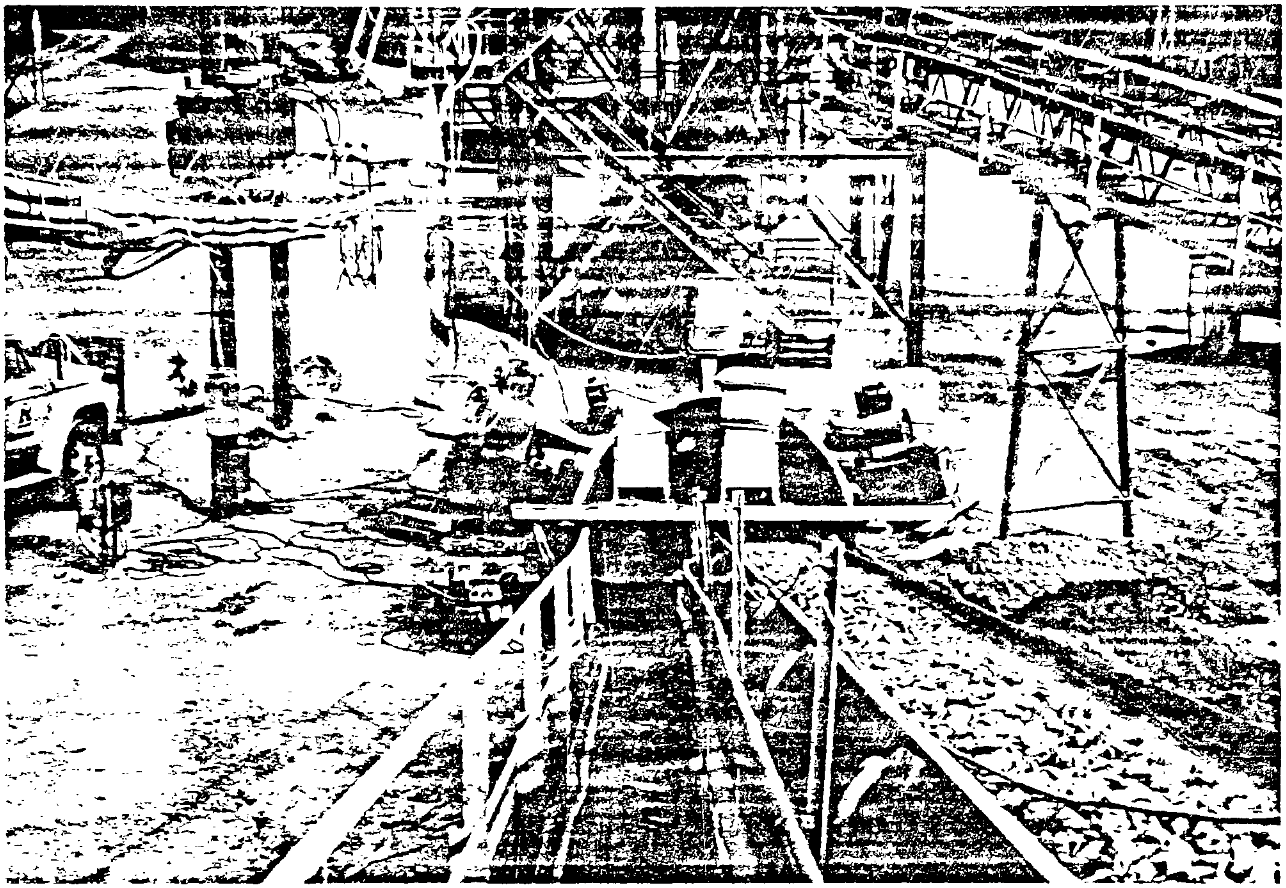


Figure 30. Equipment locations for crusher/conveyor test: samplers and foggers.

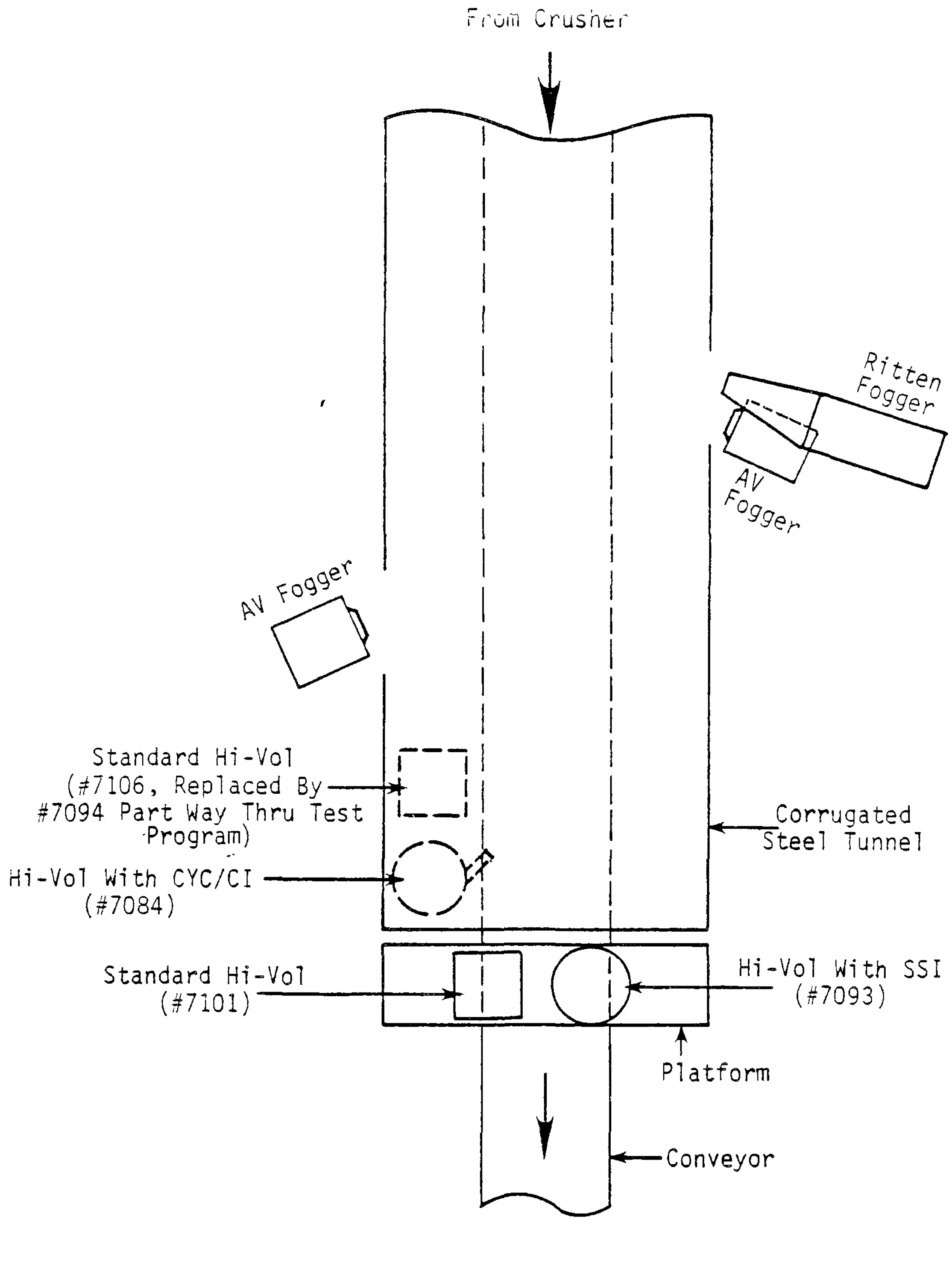


Figure 31. Equipment location sketch for crusher/conveyor test.

TABLE 30. TEST CONDITIONS - CRUSHER/CONVEYOR OPERATION

Run No.	Date	Start Time	Duration of run (min)	Type of Test	Equipment Position*	Ritten Foggers† Water flow (ℓ/hr)	Ritten Foggers† Air-flow (m^3/hr)	Fan Speed (% of max.)	AV Foggers Water Flow (ℓ/hr)‡	AV Foggers Fan Speed (% of max.)	Cascade Impactor
1	11-16-81	1040	5	Uncontrolled	a						Yes
2	11-16-81	1200	5	Ritten-Fan Only	a			40			Yes
3	11-16-81	1215	5	Ritten-Uncharged	a	113.5	5.2	40			Yes
4	11-16-81	1230	4	Ritten-(+) Fog	a	113.5	5.2	40			Yes
5	11-16-81	1240	4	Ritten-(-) Fog	a	113.5	5.2	40			Yes
6	11-16-81	1330	4	AV-Fan Only	a					50	Yes
7	11-17-81	0825	4	Uncontrolled	a						Yes
8	11-17-81	0835	4	AV-Fan Only	a					50	Yes
9	11-17-81	0845	4	AV-Uncharged	a				56.8	50	Yes
10	11-17-81	0855	4	AV-(+) Fog	a				56.8	50	Yes
11	11-17-81	0910	4	Ritten-Fan Only	a			40			Yes
12	11-17-81	0920	4	Ritten-Uncharged	a	113.5	5.2	40			Yes
13	11-17-81	0930	4	Ritten-(+) Fog	a	113.5	5.2	40			Yes
14	11-17-81	0940	4	Ritten-(-) Fog	a	113.5	5.2	40			Yes
15	11-17-81	1010	4	Uncontrolled	a						Yes
16	11-17-81	1025	4	AV-Fan Only	a					50	Yes
17	11-17-81	1035	4	AV-Uncharged	a				56.8	50	Yes
18	11-17-81	1045	4	AV-(+) Fog					56.8	50	Yes
19	11-17-81	1055	4	Ritten-Fan Only	a			40			Yes
20	11-17-81	1105	4	Ritten-Uncharged	a	113.5	5.2	40			Yes
21	11-17-81	1115	4	Ritten-(+) Fog	a	113.5	5.2	40			Yes
22	11-17-81	1125	4	Ritten-(-) Fog	a	113.5	5.2	40			Yes
23	11-17-81	1310	4	Uncontrolled	a						Yes
24	11-17-81	1320	4	AV-Fan Only	a					50	Yes
25	11-17-81	1330	4	AV-Uncharged	a				56.8	50	Yes
26	11-17-81	1345	4	AV-(+) Fog	a				56.8	50	Yes
27	11-17-81	1355	4	Ritten-Fan Only	a			40			Yes
28	11-17-81	1405	4	Ritten-Uncharged	a	113.5	5.2	40			Yes
29	11-17-81	1415	4	Ritten-(+) Fog	a	113.5	5.2	40			Yes
30	11-17-81	1425	4	Ritten-(-) Fog	a	113.5	5.2	40			Yes
31	11-18-81	0750	4	Uncontrolled	a						Yes
32	11-18-81	0800	4	Ritten-Fan Only	a			40			Yes
33	11-18-81	0810	4	Ritten-Uncharged	a	113.5	5.2	40			Yes
34	11-18-81	0820	4	Ritten-(+) Fog	a	113.5	5.2	40			Yes
35	11-18-81	0835	4	Ritten-(-) Fog	a	113.5	5.2	40			Yes
36	11-18-81	0845	4	AV-Fan Only	a					50	Yes

*Refer to Figure 31.
†Only one fogger used during test.
‡Values are per individual fogger.

TABLE 30. TEST CONDITIONS - CRUSHER/CONVEYOR OPERATION (Continued)

Run No.	Date	Start Time	Duration of run (min)	Type of Test	Equipment Position*	Ritten Foggers† Water flow (ℓ/hr)	Ritten Foggers† Air-flow (m^3/hr)	Ritten Foggers† Fan Speed (% of max.)	AV Foggers Water Flow (ℓ/hr)‡	AV Foggers Fan Speed (% of max.)	Cascade Impactor
37	11-18-81	0855	4	AV-Uncharged	a				56.8	50	Yes
38	11-18-81	0905	4	AV-(+) Fog	a				56.8	50	Yes
39	11-18-81	0955	4	Uncontrolled	a						Yes
40	11-18-81	1005	4	Ritten-Fan Only	a			40			Yes
41	11-18-81	1015	4	Ritten-Uncharged	a	113.5	5.2	40			Yes
42	11-18-81	1025	4	Ritten-(+) Fog	a	113.5	5.2	40			Yes
43	11-18-81	1035	4	Ritten-(-) Fog	a	113.5	5.2	40			Yes
44	11-18-81	1045	4	AV-Fan Only	a					50	Yes
45	11-18-81	1055	4	AV-Uncharged	a				56.8	50	Yes
46	11-18-81	1105	4	AV-(+) Fog	a				56.8	50	Yes
47	11-18-81	1235	4	Uncontrolled	a						Yes
48	11-18-81	1245	4	Ritten-Fan Only	a			40			Yes
49	11-18-81	1255	4	Ritten-Uncharged	a	113.5	5.2	40			Yes
50	11-18-81	1305	4	Ritten-(+) Fog	a	113.5	5.2	40			Yes
51	11-18-81	1315	4	Ritten-(-) Fog	a	113.5	5.2	40			Yes
52	11-18-81	1325	4	AV-Fan Only	a					50	Yes
53	11-18-81	1345	4	AV-Uncharged	a				56.8	50	Yes
54	11-18-81	1355	4	AV-(+) Fog	a				56.8	50	Yes
55	11-18-81	1415	4	Uncontrolled	a						Yes
56	11-18-81	1425	4	Both-Fan Only	a			40		50	Yes
57	11-18-81	1435	5	Both-Uncharged	a	113.5	5.2	40		50	Yes
58	11-18-81	1445	5	Both-(+) Fog	a	113.5	5.2	40		50	Yes
59	11-23-81	1130	5	Uncontrolled	a						Yes
60	11-23-81	1150	5	AV-Fan Only	a					50	Yes
61	11-23-81	1205	5.75	AV-Uncharged	a				56.8	50	Yes
62	11-23-81	1220	5	AV-(+) Fog	a				56.8	50	Yes
63	11-23-81	1240	5.08	Ritten-Fan Only	a			40			Yes
64	11-23-81	1300	5	Ritten-Uncharged	a	113.5	5.2	40			Yes
65	11-23-81	1405	5.17	AV-Fan Only	a				56.8	50	Yes
66	11-23-81	1425	5	AV-Uncharged	a				56.8	50	Yes
67	11-23-81	1440	5.23	AV-(+) Fog	a				56.8	50	Yes
68	11-23-81	1450	5	Uncontrolled	a						Yes
69	11-24-81	0905	5	Uncontrolled	a						Yes
70	11-24-81	0920	5	Ritten-Fan Only	a			40			Yes
71	11-24-81	0935	5	Ritten-Uncharged	a	113.5	5.2	40			Yes
72	11-24-81	0950	5	Ritten-(+) Fog	a	113.5	5.2	40			Yes
73	11-24-81	1005	5	AV-Fan Only	a					50	Yes
74	11-24-81	1015	5	AV-Uncharged	a				56.8	50	Yes
75	11-24-81	1030	5.08	AV-(+) Fog	a				56.8	50	Yes
76	11-24-81	1125	5	Uncontrolled	a						Yes
77	11-24-81	1145	5.42	Ritten-Fan Only	a			40			Yes
78	11-24-81	1155	5	Ritten-Uncharged	a	113.5	5.2	40			Yes
79	11-24-81	1210	5	Ritten-(+) Fog	a	113.5	5.2	40			Yes
80	11-24-81	1225	5	AV-Fan Only	a					50	Yes
81	11-24-81	1235	5	AV-Uncharged	a				56.8	50	Yes
82	11-24-81	1247	5	AV-(+) Fog	a				56.8	50	Yes
83	11-24-81	1312	5	Both-Fan Only	a			40		50	Yes
84	11-24-81	1325	5	Both-Uncharged	a	113.5	5.2	40		50	Yes
85	11-24-81	1336	5	Both-(+) Fog	a	113.5	5.2	40		50	Yes
86	11-24-81	1350	5	Uncontrolled	a						Yes

*Refer to Figure 31.
†Only one fogger used during test. ‡Values are per individual fogger.

TABLE 30. TEST CONDITIONS - CRUSHER/CONVEYOR OPERATION (Continued)

Run No.	Date	Start Time	Duration of run (min)	Type of Test	Equipment Position*	Ritten Foggers† Water flow (ℓ/hr)	Ritten Foggers† Air-flow (m^3/hr)	Fan Speed (% of max.)	AV Foggers Water Flow (ℓ/hr)‡	AV Foggers Fan Speed (% of max.)	Cascade Impactor
87	11-24-81	1400	5	Ritten-Fan Only	a			40			Yes
88	11-24-81	1413	5.25	Ritten-Uncharged	a	113.5	5.2	40			Yes
89	11-24-81	1425	5	Ritten-(+) Fog	a	113.5	5.2	40			Yes
90	12-1-81	1050	5	Uncontrolled	a						Yes
91	12-1-81	1110	5.25	AV-Fan Only	a					50	Yes
92	12-1-81	1125	5	AV-Uncharged	a				56.8	50	Yes
93	12-1-81	1200	5.08	AV-(+) Fog	a				56.8	50	Yes
94	12-1-81	1220	5.08	Ritten-Fan Only	a			40			Yes
95	12-1-81	1235	5.50	Ritten-Uncharged	a	113.5	5.2	40			Yes
96	12-1-81	1250	5	Ritten-(+) Fog	a	113.5	5.2	40			Yes
97	12-1-81	1330	5.08	Uncontrolled	a						Yes
98	12-1-81	1345	5	AV-Fan Only	a					50	Yes
99	12-1-81	1405	5	AV-Uncharged	a				56.8	50	Yes
100	12-1-81	1415	5	AV-(+) Fog	a				56.8	50	Yes
101	12-2-81	0805	5.25	Ritten-Fan Only	a			40			Yes
102	12-2-81	0820	5.25	Ritten-Uncharged	a	113.5	5.2	40			Yes
103	12-2-81	0835	5.17	Ritten-(+) Fog	a	113.5	5.2	40			Yes
104	12-2-81	0855	5	AV-Fan Only	a					50	Yes
105	12-2-81	0915	5	AV-(+) Fog	a				56.8	50	Yes
106	12-2-81	0925	5	AV-Fan Only	a					50	Yes
107	12-2-81	1005	5	AV-(+) Fog	a				56.8	50	Yes
108	12-2-81	1020	5	Ritten-Fan Only	a			40			Yes
109	12-2-81	1030	5	Ritten-Uncharged	a	113.5	5.2	40			Yes
110	12-2-81	1045	5	Ritten-(+) Fog	a	113.5	5.2	40			Yes
111	12-2-81	1055	5	AV-Fan Only	a					50	Yes
112	12-2-81	1110	5	AV-(+) Fog	a				56.8	50	Yes
113	12-2-81	1125	5	Both-Fan Only	a			40		50	Yes
114	12-2-81	1135	5	Both-Uncharged	a	113.5	5.2	40	56.8	50	Yes
115	12-2-81	1150	5	Both-(+) Fog	a	113.5	5.2	40	56.8	50	Yes
116	12-2-81	1220	5.17	Ritten-Fan Only	a			40			Yes
117	12-2-81	1255	5	Ritten-Uncharged	a	113.5	5.2	40			Yes
118	12-2-81	1305	5	Ritten-(+) Fog	a	113.5	5.2	40			Yes
119	12-2-81	1320	5	AV-Fan Only	a					50	Yes
120	12-2-81	1330	5	AV-(+) Fog	a					50	Yes
121	12-2-81	1345	5	AV-Fan Only	a				56.8	50	Yes
122	12-2-81	1355	5	AV-(+) Fog	a					50	Yes

*Refer to Figure 31.
†Only one fogger used during test.
‡Values are per individual fogger.

TABLE 30. TEST CONDITIONS - CRUSHER/CONVEYOR OPERATION (Continued)

Run No.	Date	Start Time	Duration of run (min)	Type of Test	Equipment Position*	Ritten Foggers†			AV Foggers		Cascade Impactor
						Water flow (ℓ/hr)	Air-flow (m^3/hr)	Fan Speed (% of max.)	Water Flow (ℓ/hr)‡	Fan Speed (% of max.)	
123	12-3-81	0845	5	Ritten-Fan Only	a			40			Yes
124	12-3-81	0855	5	Ritten-Uncharged	a	113.5	5.2	40			Yes
125	12-3-81	0910	5	Ritten-(+) Fog	a	113.5	5.2	40			Yes
126	12-3-81	0920	5	AV-Fan Only	a					50	Yes
127	12-3-81	0935	5	AV-(+) Fog	a				56.8	50	Yes
128	12-3-81	0945	5	AV-Fan Only	a					50	Yes
129	12-3-81	1000	5	AV-(+) Fog	a				56.8	50	Yes
130	12-3-81	1010	5	Ritten-Fan Only	a			40			Yes
131	12-3-81	1020	5.42	Ritten-Uncharged	a	113.5	5.2	40			Yes
132	12-3-81	1030	5	Ritten-(+) Fog	a	113.5	5.2	40			Yes
133	12-3-81	1045	5	AV-Fan Only	a					50	Yes
134	12-3-81	1055	5.17	AV-(+) Fog	a				56.8	50	Yes

*Refer to Figure 31.
†Only one fogger used during test.
‡Values are per individual fogger.

113.6 ℓ/hr (30 gph). Fan speed was kept to the minimum required to project the fog across the tunnel.

The sampling procedure was essentially the same for each test. Prior to each test run, preweighed filters were placed into the samplers. For the controlled tests, the foggers were then turned on and adjusted to the desired conditions. The samplers were then all started simultaneously by a control box. During the duration of the test, the samplers' flow rates were monitored to ensure that the flow controllers were maintaining the flow at approximately 1.1 m^3/min. The samplers were allowed to run for approximately 4 to 5 minutes since sufficient material was collected on the filters during this time for analysis. At the end of each sampling period, the samplers were shut off simultaneously and the filters removed from the hi-vols and placed into individual envelopes.

Test Results

Following completion of all the test runs, the hi-vol filters were returned to the TRC chemistry laboratory, desiccated and weighed. The resulting filter loadings were then used in conjunction with the sampler flow rates to calculate particulate matter concentrations.

The next step in the analysis procedure consisted of determining the arithmetic mean particulate matter concentration for each test condition for each of the four hi-vols and for the standard hi-vols combined. The resulting values are presented in Table 31. (Stage 1 impactor data were not included because it was frequently noted that material from inside the cyclone preseparator would fall onto the first stage of the impactor during its removal, thus invalidating the results.) These values are reproduced graphically in Figures 32 (combined standard hi-vols and hi-vol with SSI data) and Figure 33 (hi-vol with CYC/CI data).

TABLE 31. CRUSHER/CONVEYOR OPERATION: ARITHMETIC MEAN PARTICULATE MATTER CONCENTRATIONS UNDER VARIOUS TEST CONDITIONS ($\mu g/m^3$)

Test Condition	Particulate Matter Concentrations As Measured By: Standard Hi-Vol (7101)	Standard Hi-Vol (7106/7094)	Standard Hi-Vols Combined	Hi-Vol with SSI (7093)	Hi-Vol with CYC/CI (7084) Stage 3	Backup
Uncontrolled	338001	446316	390153	152607	38079	11383
Ritten-Fan Only	263584	404161	320856	160173	33666	8593
Ritten-Uncharged	231882	386572	289175	126164	31855	6788
Ritten-(+) Fog	214649	335880	255059	126299	26762	6220
Ritten-(-) Fog	283880	394288	339084	199914	37390	5752
AV-Fan Only	310089	461961	368158	148088	36469	9411
AV-Uncharged	278708	446296	354884	154179	40051	10061
AV-(+) Fog	245271	354619	284072	110528	31656	7849
Both-Fan Only	170833	*	*	123696	31520	10958
Both-Uncharged	150459	*	*	103056	28678	7792
Both-(+) Fog	192535	*	*	101092	27477	7730

*Insufficient data for analysis.

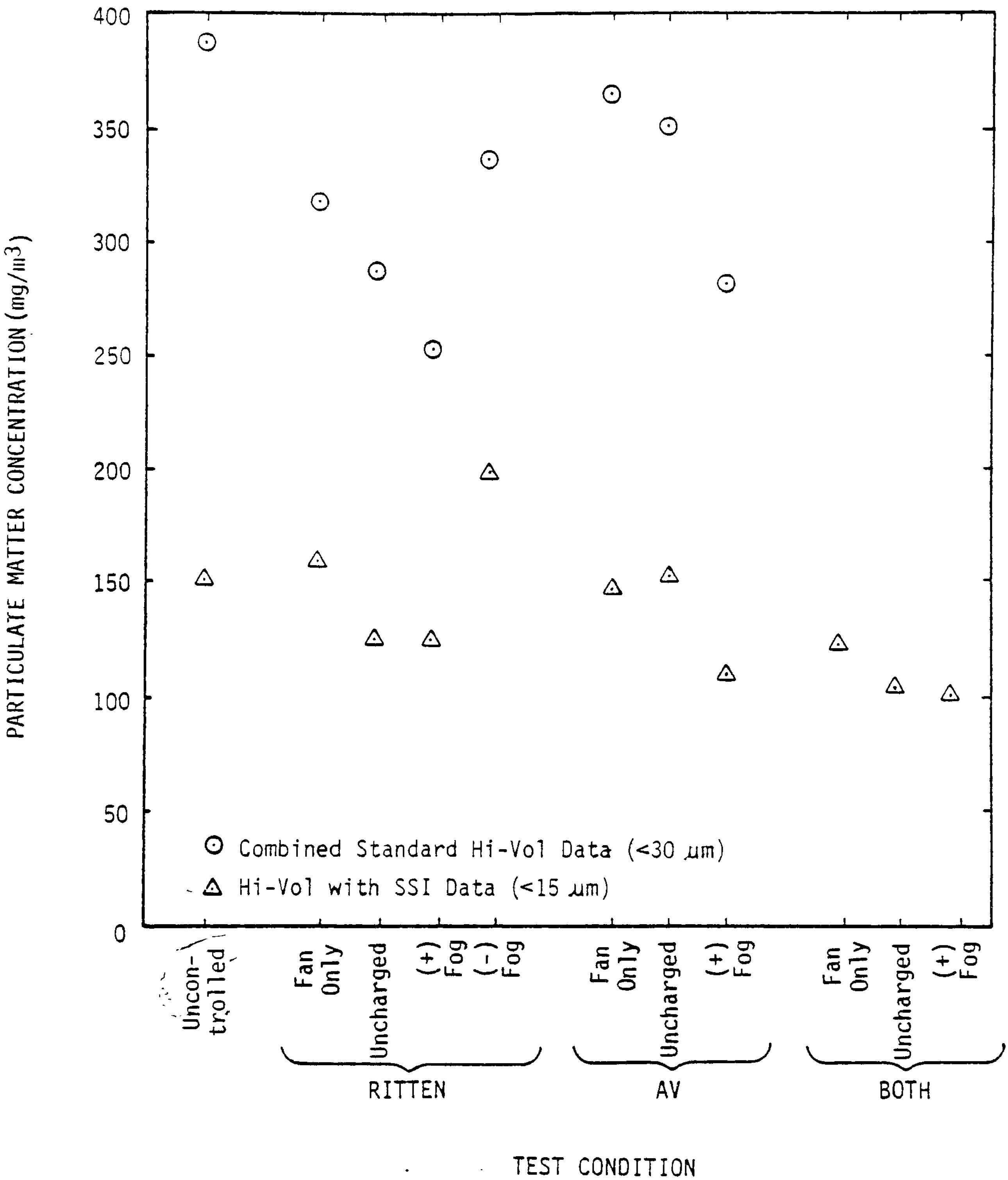


Figure 32. Arithmetic mean particulate matter concentrations under various test conditions (mg/m^3)-crusher/conveyor operation

For this test setup, it is appropriate to compare the controlled emission levels with the uncontrolled emission levels since all of the emissions must exit the mouth of the tunnel. This comparison was performed and the results, in terms of percent reduction from the uncontrolled level, are presented in Table 32. An examination of these data reveals that the positively charged fog reduced the uncontrolled level by 17 to 45 percent using the Ritten fogger and by 17 to 31 percent using the AV foggers, with the greater reductions occuring in the less than 1.5 μm fraction. Using the three foggers together reduced the uncontrolled levels up to 55 percent.

An additional analysis was performed on the data to determine the increase in efficiency from charging the spray. The results of this analysis are presented in Table 33. It can be seen that charging increased the efficiency approximately 10 percent for the Ritten fogger and 25 percent for the AV foggers. However, the increase in efficiency using both foggers was essentially zero, possibly because of the limited data obtained during the test condition using both foggers. The lower increase in efficiency with the Ritten fogger may be due to the fact that only one fogger was used at a higher flow rate, causing the charge/droplet ratio to decrease (same overall charge with increased number of droplets). There is also the possibility that the spray coverage using one fogger is not as good as with two foggers.

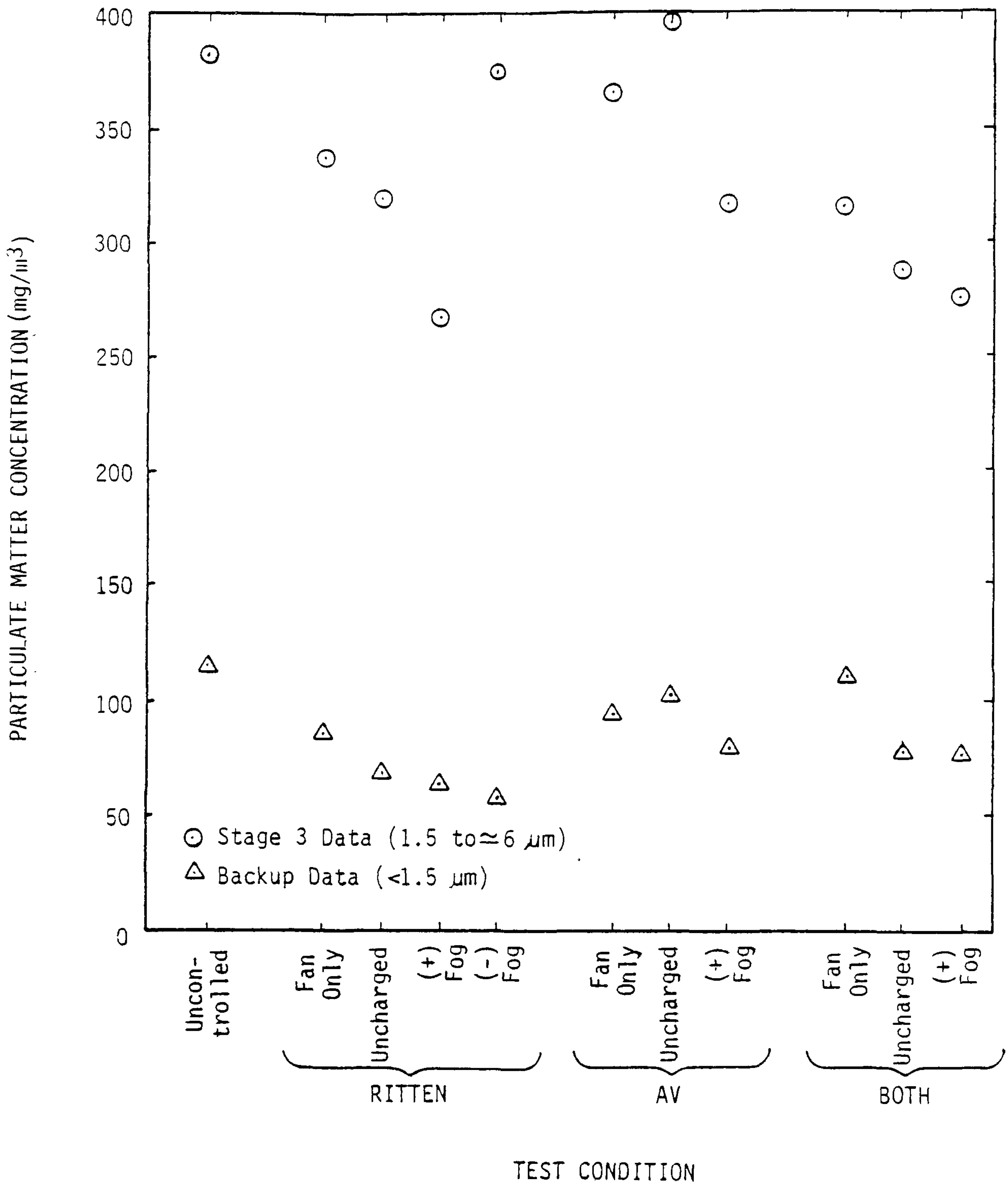


Figure 33. Arithmetic mean particulate matter concentrations under various test conditions (mg/m^3)-crusher/conveyor operation CYC/CI data

TABLE 32. PERCENT REDUCTION IN ARITHMETIC MEAN UNCONTROLLED PARTICULATE MATTER CONCENTRATIONS DUE TO VARIOUS TEST CONDITIONS - CRUSHER/CONVEYOR OPERATION

	Percent Reduction from Background as Measured By:					
Test Condition	Standard Hi-Vol (7101)	Standard Hi-Vol (7106/7094)	Standard Hi-Vols Combined	Hi-Vol with SSI (7093)	Hi-Vol with CYC/CI (7084) Stage 3	Hi-Vol with CYC/CI (7084) Backup
Ritten-Fan Only	22.0	9.4	17.8	-5.0	11.6	24.5
Ritten-Uncharged	31.4	13.4	25.9	17.3	16.3	40.4
Ritten-(+) Fog	36.5	24.7	34.6	17.2	29.7	45.4
Ritten-(-) Fog	16.0	11.7	13.1	-31.0	1.8	49.5
AV-Fan Only	8.3	-3.5	5.6	3.0	4.2	17.3
AV-Uncharged	17.5	0.0	9.0	-1.0	-5.2	11.6
AV-(+) Fog	27.4	20.5	27.2	27.6	16.9	31.0
Both-Fan Only	49.5	*	*	18.9	17.2	3.7
Both-Uncharged	55.5	*	*	32.5	24.7	31.5
Both-(-) Fog	43.0	*	*	33.8	27.8	32.1

*Insufficient data for analysis.

TABLE 33. PERCENT REDUCTION IN ARITHMETIC MEAN PARTICULATE MATTER CONCENTRATIONS DUE TO CHARGING AN UNCHARGED FOG - CRUSHER/CONVEYOR OPERATION

	Percent Reduction from Uncharged as Measured By:					
Test Condition	Standard Hi-Vol (7101)	Standard Hi-Vol (7106/7094)	Standard Hi-Vols Combined	Hi-Vol with SSI (7093)	Hi-Vol with CYC/CI (7084) Stage 3	Hi-Vol with CYC/CI (7084) Backup
Ritten-(+) Fog	7.4	13.1	11.8	0.0	16.0	8.4
AV-(+) Fog	12.0	20.5	20.0	28.3	21.0	22.0
Both-(+) Fog	-28.0	*	*	1.9	4.2	0.8

*Insufficient data for analysis.

SECTION 6

DISCUSSION OF RESULTS

There are two major factors to consider when evaluating the fogger test program: (1) overall emission level reduction due to control, and (2) an increase in fog efficiency from charging. The results for the first of these factors, the control device efficiency, are presented in Table 34. The torch cutting operation data are not presented in this table since, as previously discussed, there are no real baseline levels for comparison. The results for the second evaluation factor, the increase in fog efficiency from charging, are presented in Table 35. Based on the data presented in these two tables, several generalized comments may be made:

- The control of emissions by the two types of fog devices are generally comparable, with the Ritten fogger appearing slightly more efficient in the finer size fractions.
- The control efficiencies of the Ritten foggers were higher for the primary rock crusher and coke screen tests than for the Armco tests. While this was probably the result of the former tests being performed with water flow rates that were 50 to 100 percent greater than the rates used in the Armco tests (due to the AV fogger flow rate limitation), there is also the possibility that the foggers were situated in more optimum positions for control at these two sources.
- Two fog devices, in the positions tested with the flow rates used, are insufficient to completely control the emissions from the types of sources tested. This is consistent with observations which indicated that greater water flow would most likely be needed (i.e., 300 to 400 ℓ/hr of charged fog required) as would more optimal fogger locations (i.e., above the source).
- Charging a water spray does appear to increase its effectiveness in controlling particulate matter emissions. Increases in effectiveness of 10 to 40 percent were noted in some of these tests.

TABLE 34. OVERALL RESULTS OF TESTS: REDUCTIONS IN BASELINE EMISSION LEVELS DUE TO CONTROL

Test Site	Test Type	Percent Reduction by Particle Size Fraction: Suspendable Fraction (<30 μm)	Inhalable Fraction (<15 μm)	Fine Fraction (<≈6 μm)	Respirable Fraction (<2-3 μm)
Primary Rock Crusher	Ritten-(+)Fog*	57	53		
	Ritten-(-)Fog*	58	46		
Coke Screening Operation	Ritten-(+)Fog*	45	33		
	Ritten-(-)Fog*	27	15		
Recycle Plant Transfer Operation	Ritten-(+)Fog*			41	5 to 88
	Ritten-(-)Fog*			55	24 to 93
	AV-(+)Fog*			31	-552 to 54
Limestone Crusher/ Conveyor Operation	Ritten-(+)Fog†	35	17	30	45
	Ritten-(-)Fog†	13	-31	2	50
	AV-(+)Fog†	27	28	17	31

*Reduction from fan only levels
†Reduction from background levels

TABLE 35. OVERALL RESULTS OF FOGGER TESTS: INCREASE IN EFFICIENCY DUE TO APPLYING A CHARGE TO A WATER SPRAY

		Percent Increase by Particle Size Fraction			
Test Site	Test Type	Suspendable Fraction (<30 μm)	Inhalable Fraction (<15 μm)	Fine Fraction (<≈6 μm)	Respirable Fraction (<2-3 μm)
Primary Rock Crusher	Ritten-(+)Fog	36	41		
	Ritten-(-)Fog	37	32		
Coke Screening Operation	Ritten-(+)Fog	28	24		
	Ritten-(-)Fog	5	3		
Torch Cutting Operation	Ritten-(-)Fog	18	35		
Recycle Plant Transfer Operation	Ritten-(+)Fog			9	19 to 41
	Ritten-(-)Fog			33	24 to 66
	AV-(+)Fog			19	*
Limestone Crusher/ Conveyor Operation	Ritten-(+)Fog	12	0	16	8
	AV-(+)Fog	20	28	21	22

*Decrease in efficiency

Another significant result of the test program can be derived from the data from the Armco tests obtained with all four fog devices operating at the same time. The data indicated that very little benefit was derived from such action. Perhaps the increased fan air causes more dust reentrainment, thus counteracting the increased efficiency from increased water flow. This would not be the case with one set of foggers where the water flow could be doubled without an increase in fan air.

It should be noted that there was considerable scatter in the test data in several cases, most notably the Phase II tests. Thus, the efficiency results for these cases are more indicative of trends rather than statistically significant differences. The data scatter was primarily due to process variations and, in some instances, meteorological conditions. There was also the possible influence of nearby sources, particularly at the recycle plant (Test Number 6). The data obtained during the Phase I test sequence exhibit less scatter.

SECTION 7

REFERENCES

1. Hoenig, S.A. Use of Electrostatically Charged Fog for Control of Fugitive Dust Emissions. The University of Arizona, Tucson. EPA 600/7-77-131 (NTIS PB 276-645). 1977.

2. Brookman, E.T. Demonstration of the Use of Charged Fog in Controlling Fugitive Dust from Large-Scale Industrial Sources. Presented at the Symposium on Iron and Steel Pollution Abatement Technology for 1980, Philadelphia, November 1980.

3. Brookman, E.T., R.C. McCrillis, and D.C. Drehmel. Demonstration of the Use of Charged Fog in Controlling Fugitive Dust from Large-Scale Industrial Sources. Presented at the Third Symposium on the Transfer and Utilization of Particulate Control Technology, Orlando, Florida, March 1981.

4. Brookman, E.T., K.J. Kelley, and R.C. McCrillis. Demonstration of the Use of Charged Fog in Controlling Fugitive Dust from a Coke Screening Operation at a Steel Mill. Presented at the Symposium on Iron and Steel Pollution Abatement Technology for 1981, Chicago, October 1981.

5. KLD Associates, Inc. Operation and Maintenance Manual For Model DC-2 Droplet Measuring Device. Huntington Station, New York.

6. Mathai, C.V., L.A. Rathbun, and D.C. Drehmel. An Electrostatically Charged Fog Generator for the Control of Inhalable Particles. Presented at the Third Symposium on the Transfer and Utilization of Particulate Control Technology, Orlando, Florida, March 1981.

7. Mathai, C.V., L.A. Rathbun, and D.C. Drehmel. Prototype Tests of a Charged Water Droplet Generator for the Control of Inhalable Fugitive Dust. Presented at the 74th Annual Meeting of the Air Pollution Control Association, Philadelphia, June 1981.

8. Environmental Protection Agency. EPA Quality Assurance Handbook for Air Pollution Measurement Systems. Volume II, Ambient Air Specific Methods. May 1977.

9. Kunkel, W.B. The Static Electrification of Dust Particles on Dispersion into a Cloud. Journal of Applied Physics. 21:820-32. 1950.

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16. ABSTRACT The report gives results of a full-scale demonstration of a charged fogger (Ritten Corporation's Fogger IV) on several industrial fugitive emission sources. (Although charged foggers have been widely applied to industrial sources of fugitive dust, little data are available on fogger control effectiveness on particulate matter.) The sources tested included a primary rock crushing operation, a secondary rock crushing operation, a molten iron spout hole at a blast furnace cast house, and a coke screening operation. The report also gives results of three source tests using the same charged foggers, along with a charged fogger developed by AeroVironment, Inc. The sources for field testing both foggers were a stainless steel slab torch cutting operation, a conveyor transfer operation at a recycle (sinter) plant, and a limestone crusher/conveyor operation. In general, tests showed that (1) the control of emissions by the two foggers are generally comparable, (2) fogger efficiency depends on the positions of the foggers in relation to the source, and (3) charging a water spray appears to increase its effectiveness in controlling particulate matter emissions by up to 40 percent.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Fogging	Pollution Control	13B
Dust		Stationary Sources	11G
Processing		Charged Fog	13H
Leakage		Fugitive Dust	14G
Electrostatics		Particulate	20C
Spraying		Water Sprays	

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