4. SYSTEM COMPONENT DESIGN AND SPECIFICATIONS

This section contains details regarding the performance of individual components within each major subsystem detailed in Section 2.0. Whenever possible, specific components were selected from an evaluation of commercially available equipment.

4.1. Fog Generation Subsystem

The fog generation subsystem consists of a droplet generator, high pressure pump, and solution storage tank.

4.1.1. Droplet Generator

The droplet generator, shown in Figure 4.1, consists of a 24"Lx24"Wx24"H Teflon coated stainless steel chamber containing 37 Bete PJ8 atomizing nozzles (Greenfield, MA) which produce droplets over a wide size distribution. The nozzles are mounted on six manifolds located near the bottom of the droplet generation chamber. Stainless steel plug valves are installed such that one or more manifolds can be individually activated, thereby providing control over the number of droplets that are produced. The nozzles are arranged in banks of 1, 2, 4, 10, 10 and 10, so that different combinations can be selected.

The droplet size is controlled by using 18 mesh stainless steel screens at two locations within the droplet generator One or more layers of screens are placed in removable baffles mounted directly above each atomizer bank. These screens and baffles remove the coarse droplets which contribute to scavenging of smaller droplets. A second layer of screens is mounted in a removable frame located near the generator outlet. These screens remove additional large droplets to further reduce the droplet size distribution. In addition to varying the number of screens, the porosity can also be changed to alter the droplet size. Screen sizes of 18 mesh x 0.017 in. diameter wire (48% open area) and 18 mesh x 0.009 in. diameter wire (70% open area) are available for this purpose.

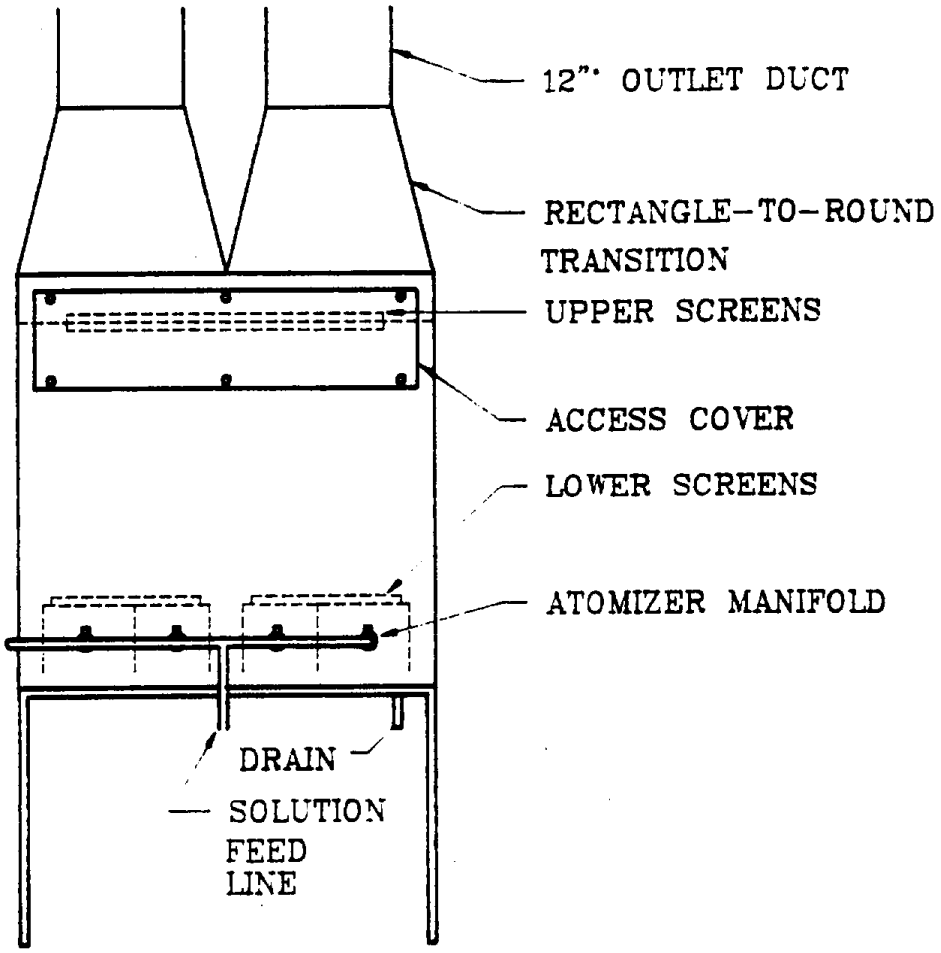

Figure 4.1. Droplet Generator

4.1.2. Solution Tank

The solution to be atomized is pre-mixed and stored in a 15 gallon polyethylene storage tank. The tank contains isolation valves and PVC unions to facilitate cleaning. A cooling coil (3/8" OD x 0.035" wall thickness x 20 ft.) maintains the solution temperature. A stainless steel thermometer is mounted in the top of the tank to monitor the solution temperature.

4.1.3. Solution Pump

A high pressure stainless steel pump is used to pressurize the solution for atomization. The pump is a CAT Model 281 pump (Minneapolis, MN) with all wetted parts in contact with type 316 stainless steel. A Model 7001.100 stainless steel pressure regulator allows the pressure to be varied from 300-1000 psig. The pressure is monitored with a 0-1500 psig stainless steel pressure gauge mounted on the regulator. The pump is powered by a belt driven 2 HP electric motor. The pump and motor are skid mounted. A Nupro Model SS-6TF2-140 stainless steel mesh filter (140 micron) (Willowby, OH) is located down stream of the pressure regulator to prefilter the solution flowing to the atomizers.

4.2. Fog Delivery Subsystem Components

The fog delivery subsystem circulates the fog produced by the droplet generator in a closed loop mode through the exposure chamber. The components associated with this subsystem include the blower, ducts, droplet filtration system, and makeup air system.

4.2.1. Blower

A backward inclined centrifugal blower, Central Blower Model No. FC-109SR (Los Angeles, CA), is used as the primary air mover in the fog generation system. It is capable of delivering air at flowrates in excess of 400 ft^3/min at static pressures up to 2.0 inches of water. A manually activated damper is located at the blower outlet to adjust the circulation

rate through the chamber. The blower housing and impeller have been Teflon coated for corrosion resistance.

4.2.2. Flowmeter

The chamber air flowrate is monitored with a Kurz Model 430 DC air velocity meter (Monterey, CA). The meter consists of a hot wire velocity probe powered by a 12 volt regulated power supply. The probe is mounted in a section of 9" diameter duct down stream of the Droplet Filtration System. The output of the air velocity probe is monitored by the data acquisition system, which converts the air velocity voltage signal into flowrate.

4.2.3. Ducts

Three flexible round Teflon lined ducts, 12 inches in diameter, are used to connect the fog generation system to the exposure chamber. Flexible ducts were selected over rigid ducts so that, if necessary, the system can be easily disassembled for cleaning. Also, flexible ducts reduce noise transmission. The inlet ducts are connected to two square-to-round transitions mounted at the top of one of exposure chamber walls. The other end of each square to round transition is connected to a 13 inch square duct which run the full length of the chamber, as illustrated in Figure 4.2. The rigid duct is constructed from 22 and 24 gauge Type 316 stainless steel. The stainless steel is Teflon coated for additional chemical resistance. These ducts have holes on each side to evenly distribute the fog within the exposure chamber. A tray is attached to the bottom of the ducts to prevent fogwater from dripping on equipment or subjects. The chamber air is exhausted through stainless steel ducts mounted on the perimeter of the chamber floor. These ducts are manifolded to a square-to-round transition located at the bottom of the chamber wall. A flexible Teflon lined duct attaches the transition to the inlet of the droplet filtration system.

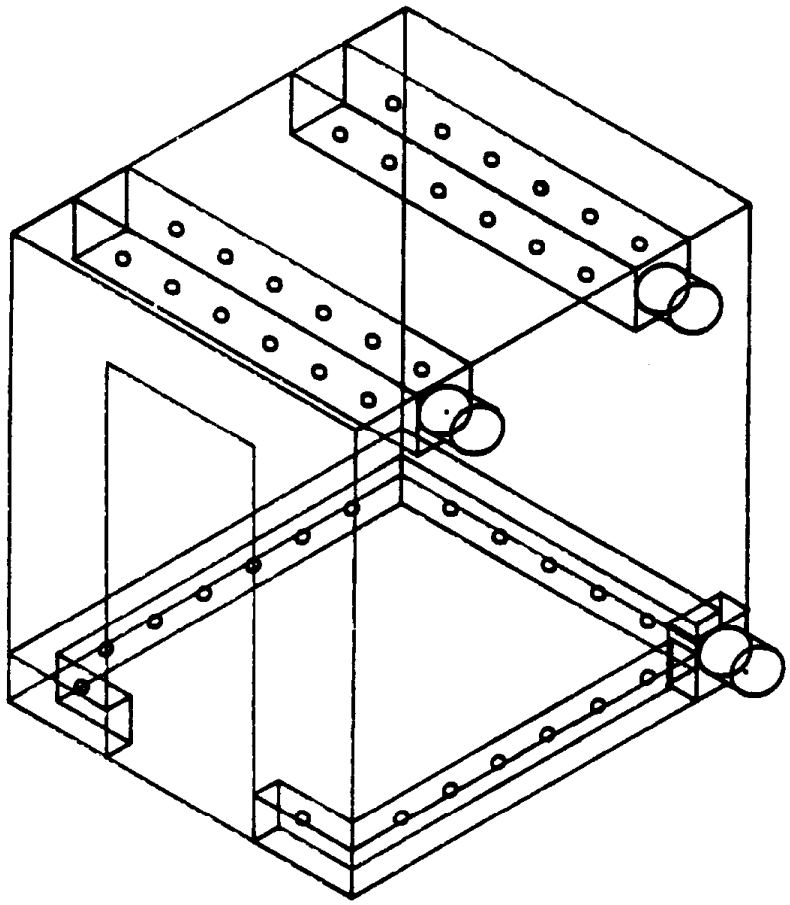

Figure 4.2. Exposure Chamber Air Distribution System

4.2.4. Droplet Filtration System

After the air exits the chamber, the droplets are removed using a filtration system which provides humidified, filtered air to transport new droplets to the chamber. Circulating the air decreases the amount of evaporation and increases droplet stability.

The droplet filtration system consists of two components: a mesh collector to remove a large fraction of the liquid water associated with droplets larger than several microns in diameter, and a HEPA filter to remove the remaining small droplets.

4.2.4.1. Mesh Collector

The mesh collector consists of an ACS Industries Style 8TW layered mesh unit (Houston, TX), 23"x23"x18" thick, with Teflon fibers and type 316 stainless steel wire. The Teflon is a 10-20 micron multifilament fiber co-knitted to a 0.011 in. diameter stainless steel wire. Type 316 stainless steel grids are used to keep the mesh in place. The mesh collector is installed in a Teflon coated stainless steel housing. Pressure taps, located at each end of the filter, are attached to differential pressure gauges and transducers to monitor filter loading. The pressure drop is measured with a Dwyer Model 2010 Magnehelic differential pressure gauge (Michigan City, IN) and an Omega Model PX163-005BD5V pressure transducer (Stamford, CT). The output of the pressure transducer is interfaced to the data acquisition system.

4.2.4.2. HEPA Filter

A HEPA filter is used to collect the small droplets which pass through the mesh collector. A treated glass fiber filter medium has been selected, since this type of filter material has been proven to be resistant to harsh environments and has been installed in production processes using moisture laden air.

The HEPA filter consists of a Flanders Model 7033IU-GGF filter (Washington, NC) with a nominal rated capacity of 1000 CFM. Operating the filter at 400 CFM results in a differential pressure less than 0.5 in. w.c. The filter has a minimum collection efficiency of 97% at 0.3 microns and 100% at 1.0 microns. A Dwyer Model 2010 Magnehelic differential pressure gauge and Omega Model PX163-000BD5V pressure transducer monitors the pressure drop across the filter during operation. The output of the pressure transducer is interfaced to the data acquisition system.

4.2.5. Makeup Air System

A small portion of the air circulating through the droplet generation system is exhausted and replaced with filtered air from the chamber air purification system. A maximum of 70 CFM of air can removed using the fogwater collector described in Section 4.3.2.1. The replacement air is introduced into the inlet of the mesh filter so that it can be humidified while passing through the large surface area of wet mesh. A Dayton Model 4C818 blower (Chicago, IL) and Variac are used to regulate the air flowrate. A Dwyer Model 2001 Magnehelic differential pressure gauge is used to measure the pressure drop across the fogwater collector to monitor the flowrate.

A separate air conditioning system has been installed on the makeup air system to regulate the chamber temperature at 70^{o}F. This system consists of Colmac DXMA5X5X10-6 direct expansion evaporator, a Tecumesch AE2410 condenser (0.25 HP), and a 1000 watt strip heater. The unit is run at constant suction pressure to prevent the evaporator coils from forming excessive ice. The strip heater is mounted upstream of the evaporator to reduce icing and to provide a rapid response to temperature changes. A thermostat with a remote sensing unit mounted inside the chamber monitors outlet temperature and varies the current to the strip heater to adjust the temperature to the desired set point. This system has been designed to remove the heat generated by one subject exercising heavily for a one hour period.

4.3. Fog Monitoring Subsystem

The fog monitoring subsystem consists of instrumentation to determine the size, liquid water content, and chemical composition of the chamber fog droplets. Major components include: a Phase Doppler Particle Analyzer, a series cyclone sampler, a total filter, a fogwater chemical analysis system, and a computerized data acquisition and storage system.

4.3.1. Phase Doppler Particle Analyzer

An Aerometrics Phase Doppler Particle Analyzer (PDPA) (Mountain View, CA) measures the fog droplet size distribution and number concentration within the exposure chamber. The PDPA measures the size and velocity of droplets above 0.3 microns in diameter by optical methods similar to those used in a laser Doppler velocimeter, in which two intersecting laser beams define a sampling volume. When a particle passes through the intersecting region, an interference fringe pattern is formed by the scattered light. Since the particle is moving, the scattered interference pattern sweeps past the receiver aperture at the Doppler difference frequency which is proportional to the particle velocity. The spatial frequency of the fringe pattern is inversely proportional to the particle diameter.

The measurement range of the PDPA can be varied from 0.3 to 3000 microns by changing optical components. For the fog exposure chamber measurements, the PDPA transmitter has been installed with a beam expander and operates with a wide beam separation to give the smallest sampling volume to increase resolution of the small droplets. A 100 micron slit is used in the receiver to increase light gathering to enhance the signals from the smaller droplets. With the PDPA assembled in this configuration, the available size span ranges from 0.3 to 41 microns. Over this span, a droplet measurement range of 1:35 can be specified with the software. Thus, the smallest size range that can be selected is 0.3 to 11.0 microns and the largest range is 1.2 to 41 microns.

The PDPA transmitter and receiver are mounted on a stainless steel cart which is located inside the exposure chamber, while the signal processor

and acquisition system are located outside the chamber with cabling routed through the chamber wall. The transmitter and receiver are covered with a protective Lucite housing to protect them from acidic fogs within the exposure chamber. Dry air is passed over transparent windows to prevent droplets from collecting on them and distorting the signal.

The PDPA requires a flow system to direct fog droplets through the sampling volume which is defined by the intersecting laser beams. Fog droplets are sampled at velocities between 0.5 and 2 meters/second by flowing a small amount of chamber air through a suction tube mounted directly below the laser beam intersection. The velocity can be varied by inserting orifices of different sizes into the suction tube.

4.3.1.1. PDPA Calibration System

The PDPA was calibrated by Aerometrics using a monodispersed droplet stream prior to shipment. The accuracy and precision of measurements made with the PDPA can be routinely checked before an exposure by using a calibration system which can generate both monodispersed spheres and fog droplets in a size range similar to that of the chamber fog generation system. The calibration system consists of a Bird Model 830 Nebulizer (Palm Springs, CA) and duct system that attaches directly to the PDPA suction tube. Monodispered polystyrene latex spheres (up to 0.8 microns) or distilled water fog can be generated to check the PDPA response.

4.3.1.2. Filter Sampler

The liquid water content of the chamber fog is automatically calculated by the PDPA after each measurement cycle. Provisions have also been made to obtain a total filter sample for comparison with the PDPA calculations. The filter sampler consists of a 47 mm glass fiber filter mounted in a Teflon filter holder. The holder is connected to two rotameters (mounted in parallel), a vacuum gauge, and a vacuum pump. A rotameter is selected to give either high or low flowrate while the vacuum gauge indicates the pressure at the filter to monitor filter loading. The filter flowrate can be adjusted between 0-60 liters/min, depending on the chamber liquid water

content. Two sizes of filter inlets have been provided to efficiently collect droplets above 15 microns over the entire range of sampling flowrates. The liquid water content is determined by weighing the filter before and after a recorded sampling interval.

4.3.1.3. Cyclone Sampler

A series cyclone sampler is used to collect several size fractions of fogwater for chemical and gravimetric analysis. The sampler consists of two cyclones and an backup filter. The first cyclone has a 50% cut-point between 5 and 9 microns while the second has a 50% cutpoint between 2 and 4 microns. The backup filter collects the remaining smaller droplets which are not removed by the cyclones. The cyclones are weighed before and after sampling for a prescribed time period to determine the droplet mass distribution with size. Chemical analysis can be performed on the collected fogwater for comparison with data obtained with the automated analytical chemistry subsystem.

4.3.2. Analytical Chemistry Subsystem

The analytical chemistry system for the fog generation and monitoring system comprises a fogwater collector, a sample handling and delivery subsystem, chemical analysis instrumentation, and a data acquisition and control subsystem. The specifications for these components are described below.

4.3.2.1. Fogwater Collector

A modified Caltech String Collector (MCSC) (Pasadena, CA), shown in Figure 3.3, was designed and constructed to collect fogwater from the exposure chamber. The MCSC was designed using the performance criteria listed in Section 3.2.

The housing of the MCSC is constructed of plexiglass. Eight banks of nylon strings, wound on Teflon coated frames, are oriented at a 45 degree angle to the flow from a 7.5 cm square inlet. Chamber air is drawn past

the strings, through a stainless steel flow straightener, and out of the chamber via 10 cm diameter stainless steel duct by a 70 CFM blower. Impacted fog droplets flow down the strings to a Teflon collector. Collected fogwater drains through the Teflon collection block into a glass micro reservoir, where a sample is drawn using a small bore sampling line.

Flow through the MCSC is regulated by a Variac connected to the blower. Flow should be maintained at 2 m^3/min to ensure an adequate fogwater sample collection rate (minimum of 100 ul/min) during periods of low fog (liquid water content < 0.2 g/m^3). A 2.0 m^3/min flow is also required to achieve to the 2.5 m diameter 50% collection efficiency cutpoint. Flow is determined from a measurement of the pressure drop across the flow straightener with a Magnahelic gauge according to the following equation:

$$F = (32.4 \times P + 1.29) \times A \times 60$$

where: F is the flow in m^3/min

A is the inlet area in m^3

P is the pressure drop in inches of water.

A pressure drop of 0.15 inches of water corresponds to a flow of 2 m^3/min and is the nominal operating condition of the MCSC.

The nominal diameter of the nylon string used in the MCSC is 0.011 inches or 280 microns. The nylon stings currently employed in the fog-water collector (Stren 4 lb. test monofilament fishing line) were found to be subject to attack by the high levels of acidity that occur when the strings are subjected to dry conditions after an acidic fog exposure. During routine operation, this situation can be avoided by rinsing the strings with distilled water after collecting acid fogs.

4.3.2.2. Sample Handling and Delivery Subsystem

The sample handling and delivery subsystem transports collected fogwater samples and standards to the chemical instrumentation for analysis. The

subsystem is shown schematically in Figures 4.3 and 4.4. The subsystem consists of four components:

1) A glass micro reservoir between the MCSC and the small-bore sampling line. This custom-made piece of glassware is designed to:
   - Filter the collected fogwater before it is introduced to the small-bore sampling line. Filtration is accomplished by means of a Teflon frit contained in the stainless steel fitting connecting the bottom of the glassware to the sampling line.
   - Allow collected fogwater to accumulate for continuous sampling. An S-shaped, lower side arm maintains the reservoir level above the sampling line inlet.
   - Provide for sample overflow. A lower side arm also serves as the overflow from the MCSC allowing for collection of bulk fogwater samples.
   - Facilitate initial flow through the glass reservoir by allowing sufficient head to build up to push trapped air bubbles out the overflow.
2) A four-port stream selection valve (Valco Instruments Model ECSD4PHC, Houston, TX) that controls the delivery of fogwater samples, analytical standards, manual samples, and distilled water to the injection port of the ion chromatograph (IC);
3) An injection valve for the IC that allows the sample stream to flow continuously through the valve to the pH electrode during sample injection;
4) A peristaltic pump (Cole Parmer Model J-7553-30 with Model J-7021-20 Pumphead, Chicago, IL) to draw the samples and standards through the system.

Small-bore, nonreactive tubing has been used in the sample handling subsystem whenever possible to minimize dead volume and preserve the chemical integrity of the fogwater samples.

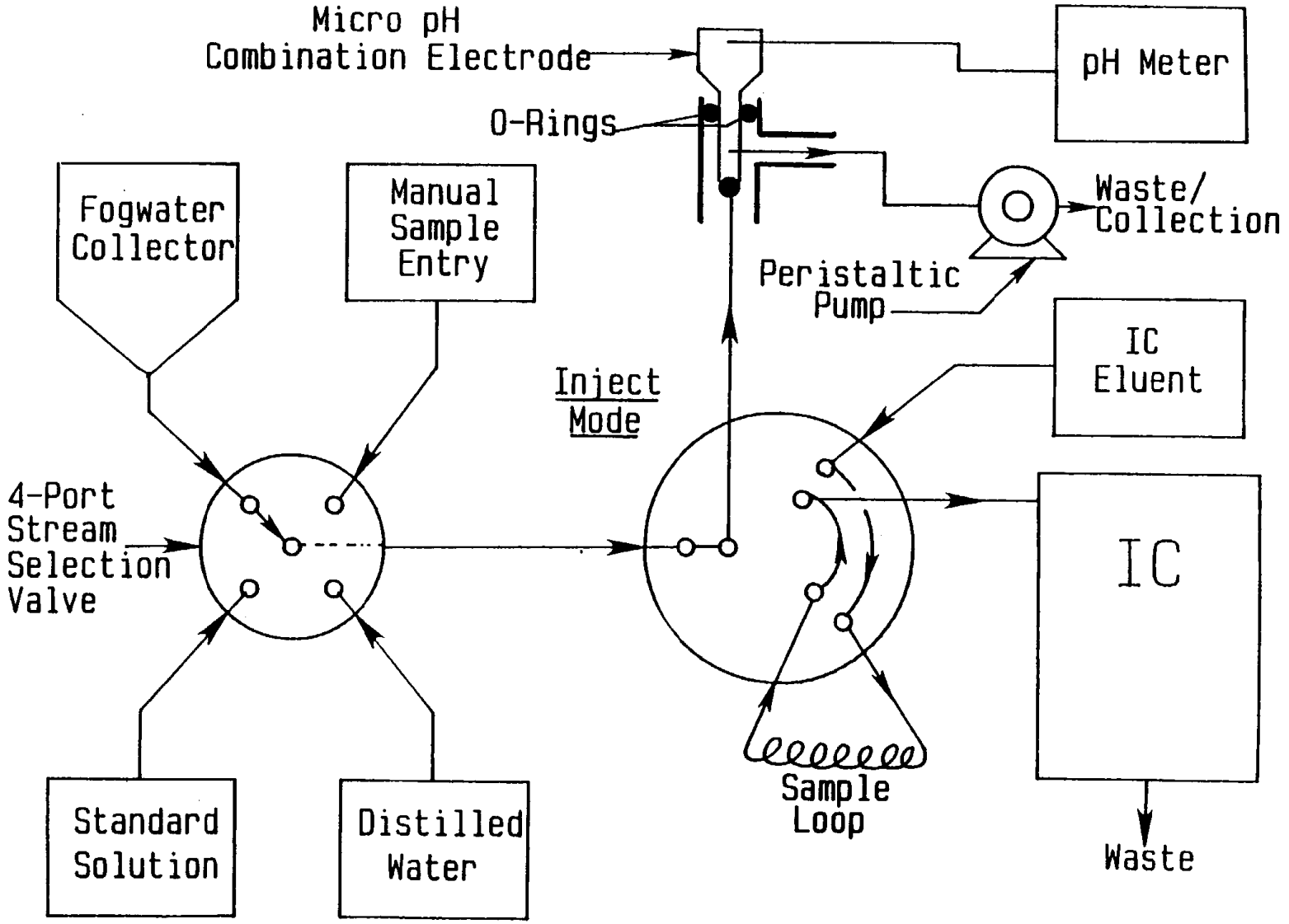

Figure 4.4. Sampling Handling and Delivery Schematic for Inject Mode

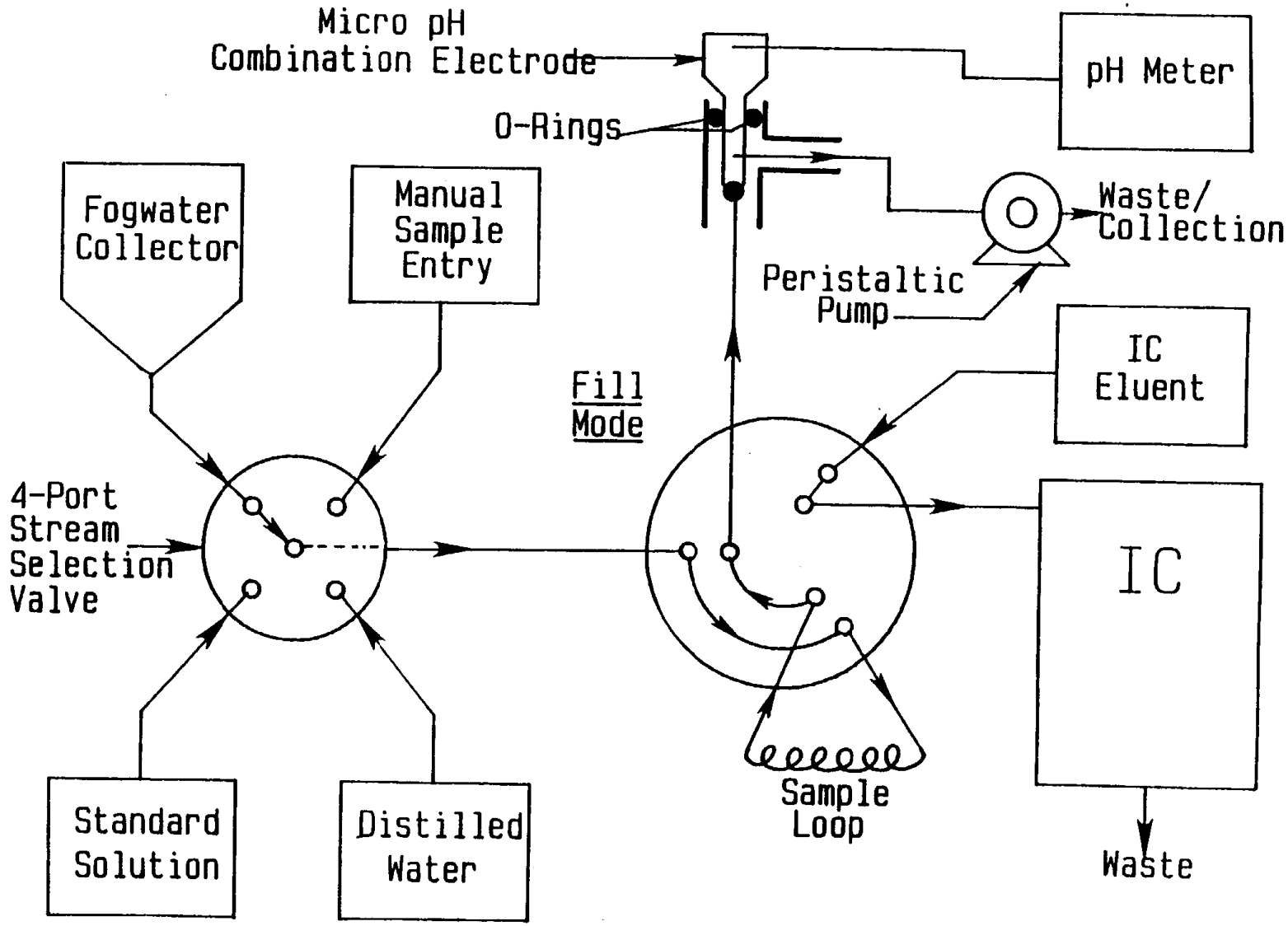

Figure 4.3. Sampling Handling and Delivery Schematic for Fill Mode

The operation of the stream selection and IC injection valves is controlled by the data acquisition and control subsystem described in Section 4.3.2.4. The peristaltic pump is manually controlled by a rheostat.

4.3.2.3. Chemical Analysis Instrumentation

A single channel Dionex ion chromatography system (Model 4000) performs sulfate, nitrate, and ammonium ion determinations on collected fogwater samples. The single channel system analyzes sulfate and nitrate on a semi-continuous basis. Ammonium concentrations are determined on integrated samples collected during the experiment and analyzed after the experiment has been completed.

The pH meter used in the system is a Beckman Model 40 high quality research-type pH meter (Fullerton, CA).

The micro pH combination electrode meets two requirements for successful operation:

1) The electrode body and tip has been designed to minimize the sample volume required for an accurate reading; and
2) The electrode has a response time of less than 10 seconds.

A Lazar Research Labs micro flow-through pH electrode (Model FTPH-1, Los Angeles, CA) is used for continuous pH measurement of collected fogwater samples. The low dead volume (< 50 ul) of its flow cell and available connections to microbore tubing made this system an ideal choice for the present application.

4.3.2.4. Analytical Chemistry Data Acquisition and Control Subsystem

An IBM Personal Computer acquires data and controls the analytical chemistry subsystem. The configuration for the IBM PC is as follows:

360 Kbyte 5 1/4" floppy disk drive
20 Mbyte hard disk
640 Kbyte memory
composite monochrome monitor
IBM color graphics adapter card
serial and parallel ports
clock/calendar
IBM PC-DOS Version 3.1
IBM BASIC Version 3.0
Epson FX80 printer

A data acquisition card and packaged driver software from Strawberry Tree Computer Inc. (Model AC Jr., Sunnyvale, CA) is used to interface with the IC and pH meter to acquire and display real-time data and control the sample handling and delivery subsystem. Specifications for the Strawberry Tree data acquisition hardware and software are:

1) 8 differential analog inputs with 12-bit resolution at 1000 Hz sampling rate, and selectable input voltage ranges;
2) 12 individually controllable digital I/O lines;
3) counter/timer;
4) thermocouple support;
5) interrupt handling; and
6) driver software to interface with high-level programming languages to provide for
   - setup
   - data acquisition
   - data logging
   - real-time data displays
   - timing and process control
   - signal integration
   - communications

A FORTRAN 77 program (ACQUIRE) was written to control the chemical analysis system from the IBM PC. The major features of the control program are listed below.

- real-time acquisition, digitizing, integration, and graphical display of chromatograph data from the IC,
- automated, programmable control of the stream selection valve, IC calibration, and sample injection,
- automated, prerun, postrun, and span check IC calibration procedures,
- real-time, continuous acquisition, digitizing, and graphical display of pH data,
- real-time serial communications interface with the IBM-AT for textual display of chamber operating conditions,
- archival of experimental data files to hard disk and/or floppy disk.

In addition, the ACQUIRE program can be operated in a manual mode to determine the concentrations of low-level filter extracts.

4.3.2.5. Fog Monitoring Subsystem Hardware Configuration

An IBM-AT serves as the master computer for acquiring and storing data and consists of:

20 Mbyte fixed disk
1.2 Mbyte 5-1/4" dual density floppy disk drive
Color graphics video adapter
640 Kb RAM
80287 math coprocessor
Monochrome monitor
Serial and parallel ports
Clock/Calendar
Hewlett-Packard ThinkJet Printer

The IBM PC, described in Section 4.3.2.4, is interfaced to the IBM-AT and serves as a slave computer for acquiring chemistry and chamber operating data, and controls the analytical chemistry instruments.

4.3.2.6. Master Data Acquisition System

The master data acquisition system for the fog monitoring system performs the following tasks using the IBM-AT:

1. allows experiment and configuration setup;
2. tests IBM-PC to IBM-AT communications prior to test;
3. acquires data from the Phase/Doppler Particle Analyzer and the Analytical Chemistry Data Acquisition System;
4. displays critical variables in real time during an experiment;
5. stores data for later processing;
6. post processes the stored data.

4.3.2.7. Data Acquisition

The data acquisition portion of the master data acquisition system samples data from the Phase/Doppler Particle Analyzer at a rate that can be selected by the operator. The recommended sampling interval is 30 seconds between samples. These data are processed to determine the fog droplet number median diameter, volume median diameter, geometric standard deviation, number concentration and liquid water content. These data are screened to determine sampling errors or parameters out of the desired test tolerance. Data are also sampled from the chemical composition system at one minute time intervals. These data consist of the fogwater pH and the percentage by volume of sulfate, nitrate and HMSA. Both processed data and pertinent raw data is stored on the IBM-AT hard disk at the time of the experiment. These data are stored as the average of two sample intervals. Thus, if data are being sampled from the PDPA every 30 seconds, the stored data will be a 1 minute average of two 30 second samples. At the end of the experiment, the data are stored on floppy disk in binary format to be later processed by the post processing program.

4.3.2.8. Experimental Configuration and On-line Status

Prior to the start of an exposure experiment, the monitoring system allows the input of information for the setup of the monitoring equipment and the

tolerance limits for test parameters. A pre-start setup test can be run to insure system integrity. Once the experiment has been started, the program will display the system status in real time. This on-line screen is shown in Figure 4.5. This display is updated every time the PDPA data is acquired (normally every 30 seconds) and is the default display for the program in test mode.

The generator conditions include the numerical values for the flowrates, differential pressures, and chamber inlet and outlet temperature. The displayed droplet conditions include not only the current values but will flash if they are beyond the limits as entered in the test setup program. This enables the operator to modify operating conditions to meet the desired values, or can be used as indicators of improper conditions which will require termination of the test.

4.3.2.9. Data Storage

To enable post processing of the test data, all key parameters plus the test setup values and description are output to floppy disk. This is done at half the data sampling rate. The output is in binary format to minimize the file size for data storage. The post processing program takes this data and allows statistical analysis and plotting of the data to allow hard copy output for test documentation.

4.3.2.10. Display of Critical Variables

Instead of the default on-line status display, the operator has the option to display key variables in different ways while the experiment is proceeding. Figure 4.6 shows an example of a current size distribution and mass distribution display, which represents the most current data taken for this variable. Calculation of several statistical values is also performed and displayed with the histogram and graph. Hard copy of this information can be obtained by running the post processing program after the experiment is completed. Another available display is shown in Figure 4.7. This is a real time display of selected variables versus time. This allows the viewing of the current and past values of several variables.

Fog Monitoring System

12-13-87 10:05:32 0:23:56

GENERATOR CONDITIONS			DROPLET CONDITIONS	
Chamber Air Flow Rate	201	CFM		
Pre-Filter Delta P	5.20	Psid	Mass Med Dia (um)	9.02
HEPA Delta P	4.12	Psid	Geom. Std. Dev.	0.42
Chamber Inlet Temp	21.2	Deg C	Num Concent (#/cc)	54023
Chamber Outlet Temp	22.3	Deg C	Num Median Dia (um)	5.34
			Geom. Std. Dev.	1.32
PDPA SAMPLING CONDITIONS			Liq Content gm/m3	1.28
			Sulfate (MEQ/L)	0.32
Sample Velocity	20.32	m/sec	Nitrate (MEQ/L)	0.31
Sampling Time	9.07	sec	HMSA (MEQ/L)	0.00
Rejection Ratio	4.2	%	pH	4.43

Figure 4.5 On-Line Screen

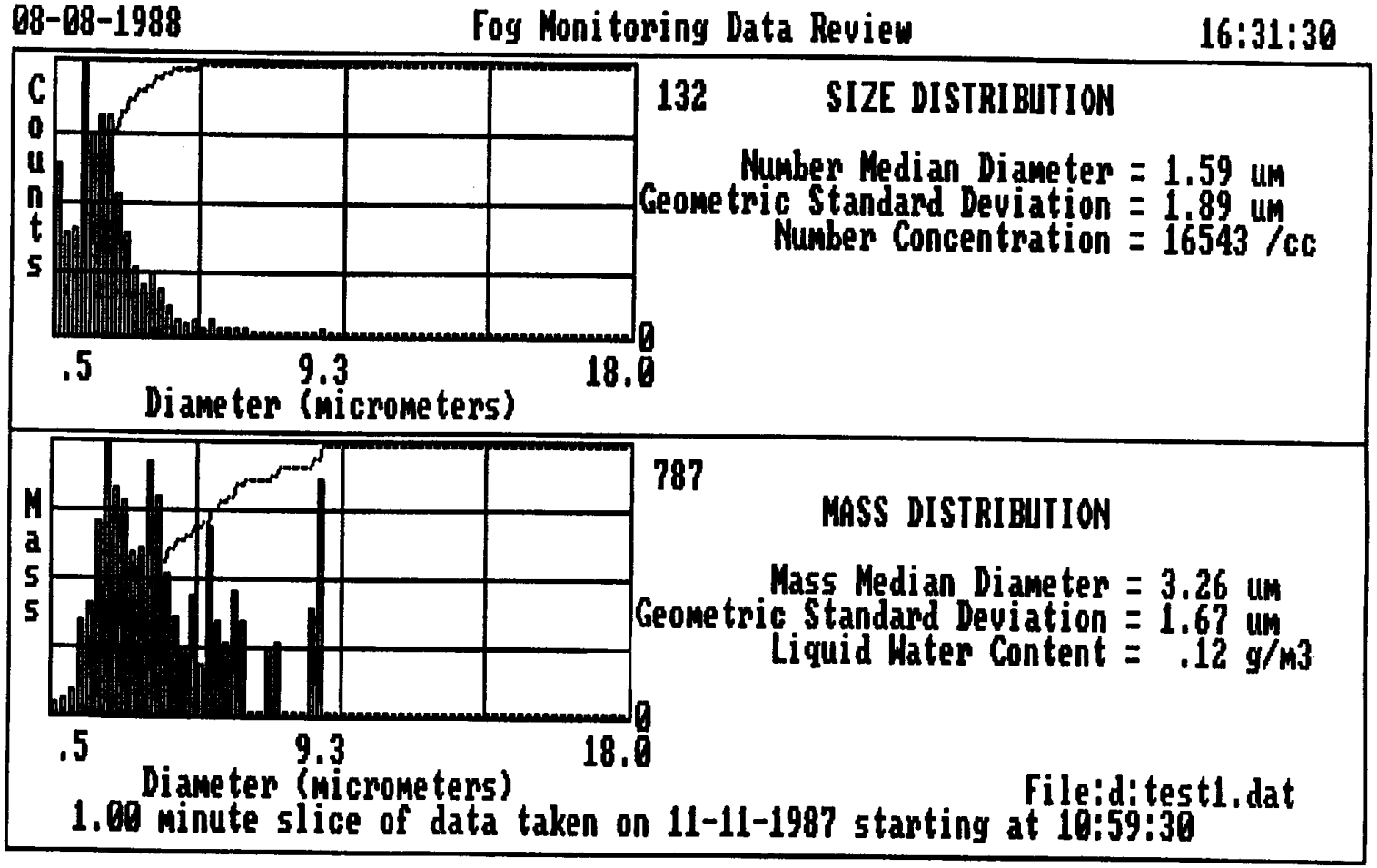

Figure 4.6. Size and Mass Distribution On-Line Display

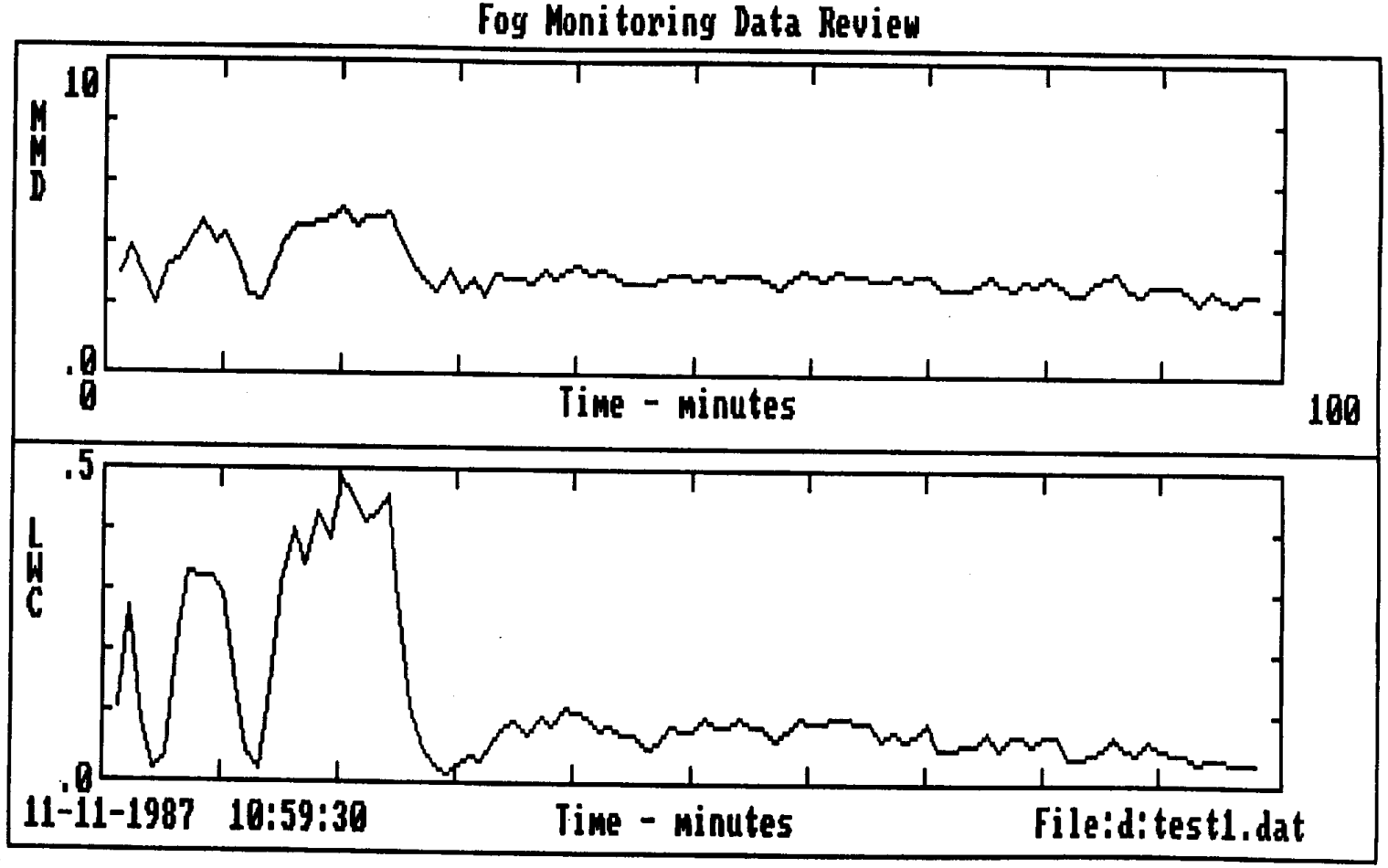

Figure 4.7. Variables versus Time On-Line Display

5. FOG GENERATION AND MONITORING SYSTEM TEST RESULTS

Several tests were conducted after the fog generation and monitoring system was installed in the UCSF exposure chamber at Moffett Hospital, San Francisco. The purpose of these tests was to demonstrate the capability of generating and monitoring stable, spatially uniform fogs over a range of droplet sizes and liquid water contents.

5.1. Uniformity Testing

Several preliminary tests were conducted to evaluate the spatial uniformity of fog within the UCSF exposure chamber by simultaneously collecting filter samples at various locations within the chamber. These data indicate a fairly uniform distribution; however, a lower concentration was measured near the door, indicating that evaporation may be occurring when the door is opened or closed. Additional testing which allows a longer time to reach steady state conditions should be performed to verify these findings.

5.2. Fog Stability with an Exercising Subject

A study was performed to determine the fog stability when a subject exercised at 100 watts for a 20 minute period. A condition of light fog with small mean size was selected for this test, since this condition should be most suspectable to perturbations due to heat load from an exercising subject. The fog consisted of distilled water with no acid present. The fog was allowed to stabilize for 10 minutes after the subject entered the chamber. During the 20 minute exercise period, the droplet size distribution and liquid water content were recorded with the PDPA. Analysis of these data show a very stable fog, with a mean size of 4.16 +/-0.06 microns and a liquid water content of 0.167 +/-0.025 g/m^3. These results verify that movement and heat loads by an exercising subject do not affect fog stability.

5.3. Performance Tests

Four tests were conducted to determine the capability of the fog generation and monitoring system to generate and measure fogs over the following range of conditions:

(1) small droplet size and high liquid water content;

(2) small droplet size and low liquid water content;

(3) large droplet size and low liquid water content; and

(4) large droplet size and high liquid water content.

All of these tests were conducted with an aqueous sulfuric and nitric acid solution of equal concentration at pH 2.0. Droplet size and liquid water content were measured with the PDPA. The cyclone sampler collected fog water for comparative size distribution and liquid water analysis. In addition, a total filter was used to collect fog water for gravimetric analysis to determine the liquid water content.

In general, the data demonstrate the following points regarding the system:

(1) The system was able to generate acidic fogs over a range of mass median sizes from 3.0 to 10.0 microns at concentrations ranging from 0.3 to 4.2 grams/m^3. In one of the tests, the PDPA determined liquid water content within 28% of a total filter sample, while in other cases the deviations were much greater.

(2) The generation of a fog with appreciable liquid water content (i.e., greater than 1 gram/m^3) appears to be limited to a mass median diameter of about 6.0 microns. Smaller sizes can be generated, however, the liquid water content is substantially reduced.

(4) The fogwater collector should not be allowed to dry out when acidic fogs have been sampled. The acid solution can dry and become concentrated, leading to string breakage in the collector.

(5) The solution temperature needs to be controlled in order to maintain a stable fog. Heat can be added to the solution because of recirculation by the high pressure pump.

(6) Fog nozzles can clog if contaminants enter the solution. An in-line filter has been installed to minimize this problem.

(7) Additional testing should be performed to determine the optimum location and number of screens for a desired mass median diameter. If too many dense screens are used, solution may become trapped on the upper screen and divert the air flow around the screen, thereby eliminating its effect.

6. CONCLUSIONS AND RECOMMENDATIONS

The fog generation and Monitoring System installed by ATEC and its subcontractor ERT at the UCSF human exposure chamber at Moffett Hospital has been shown to meet the six design goals presented in Section 2.0. Results of studies conducted under this contract demonstrate that synthetic acidic fogs can be generated and characterized at levels well above ambient concentrations. For research purposes, extremely fine fogs can be produced at reduced concentrations. The information that follows summarizes the salient features of each design goal, discusses important problems that have occurred during operation and testing, and lists recommendations for improved performance.

6.1. Droplet Size and Concentration

Synthetic fogs with droplets ranging in size from 0.5 to 50 microns have been generated at concentrations exceeding 1.0 g/m^3. Initial performance tests demonstrated that the fog size distribution can be varied between 3.0 to 10.0 microns. Concentrations exceeding 1.0 g/m^3 appear to be limited to distributions with mass median diameters above 6.0 microns. The smaller size distribution with low liquid water content may be the result of partial evaporation of the primary fog droplets. Consequently, concentration of chemical species may occur in this situation. Because no quantitative chemical data were available during the performance testing, additional studies are recommended to verify this hypothesis.

6.2. Fog Stability and Uniformity

Stable and uniform fogs have been generated within the UCSF exposure chamber. The fog concentration was determined to be evenly distributed; however, room air entering the chamber when the door was opened was probably responsible for consistently lower concentration measurements near the door. The fog concentration and size distribution within the chamber was demonstrated to be quite stable with a subject exercising at 100 watts. Standard deviations in mass median diameter and liquid water

content (measured with the PDPA) of 1.4% and 15.0% were recorded during a 20 minute period. The system has been operated without subjects for longer periods with similar results.

6.3. Ability to Vary Size and Chemical Composition

The initial size and chemical composition can be varied by adding or removing impaction screens within the droplet generator and changing the chemical composition of the bulk solution. The number and porosity of the screens can greatly influence the resulting fog size distribution and liquid water content. Bench scale studies with a single fog nozzle demonstrated predictable control over the droplet size; the installed system did not exhibit the same behavior. This may be due to the orientation of the screens, which were vertical in the bench scale system and horizontal in the final system. The accumulation of water on the top screen may divert the flow around the screens, thereby decreasing their effect. Baffles were also required to confine the spray within each atomizer bank. Tests conducted with a prototype generator without baffles showed a very non-linear effect between mass output and the number of operating nozzles, possibly due to droplets coalescing in the intersecting sprays.

6.4. Physical and Chemical Characterization

A Phase Dopler Particle Analyzer (PDPA), manufactured by Aerometrics, Inc., was installed to measure the fog droplet size distribution in-situ. The instrument was optically configured to detect droplet diameters between 0.3 and 41 microns. Calibration tests with 0.8 micron diameter monodisperse polystyrene latex spheres confirmed the factory calibration for smaller droplets. Sampling artifacts caused by lens fogging and misalignment were shown to cause substantial errors in size and concentration measurements. Care must be taken to insure proper instrument setup and operation during fog exposure studies. No consistent agreement could be obtained between liquid water measurements made with the PDPA and a total filter. As a result, simultaneous sampling with a total filter is recommended during human exposures. Under fixed

generation conditions, the total filter can be used as a primary measurement of the liquid water content while the PDPA can monitor the relative fluctuations of this parameter.

Fogwater chemical analysis can be performed using: a modified Caltech string collector (MCSC) for collecting fog droplets, a low-dead-volume sample delivery system, a pH meter and combination electrode in a micro-flow cell, a Dionex ion chromatograph (IC), and an IBM microcomputer for automated instrument control and data acquisition. Testing of the chemical analysis subsystem at ERT and UCSF demonstrated the following features:

(1) Fogwater collection with a 50% collection efficiency cutpoint at 2 um diameter with a flowrate of 2 m^3/min. At this flowrate, the MCSC could collect up to 400 ul/min of fog droplets under low liquid water content conditions of 0.2 g/m^3 once steady state sampling conditions are achieved. This sampling rate is more than adequate to provide for real-time continuous pH measurements and semi-continuous chemical analyses at 5 minute intervals with a lag time between sampling and analysis of one to two minutes. However, the time to reach steady state may be unacceptably long at these low liquid water concentrations.

(2) An automated or manually operated interface for controlling the IC and acquiring chromatographs, pH values, and chamber temperature, pressures and flowrates. Moderate to high sulfate and nitrate concentrations (0.05 - 50 mM) are determined by integrating the digitized chromatogram in real-time. Low sulfate and nitrate concentrations (0.01 - 0.05 mM) are determined by a stand-alone integration program, Chromatogchart ASCII (State College, PA), provided a suitable baseline can be specified. Ammonium concentrations could be determined using either of the above methods on bulk samples collected during an experiment and analyzed afterwards.

6.5. Flexibility for Future Aerosol Studies

The fog generation and monitoring system has been designed to accommodate future aerosol and/or multicomponent studies. Aerosols could be generated from dilute aqueous solutions by operating the chamber in a single pass mode. In this configuration, the fog droplet generator would be converted into an aerosol generator by mixing dry, purified air with the droplets at the outlet of the generator. Multi-component studies with fogs and aerosols could be performed by adding a separate aerosol generator to the delivery ducts. However, control over the resulting particle size and mass concentration may be difficult under fog conditions at high relative humidities.

6.6. Data Acquisition and Storage

A micro computer data acquisition and storage system was installed to control and acquire data from the fog generation and monitoring system. A menu driven software package was developed to:

(1) acquire, display, and record chamber operating conditions, size distribution data, and alarm conditions at 30 second intervals;

(2) acquire, display and record fogwater pH, sulfate, nitrate, and HMSA concentration at 5 minute intervals;

(3) process stored data at the end of an experiment.

APPENDIX A

DESIGN CONSIDERATIONS FOR THE CALTECH STRING COLLECTOR

The calculation of droplet collection efficiency is based on the droplet Reynolds number:

$$R_d = v\ d\ p/u$$

where

v = air velocity (cm/sec)
d = droplet diameter (cm)
p = air density (g/cm^3)
u = air viscosity (g/cm-sec)

and on the Stokes number:

$$S_t = \rho_p\ d^2\ v\ \cos\theta\ /18\ \mu R$$

where

ρ_p = droplet density (g/cm^3)
θ = string angle (degrees away from perpendicular to flow)
R = string radius (cm)

There is no simple equation relating droplet collection efficiency to droplet Reynolds number and Stokes number. Instead, Isreal and Rosner (1983) provide a pair of graphs that determine collection efficiency in a two-step process. Thus, collection efficiencies for various string diameters and air velocities were determined by calculation and graphical look up procedures for a variety of design choices.

The procedures discussed above give single string collection efficiencies for the air that interacts with the string (a vertical column of air as wide as the string diameter). To determine removal efficiency from the total air stream we must consider the fraction of air sampled by a single bank of strings. This is given by:

$$f = 2R/S$$

where

R = string radius

S = string spacing

Thus, the collection efficiency for single strings, a, must be weighted by f to determine removal efficiency, b.

$$b = af$$

It is important to note that from the standpoint of air passing through the sampler, b controls the removal efficiency curve, while from the standpoint of describing the size distribution of the collected sample, a controls the collection efficiency curve.

Next, multiple banks of strings are employed, i.e., the air stream is sampled repeatedly. Thus, the overall removal efficiency B is given by

$$B = 1-(1-b)^n$$

where

n = number of banks

Finally, consider the effect that this "compounding" has on the relative collection efficiencies for different size particles. Since large particles are removed more efficiently than small at each bank, the sample collected by each subsequent bank is relatively enriched in small particles. Consider very large particles having a single string collection efficiency,

$$a = 1$$

$$b = af = f$$

then the overall removal efficiency is

$$B = 1 - (1-b)^n = 1 - (1-f)^n.$$

Define F by

$$F = 1 - (1-f)^n$$

This provides a reference for calculating the relative amounts of particles of various sizes which are removed from the airstream. To determine the relative removal efficiency for various particle diameters we plot the values of B for each droplet diameter vs. droplet diameter.

However, to determine the relative collection efficiency for various droplet diameters in the collected fog water sample we plot B/F vs. droplet diameter. Since, as we have mentioned, small droplet removal efficiency gains more from multiple bank compounding than large droplet removal efficiency, the droplet collection efficiency curve for the collected water sample from multiple banks has a lower cutpoint than from a single bank. Mathematically, the collection efficiency for a given droplet diameter, as represented in the collected fog water is given by:

$$A = B/F = \frac{1 - (1-af)^n}{1 - (1-f)^n}$$

A plot of A versus droplet diameter is shown in Figure 3.5 in the main body of the text.

APPENDIX B

EVALUATION OF MAY AND DRI IMPACTORS

B.1 Impactor Performance Equations

Table B-1 gives the equations relevant to impactor design. These equations were derived by algebraic manipulation of the fundamental equations presented in Rader and Marple (1985), substitution of typical values for ambient air density and viscosity, and substitution of Stokes numbers representing 50% particle collection efficiency. This last substitution is possible since the collection efficiency curves in terms of Stokes numbers are nearly identical for all impactors of reasonable design. The square root of the Stokes number at 50% collection efficiency for any reasonable round jet impactor is approximately 0.48. Likewise, for any reasonable rectangular jet impactor this number is 0.78.

In order to obtain sharp cuts and reasonable air velocities, it is necessary to keep the Reynolds number between about 500 and 10,000. Lower Reynolds numbers will produce unsharp cuts. Higher Reynolds numbers will result in higher velocities leading to increased droplet shatter and to increased pressure drops. Droplet shatter will result in sample loss and high pressure drops could result in sample evaporation. Note that choosing cutpoint and Reynolds number fixes the values of jet width and jet velocity, and, therefore, total flowrate.

B.2 May Impactor

The May glass bulb collector is essentially a single, round jet impactor. The impaction surface is concave toward the jet. This curved surface is probably a more efficient collector than a flat impaction surface. Nonetheless, the collection characteristics of the bulb collector will be very similar to those of the standard round jet impactor configuration analyzed by Rader and Marple.

Table B-1. Impactor Design Equations

Impactor Type	
Rectangular	Single Circular Jet
$W = D_{50} \sqrt{R_e} (2.035 \times 10^{-3})$ $V = (\sqrt{R_e} / D_{50})(86.13)$ $F = L R_e (4.575 \times 10^{-3})$	$W = D_{50} \sqrt{R_e} (2.035 \times 10^{-3})$ $V = (\sqrt{R_e} / D_{50})(74.96)$ $F = D_50 (R_e)^{3/2} (1.463 \times 10^{-5})$

Given:

- R_e = Reynolds number for jet
- D_{50} = Particle diameter at 50% collection efficiency (um)
- W = Jet width (cm)
- L = Jet length (cm)
- V = Jet velocity (cm/sec)
- F = Jet flow (l/min)

Data from May (1961) indicates that the collector is operated at a Reynolds number of 8745 and archives a cutpoint of 5 microns. Plugging these values into the equations of Table A-1 we realize the values shown in Table B-2. These values are in fairly good agreement with May's data, confirming the accuracy of the design equations.

Also shown in Table B-2 are values of jet width, velocity, and flowrate for a cutpoint of 2.5 microns at two Reynolds numbers. A Reynolds number of 2,500 is a reasonable design choice; 10,000 is at the upper limit of recommended values. It is clear that the sample flowrate of the May impactor is inadequate to meet the design goal of a 2.5 micron cutpoint and 1,200 lpm for any reasonable Reynolds number.

B.3 DRI Impactor

The DRI impactor is a rectangular jet impactor. The actual configuration is three jets of the same length but for the purposes of analysis we have treated the impactor as having one jet of three times the length. Table A-3 shows the jet width, velocity and flowrate for three different sets of cutpoint and Reynolds number. The first is for the standard operating configuration: cutpoint at 5 microns and Reynolds number at 10,534. The results are in fairly good agreement with the data reported in Katz and Miller (1984), confirming the accuracy of the design equations.

The next set of numbers shows that by decreasing jet slot width to 0.23 cm while maintaining impactor length and flowrate, the cutpoint is reduced to 2.5 microns. The disadvantage of this design is that velocity has been increased about 176%. The increase in velocity can be expected to result in a threefold increase in operating pressure drop.

The next set of numbers shows that the original velocity and total flow can be achieved at a 2.5 micron cutpoint by tripling sampler length and taking one-third the slot width. The disadvantage here is that the wetted surface area per unit flow has increased threefold. Also the sampler performance is more likely to be affected by tolerances on the jet width.

Table B-2. Design Choices for May Circular Jet Impactor

Characteristics	Design*		
	A	B	C
Jet Width (cm)	0.80	0.24	0.48
Jet Velocity (cm/sec)	1657	1580	3160
Jet Flow (l/min)	50.0	4.3	17.2
Reynolds Number	8745	2500	10000
50% Cut Diameter (um)	4.2	2.5	2.5

*Design A: Current design.
Design B: 2.5 um cutpoint, moderate Reynolds Number.
Design C: 2.5 um cutpoint, high Reynolds Number.

A visit was made to Rancho Los Amigos Hospital to measure pressure drop through the standard DRI collector and to discuss operating behavior of the collectors with researchers who operate the collector in an exposure chamber. Pressure drop behind the sampler was observed to be 5 inches of water at the standard operating flowrate and varied as the square of the flowrate.

This pressure drop represents an expansion of air which would reduce relative humidity by about 1.3%. In a pure water system at 20 degrees Centigrade, approximately 0.21 grams of water per cubic meter would have to evaporate to restore the system to 100% relative humidity. Since the evaporation would come primarily from smaller particles, the collected sample is probably not significantly affected. However, the potential for collection of a fine droplet sample from air which has passed through the sampler is doubtful. In any event, designs modifications which increase pressure drop should be avoided.

The researchers reported no problems with sample clinging to the wetted surface. The squeegee action of the Teflon rollers appears to work very effectively. Thus, design modifications that require increased sampler length should provide little problem as a result of increased wetted surface. This suggests design C shown in Table B-3 is the most favorable modification to the DRI impactor for chamber sampling.

The only difficulty with the DRI sampler reported by the researchers was difficulty in cleaning. This is related to the complex construction of the sampler which is also a disadvantage in terms of cost, reliability, and adaptability of the sampler. Another disadvantage of this collector is the requirement for an electric motor in the fog laden chamber, though the researchers reported no problems in this regard.

Table B-3. Design Choices for Rectangular Jet Impactor

Characteristics	Design*		
	A	B	C
Jet Width (cm)	0.40	0.23	0.13
Jet Length	24.9	24.9	75.3
Jet Velocity (cm/sec)	2008	3492	2008
Jet Flow (l/min)	1200	1200	1200
Reynolds Number	10534	10534	10534
50% Cut Diameter (um)	4.35	2.50	2.50

*Design A: Current DRI design.
Design B: Current length and flow rate design; width and velocity changed.
Design C: Current velocity and flow rate design; width and length changed.

Appendix 2

OPERATIONS MANUAL FOR THE FOG GENERATION AND MONITORING SYSTEM

for

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by

Atmospheric Technology
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November 23, 1988

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1. INTRODUCTION

This document provides specifications and operating procedures for an acid fog generation and monitoring system which was developed by Atmospheric Technology (ATEC) and ERT and installed in the human exposure chamber at the University of California San Francisco (UCSF). This system has the capability of generating and monitoring synthetic acid fog within a 12 m^3 chamber over a range of droplet sizes, mass concentrations, and chemical compositions. The design is based on a preliminary design concept developed under Phase I of the state of California Air Resources Board (ARB) Contract A4-079-33.

The general specifications for the fog generation and monitoring system are reviewed in the next section, followed by an overview of the integrated system. Section 3.0 discusses the components on an individual basis, including selection rational, operating characteristics and performance limitations. Detailed operating instructions are given in Section 4.0, including system setup, start-up, running an experiment, and ending an experiment. This section is followed by information pertaining to periodic maintenance of the system. The last section presents details on post processing of experimental data.

2. GENERAL SPECIFICATIONS

The Fog Generation and Monitoring System has been designed to produce acidic fogs for human exposure studies over a wide range of conditions. In general, the system is capable of:

(1) producing and monitoring fog droplets ranging in size from 0.5 to 50 microns (with emphasis on droplet below 10 microns in diameter) at concentrations exceeding one gram per cubic meter;

(2) generating stable and uniform fogs within the exposure chamber for periods of several hours;

(3) varying the initial size and chemical composition of the fog droplets;

(4) determining the fog size distribution, liquid water content, and chemical composition on a semi-continuous basis;

(5) accommodating aerosol generation and monitoring equipment for future multi-component studies;

(6) providing computerized data acquisition and storage to minimize operator intervention during experiments;

2.1. System Overview

The fog generation and monitoring system, shown schematically in Figure 2.1, consists of three subsystems: (1) a generation subsystem which produces droplets from a bulk solution, (2) a delivery subsystem which circulates the fog through the exposure chamber, and (3) a monitoring subsystem which determines the size distribution, liquid water content, and chemical composition of the droplets.

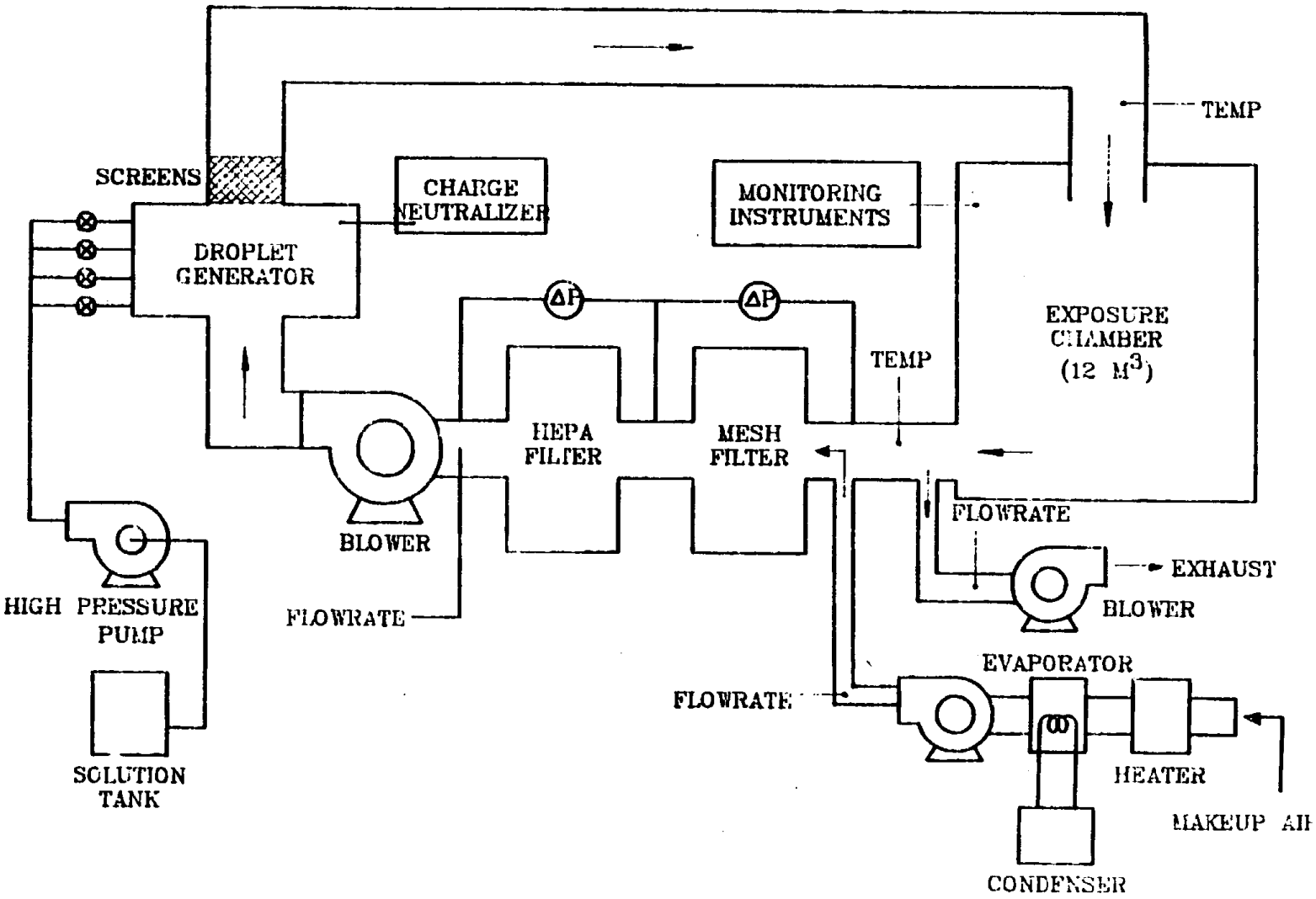

Figure 2.1 Fog Generation and Monitoring System Schematic

2.1.1. Fog Generation Subsystem

Fog droplets are produced using hydraulic atomizers located on several manifolds mounted inside a sealed chamber. Bulk solution is stored in a tank and pumped to the atomizers. Manual valves allow the selection of one or more manifolds containing combinations of atomizers. Two series of screens are located down stream of the atomizers to remove larger droplets in order to control the droplet size distribution.

2.1.2. Fog Delivery Subsystem

The fog droplets produced by the droplet generator are circulated through the exposure chamber using a centrifugal blower connected with flexible ducts. Distribution ducts are mounted along the ceiling of the exposure chamber to evenly distribute the fog. The exhaust air from the chamber passes through ducts mounted along the perimeter of the chamber floor and then flows to a mesh filter which removes the larger droplets and the majority of liquid water. The output from the mesh filter is directed through a HEPA filter to remove the remaining small droplets. The remaining filtered air at high humidity is returned to the droplet generator, where fog droplets are generated and cycled back to the chamber.

A portion of the chamber air is replaced to eliminate the buildup of contaminating gases produced by human subjects. Approximately 10% of the flow is exhausted from the chamber outlet and replaced with air drawn through the existing chamber air purification system. The makeup air is added at the inlet to the mesh filter, which acts as a humidifier, since it contains a large surface area covered with moisture from entrained droplets. Thus, the air returning to the droplet generator is near saturation, even though a fraction of unsaturated air has been added to the system.

2.1.3. Fog Monitoring Subsystem

The fog monitoring system consists of automated instrumentation capable of physically and chemically analyzing fog droplets within the exposure chamber on a semicontinuous basis. A droplet sizing instrument, capable of detecting droplets as small as 0.3 microns in diameter, is located inside the exposure chamber and samples at predetermined time intervals, depending on the fog concentration.

A fogwater collector continuously samples the chamber air and extracts droplets for chemical analysis. Fogwater samples are analyzed for sulfate, nitrate, ammonium, and pH on a semi-continuous basis. A series cyclone sampler and total filter are used to obtain additional information on liquid water content and chemical composition.

Data from the sizing and analytical chemistry instruments is processed and stored using two microcomputers. Figure 2.2 provides a schematic representation of the data transfer and control signals used in this process. In addition, the computers provide status information and historical data for the experiment in progress.

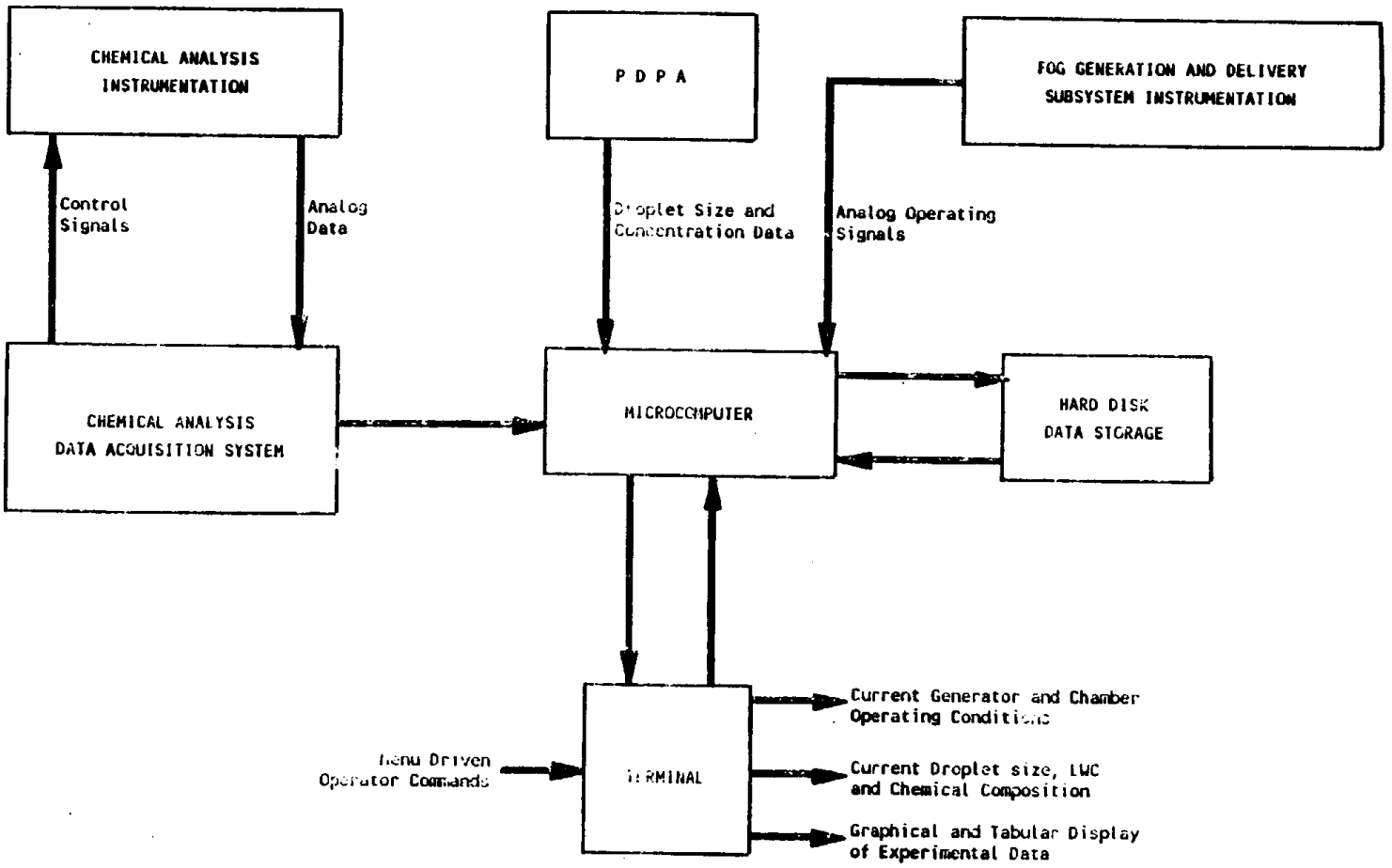

Figure 2.2. Fog Generation and Monitoring Data Acquisition System Schematic

3. SYSTEM COMPONENT DESIGN AND SPECIFICATIONS

This section contains details regarding the performance of individual components within each major subsystem detailed in Section 2.0. Whenever possible, specific components were selected from an evaluation of commercially available equipment.

3.1. Fog Generation Subsystem

The fog generation subsystem consists of a droplet generator, high pressure pump, and solution storage tank.

3.1.1. Droplet Generator

The droplet generator, shown in Figure 3.1, consists of a 24"Lx24"Wx24"H Teflon coated stainless steel chamber containing 37 Bete PJ8 atomizing nozzles which produce droplets over a wide size distribution. The nozzles are mounted on six manifolds located near the bottom of the droplet generation chamber. Stainless steel plug valves are installed such that one or more manifolds can be individually activated, thereby providing control over the number of droplets that are produced. The nozzles are arranged in banks of 1, 2, 4, 10, 10 and 10, so that different combinations can be selected.

The droplet size is controlled by using 18 mesh stainless steel screens at two locations within the droplet generator One or more layers of screens are placed in removable baffles mounted directly above each atomizer bank. These screens and baffles remove the coarse droplets which contribute to scavenging of smaller droplets. A second layer of screens is mounted in a removable frame located near the generator outlet. These screens remove additional large droplets to further reduce the droplet size distribution. In addition to varying the number of screens, the porosity can also be changed to alter the droplet size. Screen sizes of 18 mesh x 0.017 in. diameter wire (48% open area) and 18 mesh x 0.009 in. diameter wire (70% open area) are available for this purpose.

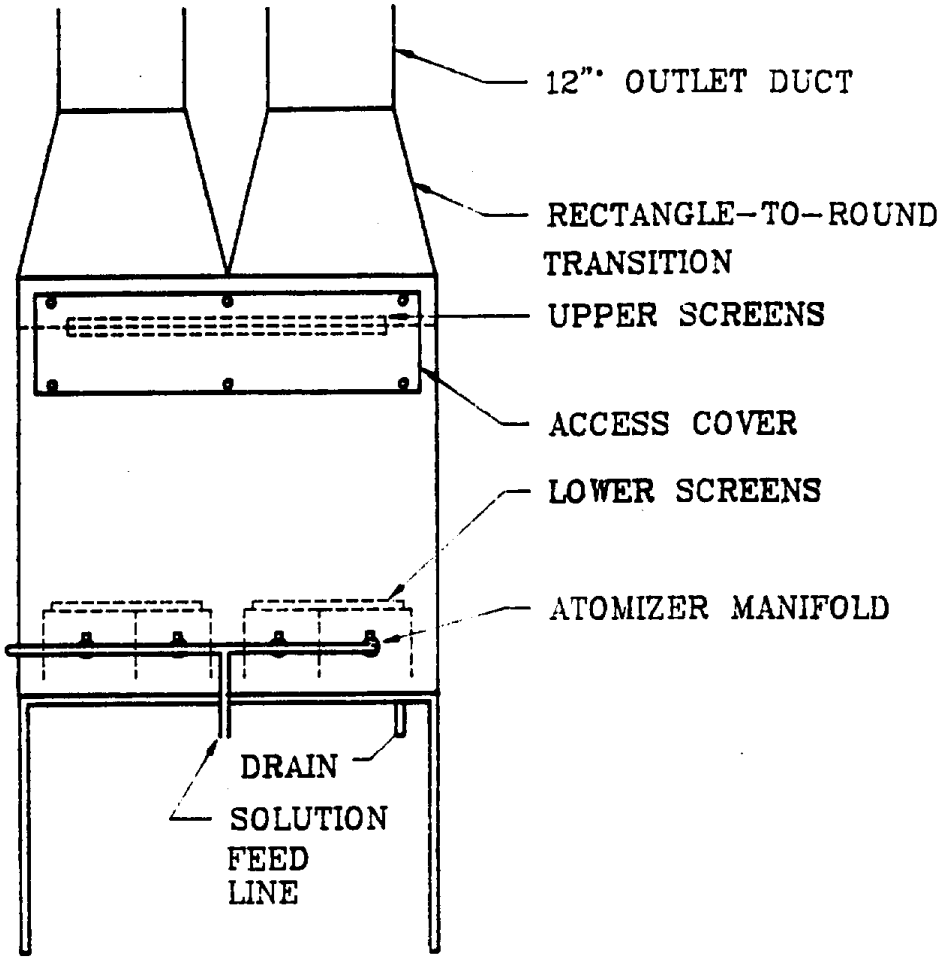

Figure 3.1. Droplet Generator

3.1.2. Solution Tank

The solution to be atomized is pre-mixed and stored in a 15 gallon polyethylene storage tank. The tank contains isolation valves and PVC unions to facilitate cleaning. A cooling coil (3/8" OD x 0.035" wall thickness x 20 ft.) maintains the solution temperature. A stainless steel thermometer is mounted in the top of the tank to monitor the solution temperature.

3.1.3. Solution Pump

A high pressure stainless steel pump is used to pressurize the solution for atomization. The pump is a CAT Model 281 pump (Minneapolic, MN) with all wetted parts in contact with type 316 stainless steel. A Model 7001.100 stainless steel pressure regulator allows the pressure to be varied from 300-1000 psig. The pressure is monitored with a 0-1500 psig stainless steel pressure gauge mounted on the regulator. The pump is powered by a belt driven 2 HP electric motor. The pump and motor are skid mounted. A Nupro Model SS-6TF2-140 stainless steel mesh filter (140 micron) (Willowby, OH) is located down stream of the pressure regulator to prefilter the solution flowing to the atomizers.

3.2. Fog Delivery Subsystem Components

The fog delivery subsystem circulates the fog produced by the droplet generator in a closed loop mode through the exposure chamber. The components associated with this subsystem include the blower, ducts, droplet filtration system, and makeup air system.

3.2.1. Blower

A backward inclined centrifugal blower, Central Blower Model No. FC-109SR (Los Angeles, CA), is used as the primary air mover in the fog generation system. It is capable of delivering air at flowrates in excess of 400 ft^3/min at static pressures up to 2.0 inches of water. A manually activated damper is located at the blower outlet to adjust the circulation

rate through the chamber. The blower housing and impeller have been Teflon coated for corrosion resistance.

3.2.2. Flowmeter

The chamber air flowrate is monitored with a Kurz Model 430 DC air velocity meter (Monterey, CA). The meter consists of a hot wire velocity probe powered by a 12 volt regulated power supply. The probe is mounted in a section of 9" diameter duct down stream of the Droplet Filtration System. The output of the air velocity probe is monitored by the data acquisition system, which converts the air velocity voltage signal into flowrate.

3.2.3. Ducts

Three flexible round Teflon lined ducts, 12 inches in diameter, are used to connect the fog generation system to the exposure chamber. Flexible ducts were selected over rigid ducts so that, if necessary, the system can be easily disassembled for cleaning. Also, flexible ducts reduce noise transmission. The inlet ducts are connected to two square-to-round transitions mounted at the top of one of exposure chamber walls. The other end of each square to round transition is connected to a 13 inch square duct which run the full length of the chamber, as illustrated in Figure 3.2. The rigid duct is constructed from 22 and 24 gauge Type 316 stainless steel. The stainless steel is Teflon coated for additional chemical resistance. These ducts have holes on each side to evenly distribute the fog within the exposure chamber. A tray is attached to the bottom of the ducts to prevent fogwater from dripping on equipment or subjects. The chamber air is exhausted through stainless steel ducts mounted on the perimeter of the chamber floor. These ducts are manifolded to a square-to-round transition located at the bottom of the chamber wall. A flexible Teflon lined duct attaches the transition to the inlet of the droplet filtration system.

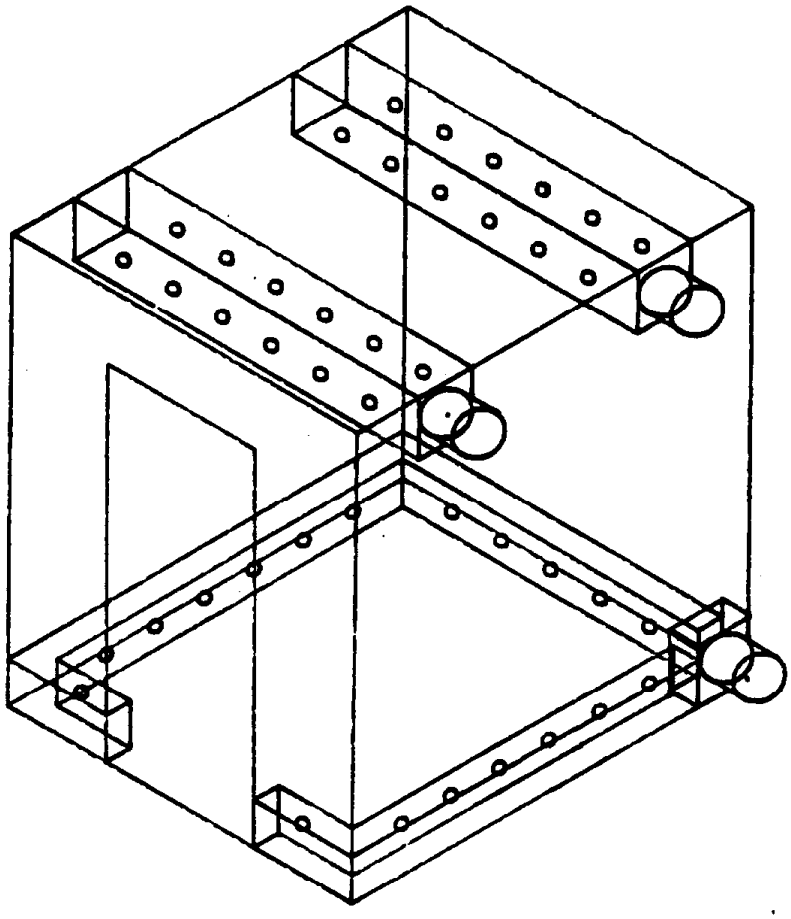

Figure 3.2. Exposure Chamber Air Distribution System

3.2.4. Droplet Filtration System

After the air exits the chamber, the droplets are removed using a filtration system which provides humidified, filter air to transport new droplets to the chamber. Circulating the air decreases the amount of evaporation and increases droplet stability.

The droplet filtration system consists of two components: a mesh collector to remove a large fraction of the liquid water associated with droplets larger than several microns in diameter, and a HEPA filter to remove the remaining small droplets.

3.2.4.1. Mesh Collector

The mesh collector consists of an ACS Industries Style 8TW layered mesh unit (Houston, TX), 23"x23"x18" thick, with Teflon fibers and type 316 stainless steel wire. The Teflon is a 10-20 micron multifilament fiber co-knitted to a 0.011 in. diameter stainless steel wire. Type 316 stainless steel grids are used to keep the mesh in place. The mesh collector is installed in a Teflon coated stainless steel housing. Pressure taps, located at each end of the filter, are attached to differential pressure gauges and transducers to monitor filter loading. The pressure drop is measured with a Dwyer Model 2010 Magnehelic differential pressure gauge (Michigan City, IN) and an Omega Model PX163-005BD5V pressure transducer (Stamford, CT). The output of the pressure transducer is interfaced to the data acquisition system.

3.2.4.2. HEPA Filter

A HEPA filter is used to collect the small droplets which pass through the mesh collector. A treated glass fiber filter medium has been selected, since this type of filter material has been proven to be resistant to harsh environments and has been installed in production processes using moisture laden air.

The HEPA filter consists of a Flanders Model 7033IU-GGF filter (Washington, NC) with a nominal rated capacity of 1000 CFM. Operating the filter at 400 CFM results in a differential pressure less than 0.5 in. w.c. The filter has a minimum collection efficiency of 97% at 0.3 microns and 100% at 1.0 microns. A Dwyer Model 2010 Magnehelic differential pressure gauge and Omega Model PX163-000BD5V pressure transducer monitors the pressure drop across the filter during operation. The output of the pressure transducer is interfaced to the data acquisition system.

3.2.5. Makeup Air System

A small portion of the air circulating through the droplet generation system is exhausted and replaced with filtered air from the chamber air purification system. A maximum of 70 CFM of air can removed using the fogwater collector described in Section 3.3.2.1. The replacement air is introduced into the inlet of the mesh filter so that it can be humidified while passing through the large surface area of wet mesh. A Dayton Model 4C818 blower (Chicago, IL) and Variac are used to regulate the air flowrate. A Dwyer Model 2001 Magnehelic differential pressure gauge is used to measure the pressure drop across the fogwater collector to monitor the flowrate.

A separate air conditioning system has been installed on the makeup air system to regulate the chamber temperature at 70^{o}F. This system consists of Colmac DXMA5X5X10-6 direct expansion evaporator, a Tecumesch AE2410 condenser (0.25 HP), and a 1000 watt strip heater. The unit is run at constant suction pressure to prevent the evaporator coils from forming excessive ice. The strip heater is mounted upstream of the evaporator to reduce icing and to provide a rapid response to temperature changes. A thermostat with a remote sensing unit mounted inside the chamber monitors outlet temperature and varies the current to the strip heater to adjust the temperature to the desired set point. This system has been designed to remove the heat generated by one subject exercising heavily for a one hour period.

3.3. Fog Monitoring Subsystem

The fog monitoring subsystem consists of instrumentation to determine the size, liquid water content, and chemical composition of the chamber fog droplets. Major components include: a Phase Doppler Particle Analyzer, a series cyclone sampler, a total filter, a fogwater chemical analysis system, and a computerized data acquisition and storage system.

3.3.1. Phase Doppler Particle Analyzer

An Aerometrics Phase Doppler Particle Analyzer (PDPA) (Mountain View, CA) measures the fog droplet size distribution and number concentration within the exposure chamber. The PDPA measures the size and velocity of droplets above 0.3 microns in diameter by optical methods similar to those used in a laser Doppler velocimeter, in which two intersecting laser beams define a sampling volume. When a particle passes through the intersecting region, an interference fringe pattern is formed by the scattered light. Since the particle is moving, the scattered interference pattern sweeps past the receiver aperture at the Doppler difference frequency which is proportional to the particle velocity. The spatial frequency of the fringe pattern is inversely proportional to the particle diameter.

The measurement range of the PDPA can be varied from 0.3 to 3000 microns by changing optical components. For the fog exposure chamber measurements, the PDPA transmitter has been installed with a beam expander and operates with a wide beam separation to give the smallest sampling volume to increase resolution of the small droplets. A 100 micron slit is used in the receiver to increase light gathering to enhance the signals from the smaller droplets. With the PDPA assembled in this configuration, the available size span ranges from 0.3 to 41 microns. Over this span, a droplet measurement range of 1:35 can be specified with the software. Thus, the smallest size range that can be selected is 0.3 to 11.0 microns and the largest range is 1.2 to 41 microns.

The PDPA transmitter and receiver are mounted on a stainless steel cart which is located inside the exposure chamber, while the signal processor

and acquisition system are located outside the chamber with cabling routed through the chamber wall. The transmitter and receiver are covered with a protective Lucite housing to protect them from acidic fogs within the exposure chamber. Dry air is passed over transparent windows to prevent droplets from collecting on them and distorting the signal.

The PDPA requires a flow system to direct fog droplets through the sampling volume which is defined by the intersecting laser beams. Fog droplets are sampled at velocities between 0.5 and 2 meters/second by flowing a small amount of chamber air through a suction tube mounted directly below the laser beam intersection. The velocity can be varied by inserting orifices of different sizes into the suction tube.

3.3.1.1. PDPA Calibration System

The PDPA was calibrated by Aerometrics using a monodispersed droplet stream prior to shipment. The accuracy and precision of measurements made with the PDPA can be routinely checked before an exposure by using a calibration system which can generate both monodispersed spheres and fog droplets in a size range similar to that of the chamber fog generation system. The calibration system consists of a Bird Model 830 Nebulizer (Palm Springs, CA) and duct system that attaches directly to the PDPA suction tube. Monodispered polystyrene latex spheres (up to 0.8 microns) or distilled water fog can be generated to check the PDPA response.

3.3.1.2. Filter Sampler

The liquid water content of the chamber fog is automatically calculated by the PDPA after each measurement cycle. Provisions have also been made to obtain a total filter sample for comparison with the PDPA calculations. The filter sampler consists of a 47 mm glass fiber filter mounted in a Teflon filter holder. The holder is connected to two rotameters (mounted in parallel), a vacuum gauge, and a vacuum pump. A rotameter is selected to give either high or low flowrate while the vacuum gauge indicates the pressure at the filter to monitor filter loading. The filter flowrate can be adjusted between 0-60 liters/min, depending on the chamber liquid water

content. Two sizes of filter inlets have been provided to efficiently collect droplets above 15 microns over the entire range of sampling flowrates. The liquid water content is determined by weighing the filter before and after a recorded sampling interval.

3.3.1.3. Cyclone Sampler

A series cyclone sampler is used to collect several size fractions of fogwater for chemical and gravimetric analysis. The sampler consists of two cyclones and an backup filter. The first cyclone has a 50% cut-point between 5 and 9 microns while the second has a 50% cut-point between 2 and 4 microns. Table 3.1 lists the cut-point for several sampling flowrates. The backup filter collects the remaining smaller droplets which are not removed by the cyclones. The cyclones are weighed before and after sampling for a prescribed time period to determine the droplet mass distribution with size. Chemical analysis can be performed on the collected fogwater for comparison with data obtained with the automated analytical chemistry subsystem.

3.3.2. Analytical Chemistry Subsystem

The analytical chemistry system for the fog generation and monitoring system comprises a fogwater collector, a sample handling and delivery subsystem, chemical analysis instrumentation, and a data acquisition and control subsystem. The specifications for these components are described below.

3.3.2.1. Fogwater Collector

A modified Caltech String Collector (MCSC) (Pasadena, CA), shown in Figure 3.3, was designed and constructed to collect fogwater from the exposure chamber. The MCSC was designed to have the following performance characteristics:

1) 50% collection efficiency for 2.5 um diameter droplets;

Table 3.1. Cyclone Cut Points for Sampling Flowrates of 14.2 and 28.3 lpm

Cyclone No.	Flowrate (lpm)	D_{50} Cut Points (um)
1	14.2	8.4
1	28.3	5.4
2	14.2	3.5
2	28.3	2.1

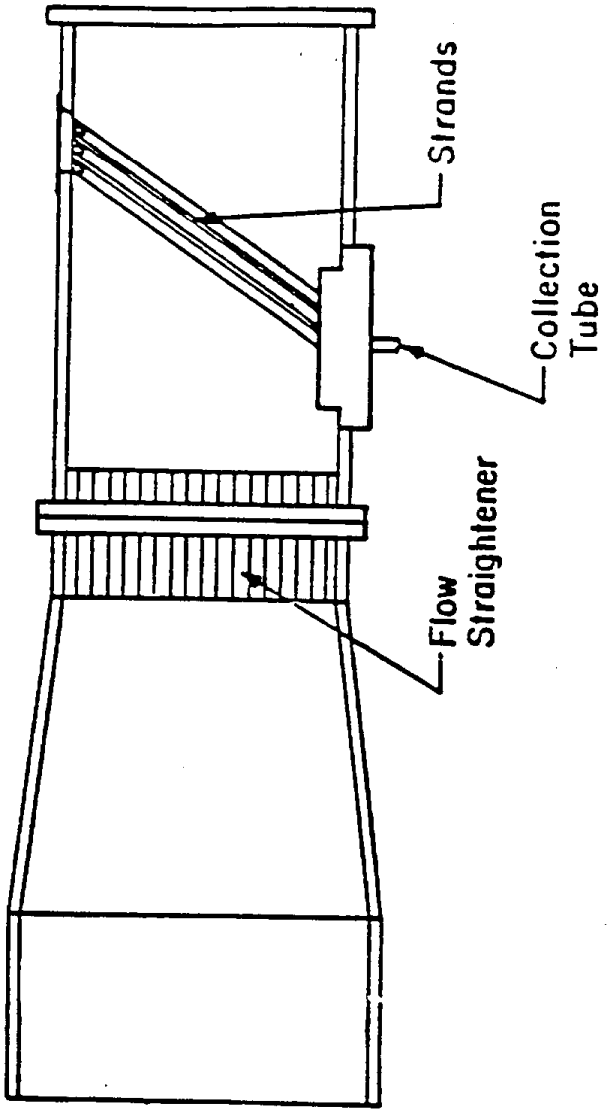

Figure 3.3. Caltech Active String Collector

2) adequate sample volume for analyses at 5 minute intervals over a range of 0.2 to 2.0 g/m^3 liquid water content (LWC); and

3) up to 2.0 m^3/min flow at a pressure drop of 50" of water in exhaust mode or up to 10 m^3/min flow at a pressure drop of 0.5" of water in recirculation mode.

The housing of the MCSC is constructed of plexiglass. Eight banks of nylon strings, wound on Teflon coated frames, are oriented at a 45 degree angle to the flow from a 7.5 cm square inlet. Chamber air is drawn past the strings, through a stainless steel flow straightener, and out of the chamber via 10 cm diameter stainless steel duct by a 70 CFM blower. Impacted fog droplets flow down the strings to a Teflon collector. Collected fogwater drains through the Teflon collection block into a glass micro reservoir, where a sample is drawn using a small bore sampling line.

Flow through the MCSC is regulated by a Variac connected to the blower. Flow should be maintained at 2 m^3/min to ensure an adequate fogwater sample collection rate (minimum of 100 ul/min) during periods of low fog (liquid water content < 0.2 g/m^3). A 2.0 m^3/min flow is also required to achieve to the 2.5 m diameter 50% collection efficiency cut-point. Flow is determined from a measurement of the pressure drop across the flow straightener with a Magnahelic gauge according to the following equation:

$$F = (32.4 \times P + 1.29) \times A \times 60$$

where: F is the flow in m^3/min

A is the inlet area in m^3

P is the pressure drop in inches of water.

A pressure drop of 0.15 inches of water corresponds to a flow of 2 m^3/min and is the nominal operating condition of the MCSC.

The nominal diameter of the nylon string used in the MCSC is 0.011 inches or 280 microns. The nylon stings currently employed in the fog-water collector (Stren 4 lb. test monofilament fishing line) were found to be subject to attack by the high levels of acidity that occur when the

strings are subjected to dry conditions after an acidic fog exposure. During routine operation, this situation can be avoided by rinsing the strings with distilled water after collecting acid fogs.

3.3.2.2. Sample Handling and Delivery Subsystem

The sample handling and delivery subsystem transports collected fogwater samples and standards to the chemical instrumentation for analysis. The subsystem is shown schematically in Figures 3.4 and 3.5. The subsystem consists of four components:

1) A glass micro reservoir between the MCSC and the small-bore sampling line. This custom-made piece of glassware is designed to:
   - Filter the collected fogwater before it is introduced to the small-bore sampling line. Filtration is accomplished by means of a Teflon frit contained in the stainless steel fitting connecting the bottom of the glassware to the sampling line.
   - Allow collected fogwater to accumulate for continuous sampling. An S-shaped, lower side arm maintains the reservoir level above the sampling line inlet.
   - Provide for sample overflow. A lower side arm also serves as the overflow from the MCSC allowing for collection of bulk fogwater samples.
   - Facilitate initial flow through the glass reservoir by allowing sufficient head to build up to push trapped air bubbles out the overflow.
2) A four-port stream selection valve (Valco Instruments Model ECSD4PHC, Houston, TX) that controls the delivery of fogwater samples, analytical standards, manual samples, and distilled water to the injection port of the ion chromatograph (IC);
3) An injection valve for the IC that allows the sample stream to flow continuously through the valve to the pH electrode during sample injection;

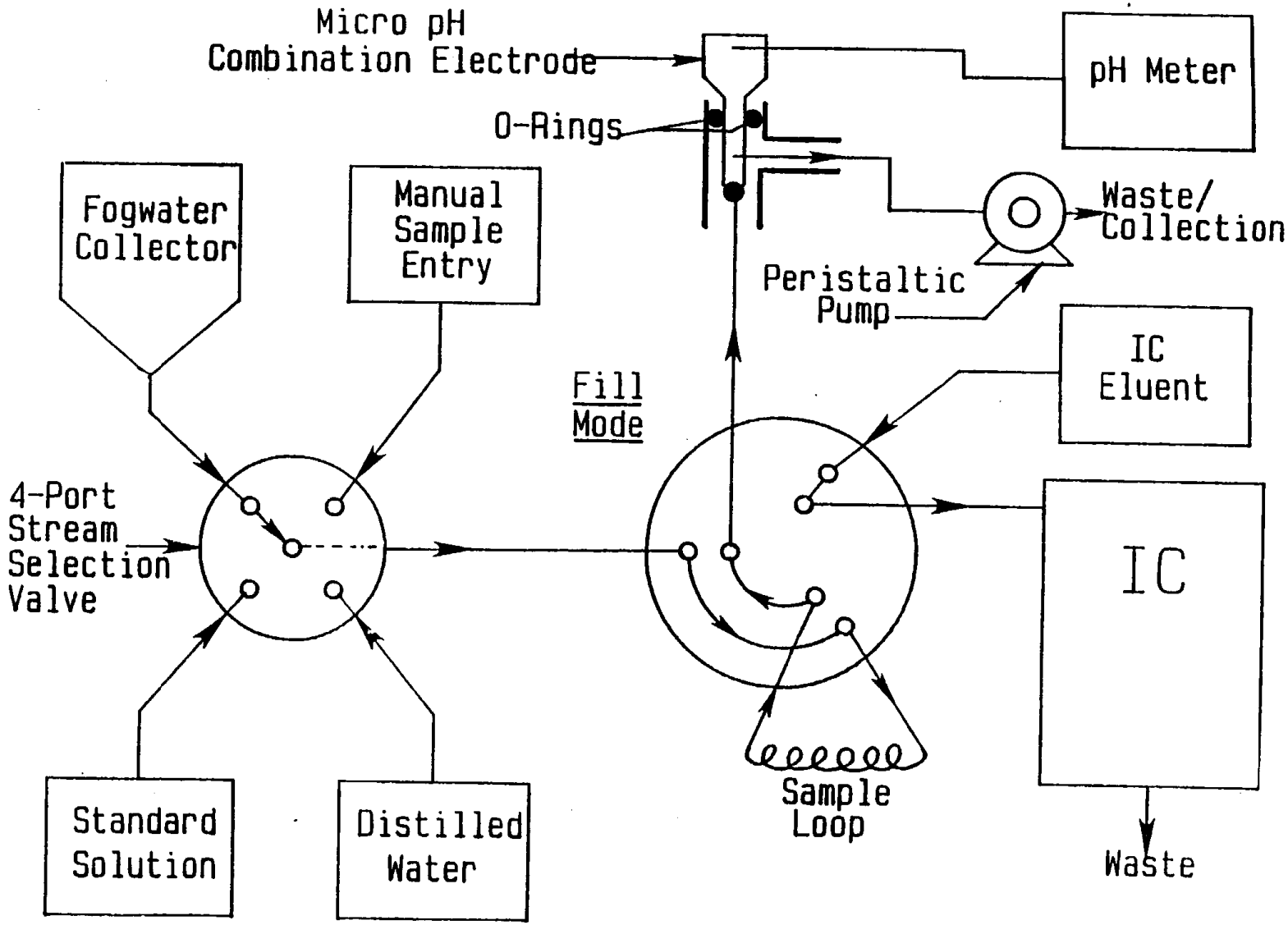

Figure 3.4. Sampling Handling and Delivery Schematic for Fill Mode

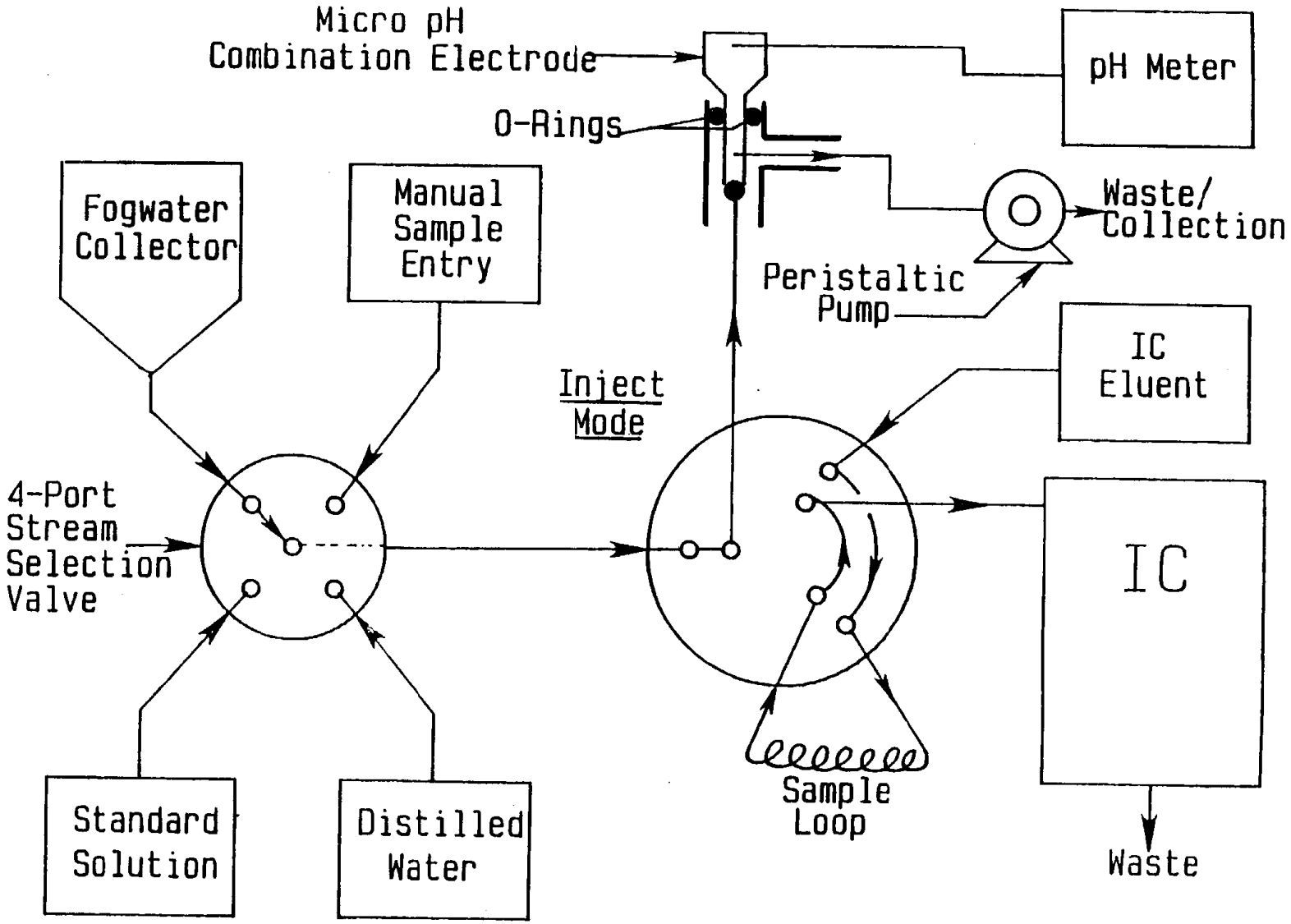

Figure 3.5. Sampling Handling and Delivery Schematic for Inject Mode

4) A peristaltic pump (Cole Parmer Model J-7553-30 with Model J-7021-20 Pumphead, Chicago, IL) to draw the samples and standards through the system.

Small-bore, nonreactive tubing has been used in the sample handling subsystem whenever possible to minimize dead volume and preserve the chemical integrity of the fogwater samples.

The operation of the stream selection and IC injection valves is controlled by the data acquisition and control subsystem described in Section 3.3.2.4. The peristaltic pump is manually controlled by a rheostat.

3.3.2.3. Chemical Analysis Instrumentation

A single channel Dionex ion chromatography system (Model 4000) performs sulfate, nitrate, and ammonium ion determinations on collected fogwater samples. The single channel system analyzes sulfate and nitrate on a semi-continuous basis. Ammonium concentrations are determined on integrated samples collected during the experiment and analyzed after the experiment has been completed.

The pH meter used in the system is a Beckman Model 40 high quality research-type pH meter (Fullerton, CA).

The micro pH combination electrode meets two requirements for successful operation:

1) The electrode body and tip has been be designed to minimize the sample volume required for an accurate reading; and
2) The electrode has a response time of less than 10 seconds.

A Lazar Research Labs micro flow-through pH electrode (Model FTPH-1, Los Angeles, CA) is used for continuous pH measurement of collected fogwater samples. The low dead volume (< 50 ul) of its flow cell and available connections to microbore tubing made this system an ideal choice for the present application.

3.3.2.4. Analytical Chemistry Data Acquisition and Control Subsystem

An IBM Personal Computer acquires data and controls the analytical chemistry subsystem. The configuration for the IBM-PC is as follows:

360 Kbyte 5 1/4" floppy disk drive
20 Mbyte hard disk
640 Kbyte memory
composite monochrome monitor
IBM color graphics adapter card
serial and parallel ports
clock/calendar
IBM PC-DOS Version 3.1
IBM BASIC Version 3.0
Epson FX80 printer

A data acquisition card and packaged driver software from Strawberry Tree Computer Inc. (Model AC Jr., Sunnyvale, CA) is used to interface with the IC and pH meter to acquire and display real-time data and control the sample handling and delivery subsystem. Specifications for the Strawberry Tree data acquisition hardware and software are:

1) 8 differential analog inputs with 12-bit resolution at 1000 Hz sampling rate, and selectable input voltage ranges;
2) 12 individually controllable digital I/O lines;
3) counter/timer;
4) thermocouple support;
5) interrupt handling; and
6) driver software to interface with high-level programming languages to provide for
   - setup
   - data acquisition
   - data logging
   - real-time data displays
   - timing and process control
   - signal integration
   - communications

A FORTRAN 77 program (ACQUIRE) was written to control the chemical analysis system from the IBM-PC. The major features of the control program are listed below.

- real-time acquisition, digitizing, integration, and graphical display of chromatograph data from the IC,
- automated, programmable control of the stream selection valve, IC calibration, and sample injection,
- automated, prerun, postrun, and span check IC calibration procedures,
- real-time, continuous acquisition, digitizing, and graphical display of pH data,
- real-time serial communications interface with the IBM-AT for textual display of chemical variables and archival data storage,
- automated backup of experimental data files to hard disk and/or floppy disk.

3.3.2.5. Fog Monitoring Subsystem Hardware Configuration

An IBM-AT serves as the master computer for acquiring and storing data and consists of:

20 Mbyte fixed disk
1.2 Mbyte 5-1/4" dual density floppy disk drive
Color graphics video adapter
640 Kb RAM
80287 math coprocessor
Monochrome monitor
Serial and parallel ports
Clock/Calendar
Hewlett-Packard ThinkJet Printer

The IBM-PC, described in Section 3.3.2.4, is interfaced to the IBM-AT and serves as a slave computer for acquiring chemistry and chamber operating data and controls the analytical chemistry instruments.

3.3.2.6. Master Data Acquisition System

The master data acquisition system for the fog monitoring system performs the following tasks using the IBM-AT:

1. allows experiment and configuration setup.
2. tests IBM-PC to IBM-AT communications prior to test.
3. acquires data from the Phase/Doppler Particle Analyzer and the Analytical Chemistry Data Acquisition System.
4. displays critical variables in real time during an experiment.
5. stores data for later processing.
6. post processes the stored data.

3.3.2.7. Data Acquisition

The data acquisition portion of the master data acquisition system samples data from the Phase/Doppler Particle Analyzer at a rate that can be selected by the operator. The recommended sampling interval is 30 seconds between samples. These data are processed to determine the fog droplet number median diameter, volume median diameter, geometric standard deviation, number concentration and liquid water content. These data are screened to determine sampling errors or parameters out of the desired test tolerance. Data are also sampled from the chemical composition system at one minute time intervals. These data consist of the fogwater pH and the percentage by volume of sulfate, nitrate and HMSA. Both processed data and pertinent raw data is stored on the IBM-AT hard disk at the time of the experiment. These data are stored as the average of two sample intervals. Thus, if data are being sampled from the PDPA every 30 seconds, the stored data will be a 1 minute average of two 30 second samples. At the end of the experiment, the data are stored on floppy disk in binary format to be later processed by the post processing program.

3.3.2.8. Experimental Configuration and On-line Status

Prior to the start of an exposure experiment, the monitoring system allows the input of information for the setup of the monitoring equipment and the

tolerance limits for test parameters. A pre-start setup test can be run to insure system integrity. Once the experiment has been started, the program will display the system status in real time. This on-line screen is shown in Figure 3.6. This display is updated every time the PDPA data is acquired (normally every 30 seconds) and is the default display for the program in test mode.

The generator conditions include the numerical values for the flowrates, differential pressures, and chamber inlet and outlet temperature. The displayed droplet conditions include not only the current values but will flash if they are beyond the limits as entered in the test setup program. This enables the operator to modify operating conditions to meet the desired values, or can be used as indicators of improper conditions which will require termination of the test.

3.3.2.9. Data Storage

To enable post processing of the test data, all key parameters plus the test setup values and description are output to floppy disk. This is done at half the data sampling rate. The output is in binary format to minimize the file size for data storage. The post processing program takes this data and allows statistical analysis and plotting of the data to allow hard copy output for test documentation. The actual file format is documented in Appendix C to allow programming access through other programs.

3.3.2.10. Display of Critical Variables

Instead of the default on-line status display, the operator has the option to display key variables in different ways while the experiment is proceeding. Figure 3.7 shows an example of a current size distribution and mass distribution display, which represents the most current data taken for this variable. Calculation of several statistical values is also performed and displayed with the histogram and graph. Hard copy of this information can be obtained by running the post processing program

Fog Monitoring System

12-13-87 10:05:32 0:23:56

GENERATOR CONDITIONS			DROPLET CONDITIONS	
Chamber Air Flow Rate	201	CFM		
Pre-Filter Delta P	5.20	Psid	Mass Med Dia (um)	9.02
HEPA Delta P	4.12	Psid	Geom. Std. Dev.	0.42
Chamber Inlet Temp	21.2	Deg C	Num Concent (#/cc)	54023
Chamber Outlet Temp	22.3	Deg C	Num Median Dia (um)	5.34
			Geom. Std. Dev.	1.32
PDPA SAMPLING CONDITIONS			Liq Content gm/m3	1.28
			Sulfate (MEQ/L)	0.32
Sample Velocity	20.32	m/sec	Nitrate (MEQ/L)	0.31
Sampling Time	9.07	sec	HMSA (MEQ/L)	0.00
Rejection Ratio	4.2	%	pH	4.43

Figure 3.6 On-Line Screen

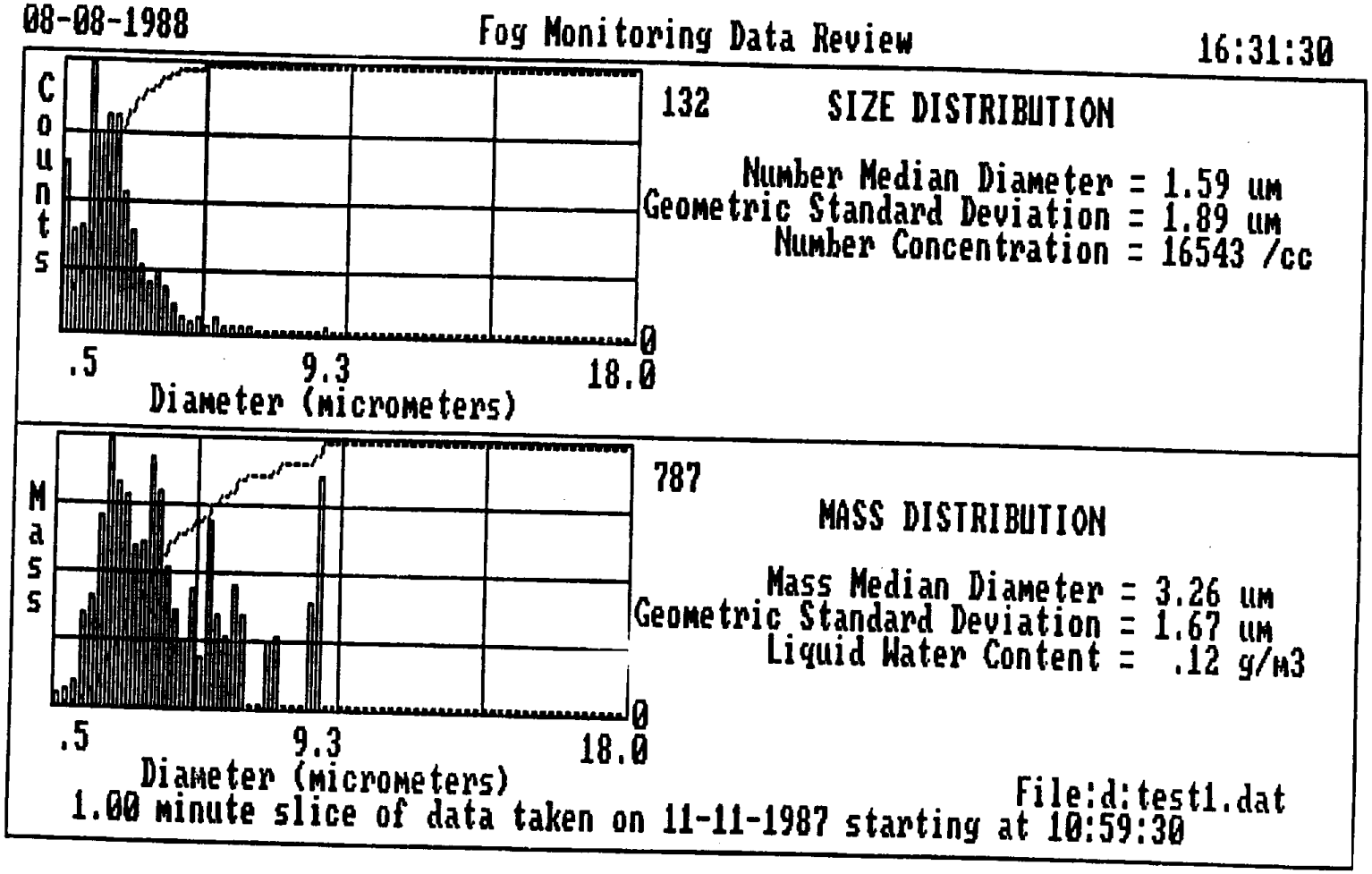

Figure 3.7. Size and Mass Distribution On-Line Display

after the experiment is completed. Another available display is shown in Figure 3.8. This is a real time display of selected variables versus time. This allows the viewing of the current and past values of several variables.

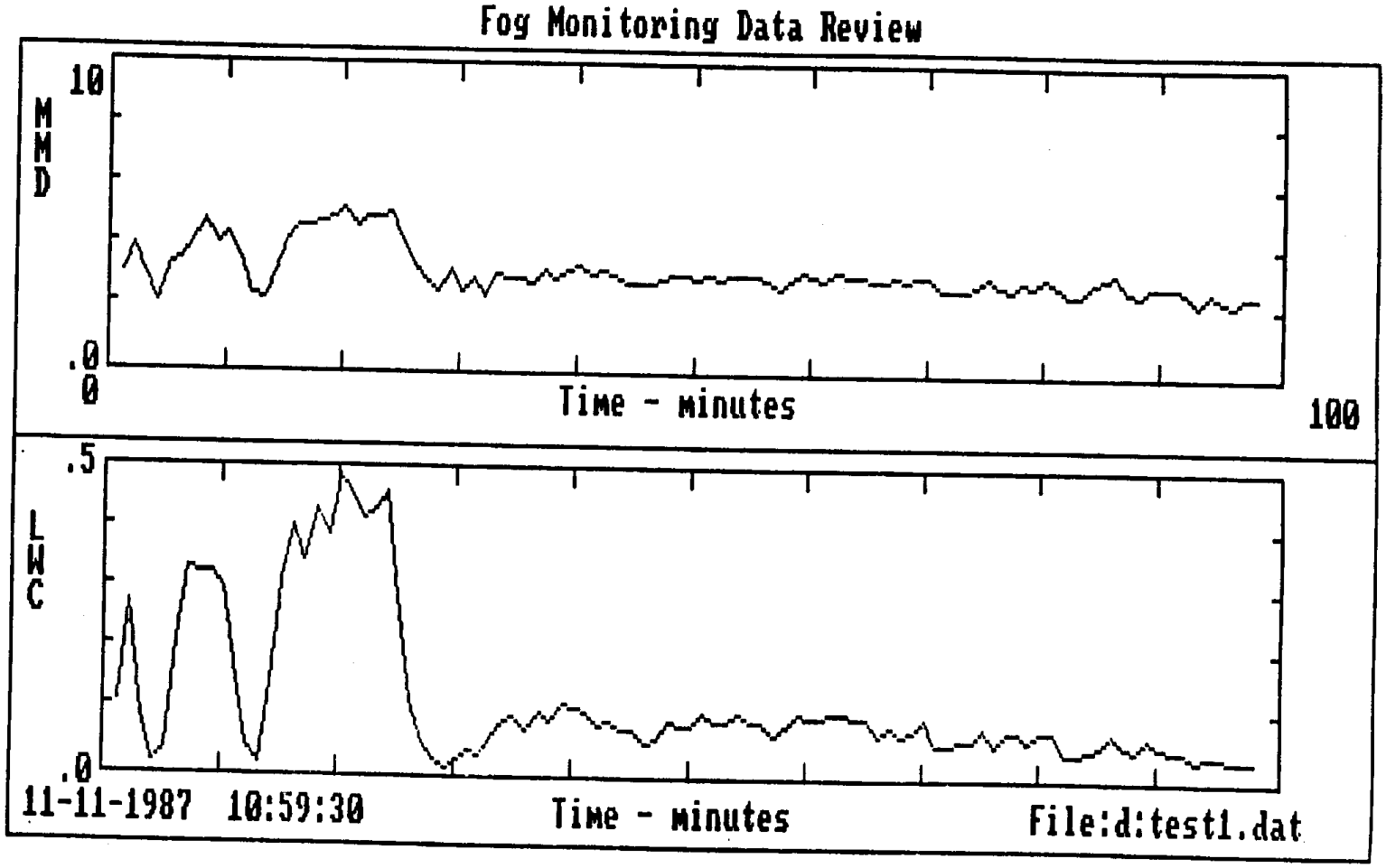

Figure 3.8. Variables versus Time On-Line Display

4. Operation Procedures

This section describes detailed procedures for operating the fog generation and monitoring system, including setup and calibration, system start-up, running experiments, and shutdown.

4.1. System Setup

Before the fog generation system can be started, several procedures must be performed to ensure all components are operating properly. These include:

(1) PDPA Adjustment
(2) IC Calibration and setup
(3) Data Acquisition setup
(4) Fog generation subsystem setup
(5) Fog delivery subsysten setup
(6) Filter and Cyclone setup

4.1.1. PDPA Adjustment

The PDPA requires adjustment prior to. running an experiment. This procedures is best performed by using the standard software supplied by Aerometrics, Inc. The adjustment procedure is performed as follows:

(1) Turn on power to the IBM-AT, PDPA power supply and laser power supply. The laser beams should be visible to verify power is on.
(2) Attach the Bird nebulizer to the black plastic manifold and insert into the hole in the stand below the intersection of the laser beams. If necessary, rotate the manifold so that the laser beams are not blocked. It may also be necessary to insert an orifice into the manifold above the slots to obtain the best sampling velocity.
(3) Turn on the compressed air supply to the nebulizer and adjust to 15 psig. Note: for this procedure the dryer air to the nebulizer manifold should be off. Fog should now be visible at the laser beam intersection.

(4) Type "PDPA" to run Aerometrics software and sample the fog from the nebulizer. Refer to the Aerometrics operations manual for procedures on running the PDPA program and instrument alignment. Note the values of parameters in the setup portions of the program (Function key #1) since these same values will be needed in the "FOG" program used during an experiment. After the PDPA has been aligned, exit the "PDPA" program, turn off the compressed air supply, and remove the nebulizer and manifold.

(5) The response of the PDPA can also be checked using monodispersed polystyrene latex particles. This is accomplished by adding several drops of the concentrated suspension of polystyrene latex spheres to 100 ml. of distilled water in the Bird nebulizer. The dilution air line should be connected to fitting at the top of the plastic manifold. The dilution air flowrate should be adjusted to approximately 20 liters/min. The smallest orifice should be used inside the manifold and positioned directly above the two slots in the side of the tubing mounted in the laser path. No fog will be seen because the dilution air dries all of the liquid droplets, leaving only residue monodispersed spheres. The PDPA should be sampled as in step #4; however, the concentration of spheres will be much less than the concentration of droplets found in a fog generated by the nebulizer. Therefore, longer sampling times will be required to obtain a statistically significant sample.

4.1.2. IC Setup and Calibration

The Beckman pH meter and the Dionex IC should be calibrated prior to running an experiment. The pH meter and the micro pH combination electrode should be calibrated using standards solutions of appropriate pH and ionic strength following the procedures set forth in the pH meter operations manual. Likewise, the IC should be calibrated by using three to five standard solutions of appropriate concentration ranges introduced into the sample port with distilled water flushes between each standard solution. The IC calibration can sequenced by using the IBM-PC and the calibration mode of the ACQUIRE program as follows:

(1) Start the program on the IBM-PC by typing ACQUIRE SSS.FIL after the system prompt. "SSS.FIL" is the name of a file containing the IC system operating parameters. (See Appendix B for a more detailed description of the ACQUIRE program and the options for preparing a setup file.) The program's main menu will appear as shown in Figure 4.1. The "START CALIBRATION SEQUENCE" options should be selected by typing "2".

(2) Four standard solutions should be prepared and entered in ascending order for the calibration routine to function correctly. Standard #1 is distilled water and standard #4 is the span solution. The other two standards should be somewhere in-between standard #1 and standard #4 with standard #2 concentration less than standard #3. Standard #1 should be connected to sample port 1 and a syringe containing standard #4 should be installed in sample port 3. The other two standards will be injected into the manual port. The program will prompt the user for the values of the standards and will tell when to load them.

The program stores the calibration numbers and read then in whenever it is started up. This means that it is not necessary to run a calibration sequence for every experiment as long as the operating parameters for the IC have not changed.

4.1.3. Data Acquisition Program Setup

The sampling parameters for the PDPA and limit settings for the monitoring instrumentation are specified by using the "SETUP" program. This program is run as follows:

(1) Bring up "SETUP" program by typing SETUP when the IBM-AT is display its main menu.

(2) The program displays a menu of 33 parameters as shown in Figure 4.2. Parameters 1-6 specify sampling conditions for the PDPA and should be the same as those used in the Aerometric's "PDPA" program to adjust and align the PDPA. Parameters 7

MAIN MENU
1) START IC RUNS
2) START CALIBRATION SEQUENCE
3) START AUTO-SPAN
4) FINISH UP
5) ENTER SETUP MODE
6) DOS
7) EXIT PROGRAM
8) ENTER DRIVER INTERFACE
9) BASELINE OFFSET

Figure 4.1. ACQUIRE Program Main Menu

Fog Chamber Monitoring Program Setup Parameters

1)	P/DPA Voltage	400	18)	pH Lower Limit	2.0
2)	P/DPA Filter No. 6 -	.0 KHz	19)	pH Upper Limit	6.0
3)	P/DPA Maximum Velocity	1.0	20)	Flowrate Lower Limit	200.
4)	P/DPA Maximum Diameter	41.0	21)	Flowrate Upper Limit	500.
5)	Seconds between samples	30	22)	Pre-Filter Delta P Lower Limit	.00
6)	Number of particles per sample	1000	23)	Pre-Filter Delta P Upper Limit	.50
7)	Maximum Sampling Rejection %	30.0	24)	HEPA Filter Delta P Lower Limit	.00
			25)	HEPA Filter Delta P Upper Limit	.50
8)	MMD Lower Limit	3.0	26)	Chamber Inlet Temp Lower Limit	15.0
9)	MMD Upper Limit	11.0	27)	Chamber Inlet Temp Upper Limit	30.0
10)	LWC Lower Limit	.1	28)	Chamber Outlet Temp Lower Limit	15.0
11)	LWC Upper Limit	2.0	29)	Chamber Outlet Temp Upper Limit	30.0
12)	Sulfate Lower Limit	.0			
13)	Sulfate Upper Limit	1.0	30)	Constant - LWC Equation	1.0
14)	Nitrate Lower Limit	.0	31)	Linear Term - LWC Equation	.0
15)	Nitrate Upper Limit	1.0	32)	Quadratic Term - LWC Equation	.0
16)	HMSA Lower Limit	.0	33)	Cubic Term - LWC Equation	.0
17)	HMSA Upper Limit	1.0			

Enter parameter number to change or <CR> to quit:

Figure 4.2. SETUP Program Menu

through 29 are limits for fog size, liquid water content, chemical composition, and chamber operating conditions. The value of each parameter will flash on the data display screen whenever the limit has been exceeded during sampling. Parameters 30-33 are terms in the relationship to correct the liquid water content determined by the PDPA. The value displayed on the data display for liquid water content (LWC) is calculated as :

$$LWC = A + B(LW) + C(LW)^2 + D(LW)^3$$

where LW is the liquid water content determined by the PDPA

To change the value of a parameter, enter the parameter number and the appropriate value. Enter <CR> to exit the program.

4.1.4. Fog Generation Subsystem Setup

The fog generation subsystem is setup as follows:

(1) Connect all fittings to the solution tank and fog generator
(2) Fill the solution supply tank so that solution is several inches above the generator drain line.
(3) Inspect all fittings to the solution pump
(4) Clean the in-line filter between the solution pump and generator manifold.
(5) Remove the cover on the front of the generator and remove the frame containing the stainless steel screens located near the outlet of the generator. If necessary, remove the lower screens and baffles. Mount the necessary screens in the baffles and frame and replace inside the generator. Replace the cover on the front of the generator.

4.1.5. Fog Delivery Subsystem Setup

The fog delivery subsystem is setup as follows:

(1) Move the damper at the inlet to the chamber air purification system (located in the mechanical room) to the "bypass" position so that clean air will flow to the fog generation system makeup air system.

(2) Insert the stainless steel covers into the chamber supply and return air ducts to isolate the chamber from the air circulation system.

(3) Turn on the blower in the fog delivery subsystem and adjust the damper to give a flow rate up to 400 CFM. Note: The "PC" program or "FOG" program must be run in order to monitor the actual flowrate. Calibration data for the flow meter is given in Table 4.1.

(4) Turn on the makeup air system and adjust the thermostat to the desired temperature

(5) Check the pressure drop across the HEPA and mesh filters to ensure that they are not loaded. The pressure drop across each filter will be a function of the chamber air flow rate. The maximum pressure drop for each filter should not exceed 0.75 inches of water.

(6) Run the "PC" program on the IBM-AT microcomputer by selecting "PC" from the menu. The program will display chamber flowrate, inlet and outlet temperature, and the pressure drop across the HEPA and MESH filter as shown in Figure 4.3. Verify that all values are within the correct operating range and adjust as necessary. Press Function Key 10 (F10) to terminate this program and to return to the main menu.

4.1.6. Filter and Cyclone Setup

The filter and cyclone samplers should be clean and dry before mounting in the chamber. Insert a clean glass fiber filter into each filter holder and weigh the filter and holder to a precision of 0.001 gms. Weigh each cyclone to the same precision. Cyclones should be weighed without tube fittings. After weighing, mount the filter and cyclones in the exposure chamber. Attach the appropriate inlet to both the total filter and cyclone sampler. The inlets should be selected according to sampling flow

KURZ INSTRUMENTS INC. CALIBRATION DATA AND CERTIFICATION

MODEL	UNITS	BV LOW	CVS LOW	CODE
430 DC	SFPM	3.430 VDC		016-048
RANGE	~~FREQUENCY~~ FULL SCALE	BV HIGH	CVS HIGH	SERIAL NO
0 - 1000	VOLTAGE 5.00 VDC	6.226 VDC		VCE - 2306H

LFE S/N	DVM S/N	TEMP. GAUGE S/N	BAROMETER S/N	FREQ. CTR. S/N
705940-W8-R1	306584	+-12	11508041	
DATE DUE	**DATE DUE**	**DATE DUE**	**DATE DUE**	**DATE DUE**
7-21-87	12-15-87	3-17-87		

	ACTUAL FLOW*	INDICATED FLOW**	OUTPUT VOLTAGE	OUTPUT CURRENT ma
1			NON LINEAR	
2	1000		5.000	
3	900		4.844	
4	800		4.644	
5	700		4.425	
6	600		4.161	
7	500		3.872	
8	400		3.567	
9	300		3.181	
10	200		2.706	
11	100		2.120	
12	50		1.631	
13	0		0	
14				
15	Document Reviewed By			
16	Quality Assurance			
17	Signed Paul M Bahde			
18				

NBS TRACEABLE FLOW DATA—SEE ABOVE
R-4487-2-R2 DUE: 3-2-88

CALIBRATION TECHNICIAN
[signature]

DATE
3-12-87

* STANDARD CONDITIONS: 25° and 760 mm Hg.
"ACTUAL FLOW" Represents flow data points using NBS calibration.
** "INDICATED FLOW" Represents a direct reading on an analog or digital meter. Indicated flow is the calculated flow for a linear unit based on full scale output voltage and full scale flow rate.

This form is to confirm that this instrument was calibrated with an NBS traceable mass flow meter and associated equipment. This calibration device is traceable to National Bureau of Standards, Test Numbers 2.6/167716 A&B 232.09/209.275.B

Chamber Monitoring System

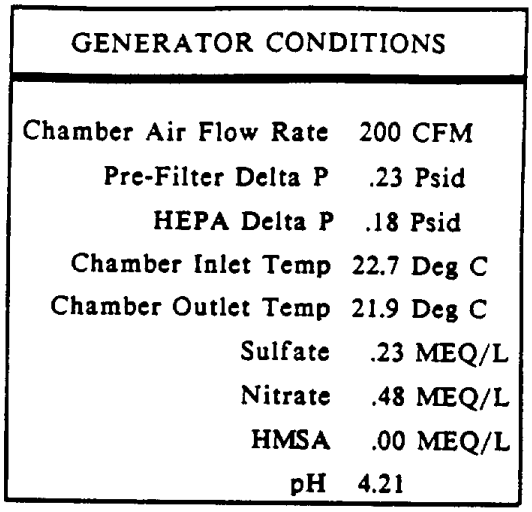

Figure 4.3. Chamber Monitoring Program Display

rate. Table 4.2 lists the inlet diameters that should be used for various sampling flowrates. Attach the appropriate suction line to the total filter holder and cyclone sampling system.

4.1.7. PDPA Purge Air

It is necessary to supply dry air to the PDPA sensor and receiver so that fog droplets will not impact on the optical components and distort the signal. A compressed air supply is connected to a flowmeter mounted on tubing attached to the PDPA receiver. The air flowrate should be adjusted to approximately 40 liters/min to provide sufficient drying air.

4.2. Fog Generator Start-Up

Fog production can begin once the delivery subsystem has been setup and verified to be operating in the desired range. The number of operating nozzles is selected by opening the required number of plug valves in the solution manifold mounted on the front of the generator. The operator can select banks of one (valve in the rear of the left hand side of the generator), two (valve in the front of the left hand side of the generator, four (valve on the left hand side of the front of the generator), or 10, 20, or 30 (second, third and fourth valves from the left on the front of the generator).

Once the number of nozzles is selected, the high pressure solution pump is turned on, and the pressure is adjusted with the regulator on the front of the pump. The operating pressure can be adjusted from 300 to 1000 psig. At least one hour should be given to allow the system to come to steady state. The fog size distribution and liquid water content can be measured once the fog concentration is high enough to produce an adequate sample.

4.3. Running an Experiment

Once the system has stabilized, the data acquisition can be started by first selecting the "START IC RUNS" option on the IBM-PC by tying "1". The program will respond:

Table 4.2. Droplet Collection Efficiency for Various Sampling Inlet Diameters Operating at Flowrates between 5.0 and 56.0 lpm.

Inlet Diameter (um)	Flowrate (lpm)	Maximum Droplet* Diameter (um)
2.5	5.0	15.
2.5	10.0	20.
2.5-3.7	14.0	17.
3.7	28.0	20.
3.7	56.0	15.

*Minimum 96% collection efficiency.

ENTER "C" FOR CONTINUOUS OR "M" FOR MANUAL

Continuous mode should be selected and then the program will prompt:

SAVE DATA? (Y/N)

This should be answered with a "Y" in order to save the IC data as the experiment is being run.

The program on the IBM-AT should be started by typing "FOG" on the IBM-AT. The screen shown in Figure 4.4 will be displayed. The actual logging of the data from the PDPA and the IC will not begin until one of the function key between 2 to 7 is pressed (F2 through F7). Once acquisition has started, the actual status of the IBM-AT will be displayed in the upper right corner of the screen. If the computer is "ACQUIRING" or "PROCESSING", it will display this status and the response to any function key that has been pressed will be delayed until it completes that operation. If no status is displayed in the upper right corner, the computer is "idling" and will respond to any function key pressed without delay. While this program is running, the computer will respond to only the Function Keys (Keys F1 through F10). All other key strokes are ignored.

Data control and on-line monitoring of the experiment is all controlled through the function keys. The following sections give more detail on the use of the function keys.

4.3.1. Run Time Menu - Function Key 1

The function key menu can be recalled at any time while the program is running by pressing Function Key 1 (F1). Figure 4.4 shows the Function Key Menu.

Select an Option

Display this menu.	F1	F2	Real Time Display.
Mass Med Dia & LWC Vs Time.	F3	F4	Temp & Del P Vs Time.
Nit, Suf & pH Vs Time.	F5	F6	Num Med Dia & Concent Vs Time.
Histogram Display.	F7	F8	
End of Test.	F9	F10	Exit Program.

Figure 4.4 Run Time Menu.

4.3.2. Real Time Display - Function Key 2

A tabular display of the real time status of the experiment can be invoked by pressing Function Key 2 (F2). The screen shown in Figure 4.5 will appear. If any the the displayed values are flashing, it means that they are beyond the limits that have been entered using the SETUP program. The values on this screen will update every time the PDPA is sampled. The sampling interval was also an input to the SETUP program. The values that are generated by the IBM-PC will be updated on the next PDPA cycle after they have been sent to the IBM-AT. The IBM-PC values are normally updated once a minute but their update time may not necessarily coincide with a PDPA update; thus, there may be a delay before they are displayed. The current date and time plus the elapsed time for data acquisition is displayed below the main title. The status of the computer is display in the upper right hand corner.

4.3.3. Graphical Displays - Function Keys 3 through 6

A display of selected variables versus time can be display in real time by pressing the function keys 3 through 6. The displayed values by function key are the following:

Function Key 3 (F3)	Mass Median Diameter and Liquid Water Content
Function Key 4 (F4)	Chamber Temperatures and Delta Pressures
Function Key 5 (F5)	Nitrate and Sulfate Per Volume and pH
Function Key 6 (F6)	Number Median Diameter and Concentration

Figure 3.7 is an example of the display if Function Key 3 had been pressed. The graphs are updated whenever a sample is taken and if the data exceeds the graph limits, the graph will be rescaled and redrawn. As with the other screens, the status of the computer is displayed in the upper right hand corner and the current data, time and experiment elapsed time are displayed.

Fog Monitoring System

12-13-87 10:05:32 0:23:56

GENERATOR CONDITIONS		DROPLET CONDITIONS	
Chamber Air Flow Rate	201 CFM		
Pre-Filter Delta P	5.20 Psid	Mass Med Dia (um)	9.02
HEPA Delta P	4.12 Psid	Geom. Std. Dev.	0.42
Chamber Inlet Temp	21.2 Deg C	Num Concent (#/cc)	54023
Chamber Outlet Temp	22.3 Deg C	Num Median Dia (um)	5.34
		Geom. Std. Dev.	1.32
PDPA SAMPLING CONDITIONS		Liq Content gm/m3	1.28
		Sulfate (MEQ/L)	0.32
Sample Velocity	20.32 m/sec	Nitrate (MEQ/L)	0.31
Sampling Time	9.07 sec	HMSA (MEQ/L)	0.00
Rejection Ratio	4.2 %	pH	4.43

Figure 4.5 Real Time Display

4.3.4. Histogram Display - Function Key 7

When Function Key 7 is pressed, a histogram of the particle size distribution and velocity distribution will be displayed. An example of this display can be seen in Figure 3.8. This display is updated after every PDPA sample is taken.

4.3.5. End of Test - Function Key 9

Function Key 9 should be pressed to end the data acquisition for an experiment. When this key is hit, the operator will be asked

Do you want to terminate this test [Y/N]?

If "N" is entered, acquisition will continue as if the key had never been pressed. If "Y" is entered, the operator will be asked

Do you want to save the data from this test [Y/N]?

If "N" is entered, the acquired data will not be saved and the program will return to the Function Key Menu. If "Y" is entered, the program will check to see if there is enough space on the floppy disk to hold the acquired data. If there is not enough space, the following will appear:

Space needed = 51,324 bytes. Disk space available = 41,729 bytes.

Not enough space on disk to store data.
Please replace disk with one with more space.
Hit return when ready.

Once the program has determined it has the required space for storing the data, the operator will be prompted:

Name to give file [XXXXXX.EEE]:

A file name should be entered at this point which will allow easy identification of the test data. The file name (XXXXXX above) cannot

exceed 8 characters and the file extension (EEE above) cannot exceed 3 characters. Once the name has been entered and a carriage return hit, the program will transfer the test data from the hard disk to the floppy disk. When this is completed, the program will display the number of records that were transferred and then will return to the Function Key Menu.

4.3.6. Exit Program - Function Key 10

Function Key 10 should be pressed to exit the program when all the data acquisition has been completed and saved. The operator will be prompted:

Do you really want to exit program [Y/N]?

If "N" is entered, the program will return to the Function Key Menu. If "Y" is entered, the program will terminate and the IBM-AT will display the Master Menu. If all work has been completed, the IBM-PC program data should be saved and the program should also be exited at this time.

4.4. Ending an Experiment

Once it has been determined that the experiment is to be completed and that adequate data has been collected, the data acquisition programs should be shut down as follows:

(1) The program on the IBM-AT should be completed by hitting Function Key 9 (F9). This option will allow the saving of the just collected data. See Section 4.2.5. for the detailed description of the questions that will be asked for saving the data onto floppy disk.

(2) The program on the IBM-PC should be terminated by hitting the "ESCAPE" key. At the end of the current IC run, the program will prompt:

OK TO EXIT (Y,N)

When the main menu appears, the "FINISH UP" option should be selected by typing "4". The program will prompt for an archival directory name which will be used to store the data to on the

hard disk. Once the data has been saved, the program will ask:

SAVE DATA TO DRIVE A? (Y/N)

By responding "Y" the data will be copied to a floppy disk in drive A into a subdirectory having the same name as the one on hard disk.

(3) If no more data is to be taken for any other experiments, the data acquisition programs should be exited by hitting Function Key 10 on the IBM-AT and by selecting the "EXIT PROGRAM" option on the IBM-PC by typing "7".

5. PERIODIC MAINTENANCE

The fog generator system has been designed to require a minor amount of maintenance. The following procedures should be periodically followed to insure reliable performance:

5.1. Monitoring Subsystem

(1) PDPA Calibration. The PDPA operation should be checked before each experiment (Refer to Section 4.1.1). Generally, no routine maintenance is required.

(2) Ion Chromatograph. Periodic maintenance of the IC is covered in the vendor's operation and maintenance manual.

5.2. Generation Subsystem

The droplet generator is constructed of Teflon coated Type 316 Stainless steel for superior resistance to corrosion. Nevertheless, the pump, manifolds, and droplet generator should be completely flushed with water at the end of an experiment. Generally, 2 to 3 flushes are required to completely clear the system.

The fog nozzles may occasionally become clogged. If this occurs, it is necessary to remove the defective nozzle, disassemble, and clean it in an ultrasonic cleaner. The in-line filter should be inspected and cleaned if necessary after each test.

The fogwater collector should be inspected before each experiment to verify string tension and proper generation of the sampler overflow reservoir and tubing. No air bubbles should be present in the tube leading to the IC. The fogwater collector strings should be washed with distilled water after each experiment, especially when nitric acid fogs have been sampled.

The oil level in the high pressure pump should be checked before each experiment by observing the level in the sight glass located on the gear box. The oil level should be to the red line on the window.

5.3. Delivery Subsystem

The pressure drop across the HEPA filter should be monitored to determine if the filter is becoming loaded. The pressure drop will be a function of the flowrate through the filter. If the pressure drop exceeds 1.0 in. w.c. at a 400 CPM flowrate, the filter should be replaced (or dried if excessive moisture is clogging the filter).

The delivery system should be flushed after an acid fog experiment by generating a pure water fog with all nozzles operating for at least one hour. The water reservoir should be changed at least four times during this period. The collector tray below the outlet duct may have to be drained if liquid is present. Excess moisture should be wiped off the chamber walls and equipment.

6. POST PROCESSING OF EXPERIMENTAL DATA

The data from an experiment can be further analyzed using the post processing capabilities on the data acquisition computers. Two programs are currently available for performing statistical analysis of the data from the PDPA and the IC. These programs are briefly described below.

6.1. Post Program

On the IBM-AT, the data stored on floppy disk at the end of an experiment can be scanned, statistically analyzed, and/or plotted by typing "POST" when the main menu is displayed on the computer. When this is done, the computer will respond with:

Enter the name of the data file to review.
Drive designator must be included if not default.
Name of file:

At this point, the floppy disk with data to be reviewed should be inserted into the floppy disk drive. The operator should not type in the name of the data file to be viewed (i.e. a:test15.dat). After the program has verified that the file is available, the screen shown in Figure 6.1 will appear. Once the operator presses one of the function keys, the data will be read from the file and the designated action will be taken.

6.1.1. Data Summary.

The data from the test will be summarized and statistically analyzed if function key 1 (F1) has been pressed. The screen shown in Figure 6.2 will be displayed. For each stored parameter, the program has calculated the average and standard deviation and it has also determined the minimum and maximum values for the data over the specified time displayed at the bottom of the screen. The operator can specify this data "window" for the analysis by selecting function key 9 (F9). See Section 6.1.3 for a more detailed description of this option.

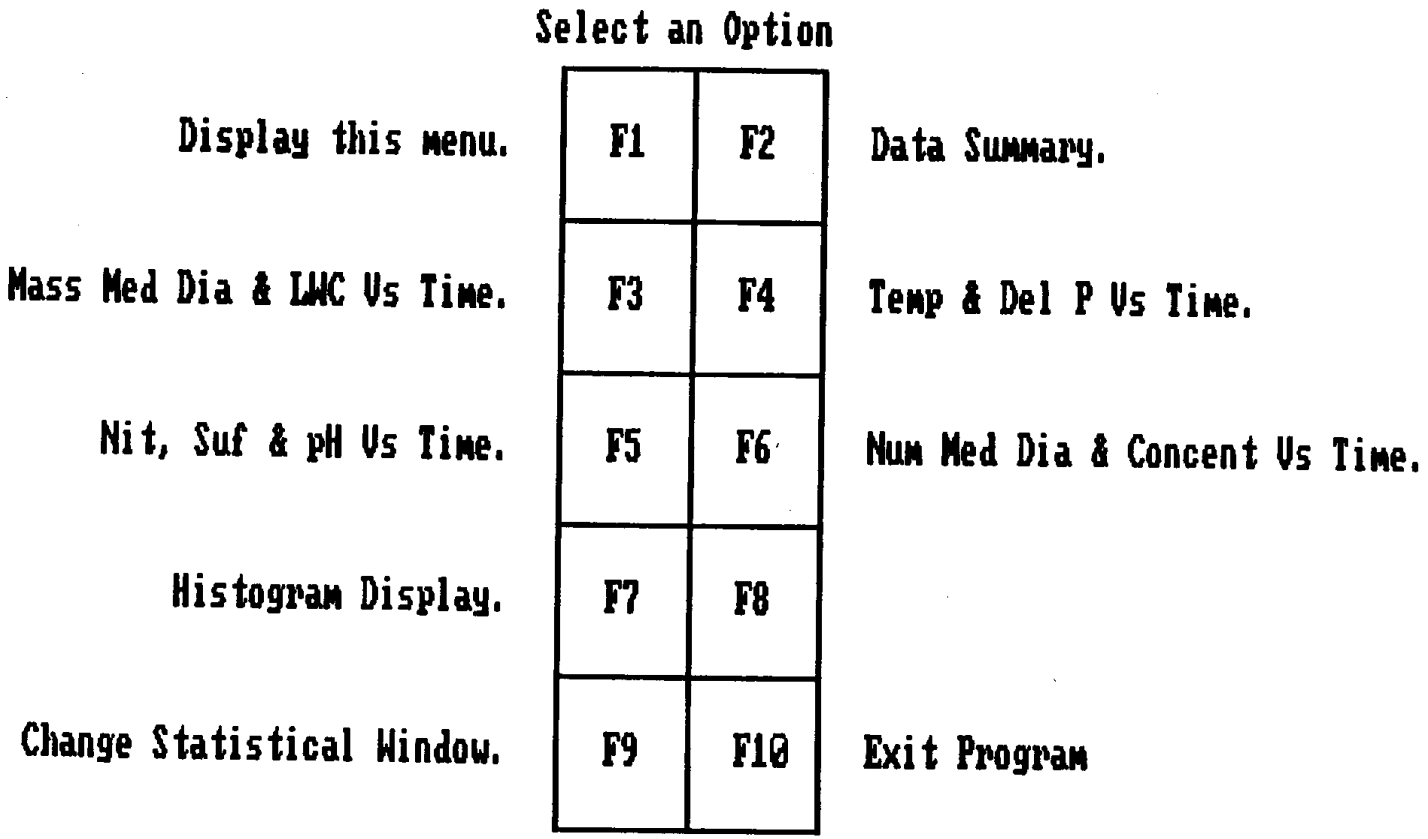

Figure 6.1. Post Processing Program Main Menu

Fog Monitoring Data Review
08-22-1988 18:49:51

DATA SUMMARY FOR FILE: testlc.dat

	Avg	σ	Min	Max
Chamber Air Flow Rate - CFM	239	17	207	296
Pre-Filter Delta P - Psid	.24	.02	.20	.28
HEPA Delta P - Psid	.18	.02	.15	.24
Chamber Inlet Temp - Deg C	23.5	.5	22.4	24.3
Chamber Outlet Temp - Deg C	22.6	.4	21.7	23.5
Mass Med Dia - μm	3.27	.69	2.25	5.34
MMD Geometric σ	1.77	.20	1.52	2.63
Num Concentration - #/cc	14166	4397	4493	24395
Number Median Diameter - μm	1.53	.24	1.08	2.12
NMD Geometric σ	1.88	.09	1.67	1.99
Liq Content - gm/m3	.12	.12	.02	.48
Sulfate - MEQ/L	.27	.60	.00	1.79
Nitrate - MEQ/L	.51	1.14	.00	3.28
HMSA - MEQ/L	.00	.00	.00	.00
pH	4.16	1.94	1.85	7.01

Data averaged from .00 to 98.00 minutes into the test.
Data taken on 11-11-1987 starting at 10:59:30 for 98.00 minutes.

Figure 6.2. Data Summary Display

6.1.2. Time History Displays

The data can be graphically display by selecting function keys 3 through 6 (F3 to F6). The resulting display for each of these key selections are shown in Figures 6.3 through 6.6. The data window for the time axis can be varied by using the window option of function key 9 (F9). Once a plot is displayed, a hard copy can be made on the printer by holding the "SHIFT" key down and hitting the "PrtSc" key. The plot will remain on the screen until another function key is pressed.

6.1.3. Histogram Display

Histograms of the size distribution and mass distribution are available at set time intervals during the experiment (normally one minute). This option can be invoked by pressing function key 7 (F7). The program will respond with the screen displayed in Figure 6.7. The time for which the histogram is desired must be entered at this point or by hitting the "ENTER" key, the specified default time will be used. Figure 6.8 shows an example of a histogram display for 1.00 minutes into the experimental data. A hard copy of the histograms can be made by holding the "SHIFT" key down and pressing the "PrtSc" key. The histogram display will stay on the screen until another function key is pressed. If the histogram option is selected again the program will automatically increment the default time up one interval, so that sequential viewing of the histograms can be easily done.

6.1.4. Changing Data Windows

The time over which the data is analyzed or displayed can be changed by pressing function key 9 (F9). When this is done, the following will appear:

Fog Monitoring Data Review

Data has been taken for 98.00 minutes.

The current averaging window is from .00 to 98.00 minutes.

Do you want to change the window [Y/N]?

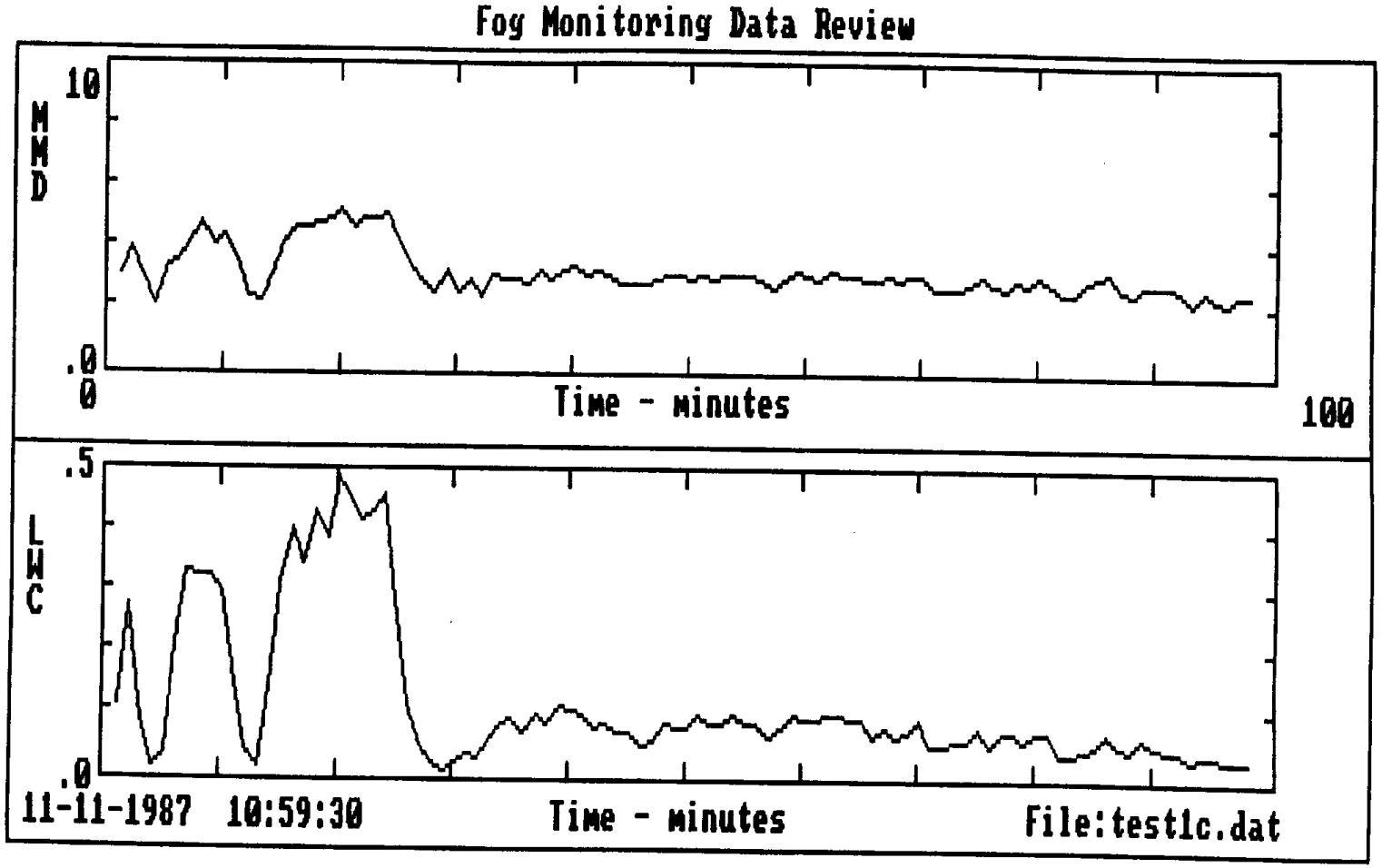

Figure 6.3. Mass Median Diameter and Liquid Water Content vs Time

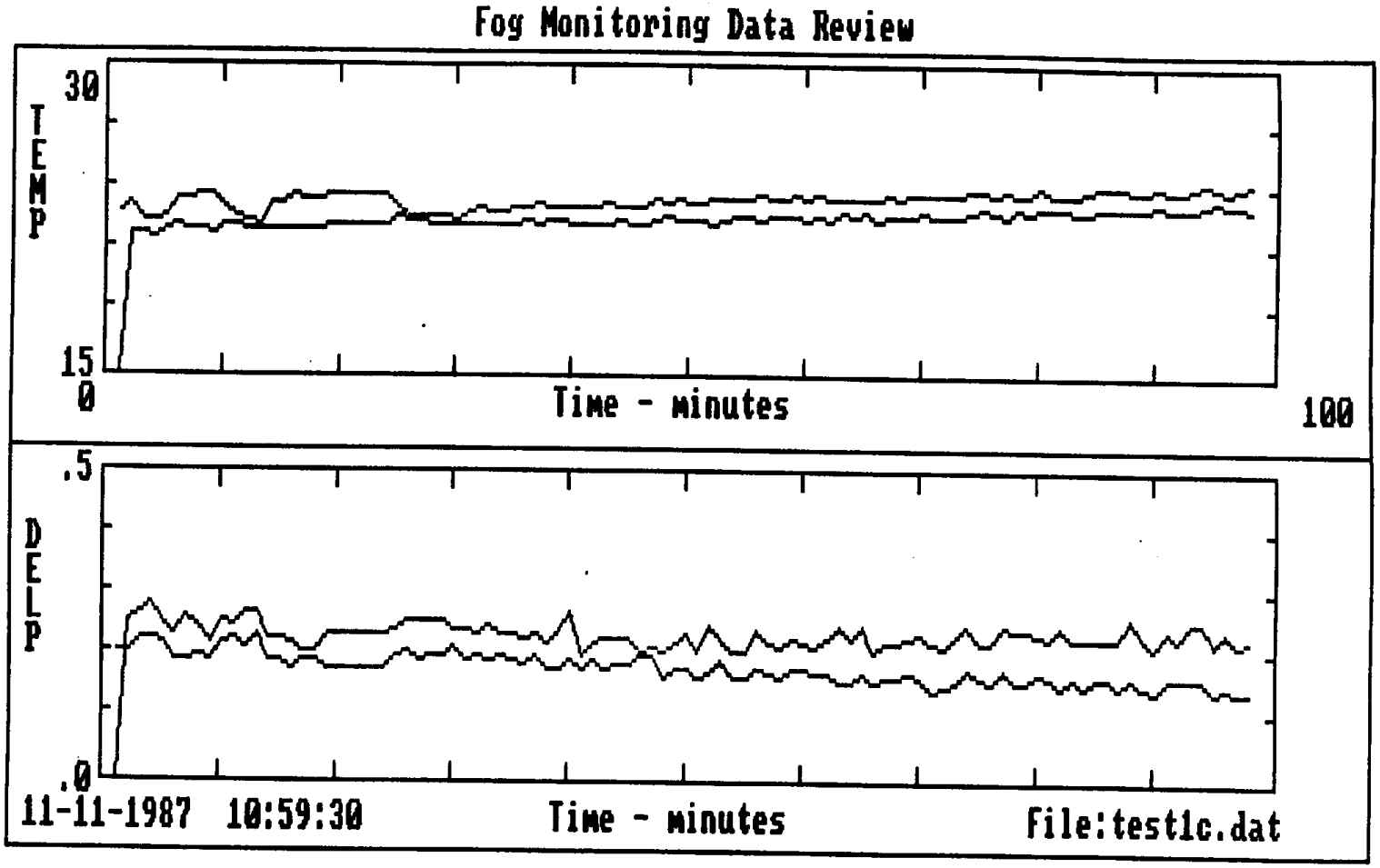

Figure 6.4. Temperature and Delta Pressure vs Time

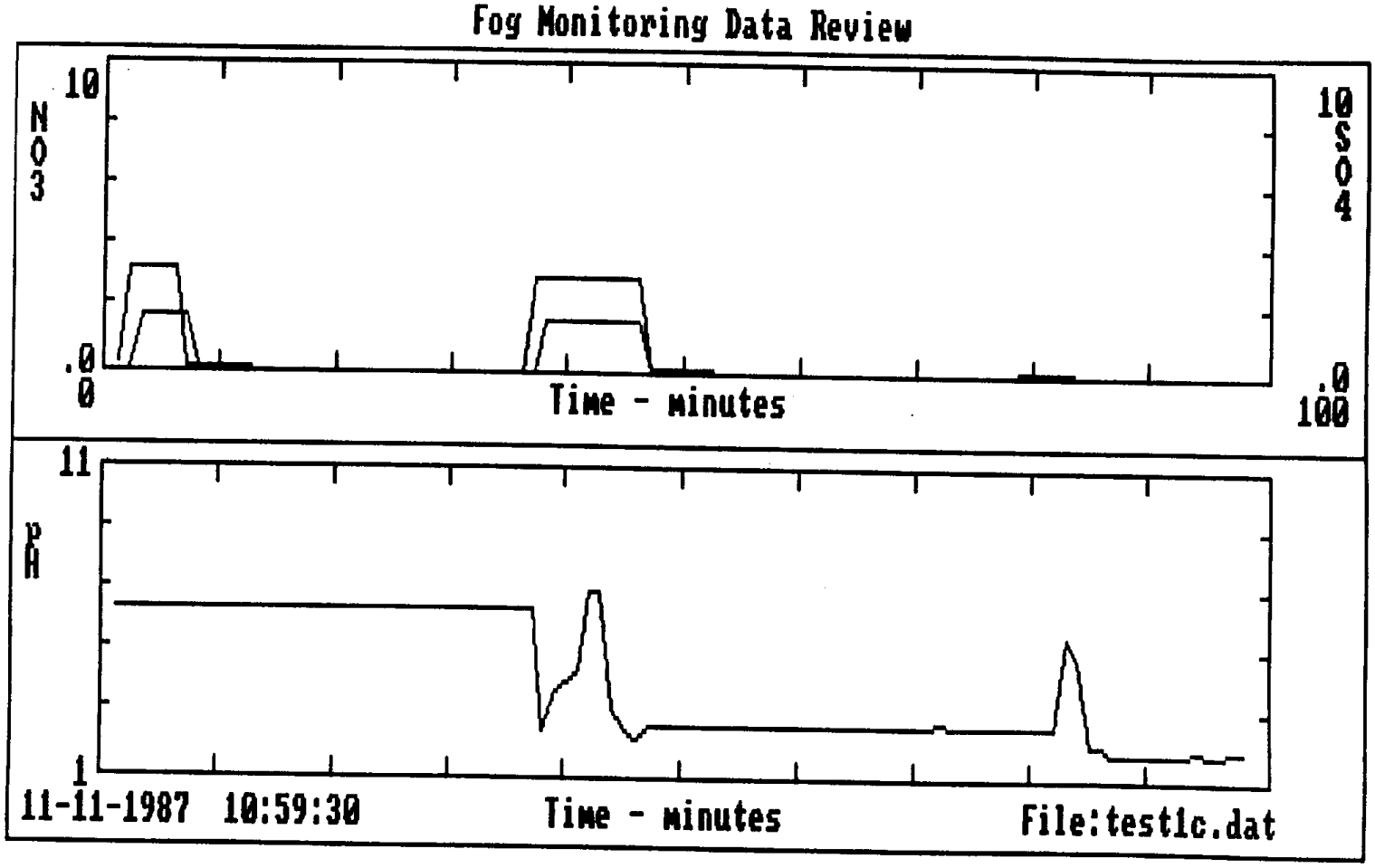

Figure 6.5. Nitrate, Sulfate and pH vs Time

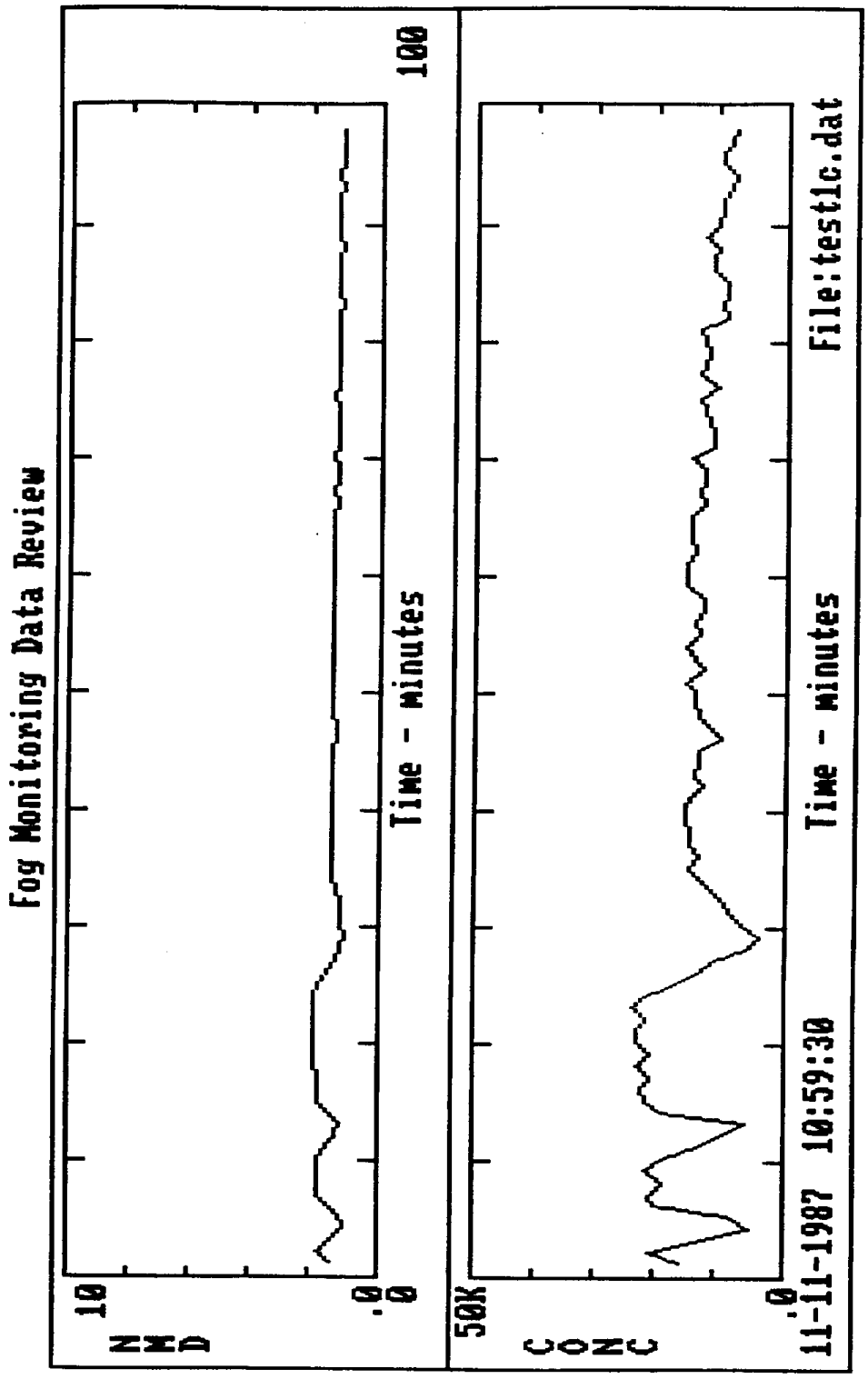

Figure 6.6. Number Median Diameter and Concentration vs Time

Data are available for the following times from test start:

1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00
21.00	22.00	23.00	24.00	25.00	26.00	27.00	28.00	29.00	30.00
31.00	32.00	33.00	34.00	35.00	36.00	37.00	38.00	39.00	40.00
41.00	42.00	43.00	44.00	45.00	46.00	47.00	48.00	49.00	50.00
51.00	52.00	53.00	54.00	55.00	56.00	57.00	58.00	59.00	60.00
61.00	62.00	63.00	64.00	65.00	66.00	67.00	68.00	69.00	70.00
71.00	72.00	73.00	74.00	75.00	76.00	77.00	78.00	79.00	80.00
81.00	82.00	83.00	84.00	85.00	86.00	87.00	88.00	89.00	90.00
91.00	92.00	93.00	94.00	95.00	96.00	97.00	98.00		

Default time: 1.00

Enter time to plot or hit RETURN for default:

Figure 6.7 Histogram Option Screen.

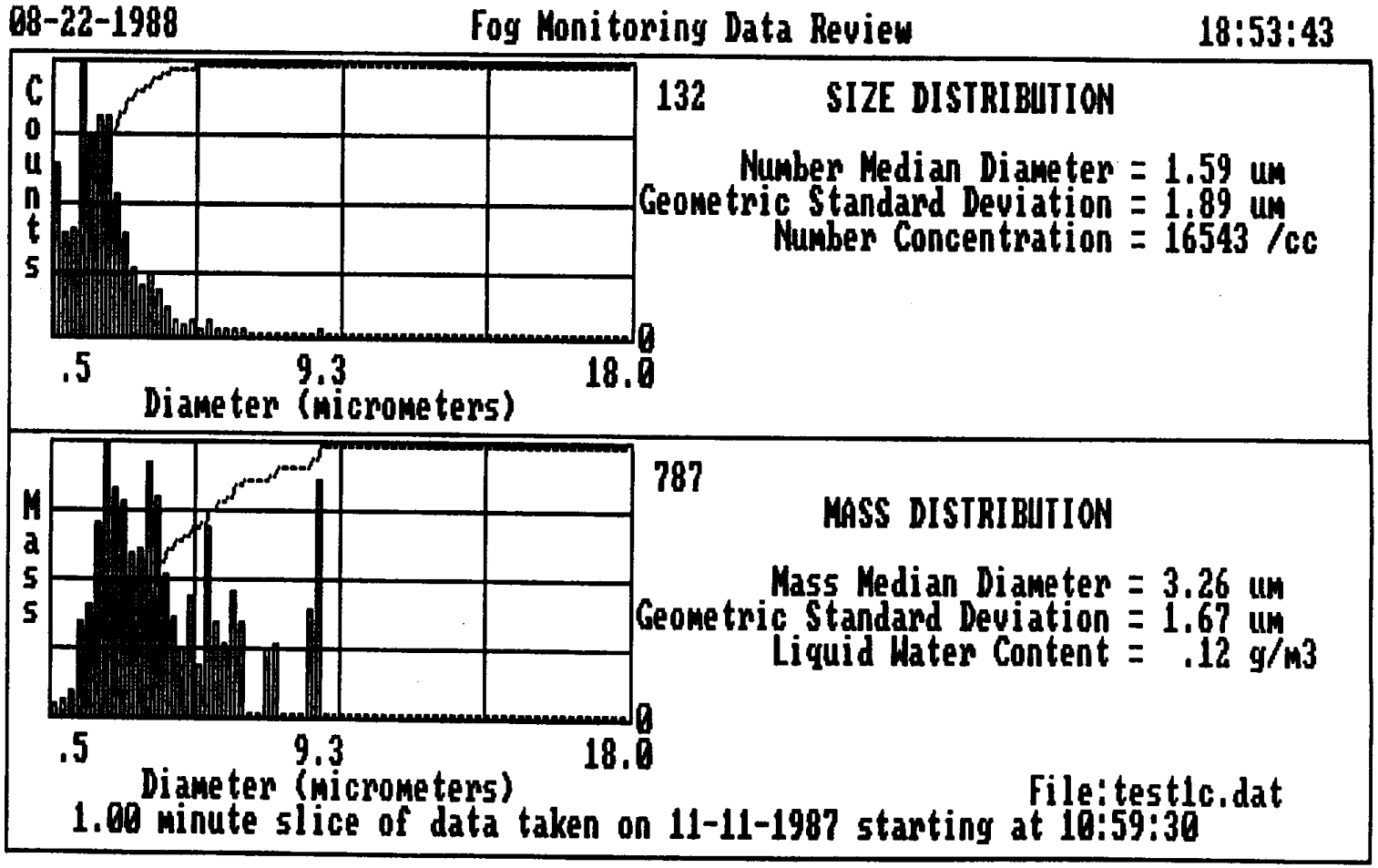

Figure 6.8. Histogram Display

If a 'Y' is entered as the response to the query, the program will respond with:

Enter window start time:

A time for the start of the window should be entered at this point. All entered times are referenced to the data acquisition start time. If the window is to be started 10 minutes into the acquisition, "10" would be entered at this point. Once the start time has been entered, the program will prompt:

Enter window stop time:

This time should be greater that the start time and, as with the start time, is referenced to acquisition start. Thus, if "20" is entered at this point, the data summary and the plots would only use the data that was acquired from 10 to 20 minutes into the acquisition. These times do not effect the plotting of the histograms (function key 7).

6.1.5. Exiting the Program

The program is exited by pressing function key 10 (F10). The program will prompt to verify that exiting is really desired and if so, the computer will return to the main menu of the operating system. If another file is to viewed, the program will have to be reentered by typing "POST" as requested by the main menu.

6.2. Chromatachart ASCII

Detailed analysis of the IC data can be performed by using the Chromatachart ASCII software package resident on the IBM-PC. For a detailed description of this program, the software manual should be referred to for both it capabilities and procedure for operation.

APPENDIX A

The Dionex documentation covers all aspects of IC operation with the following changes:

1) The sample inject valve is now controlled by the pump program. The pump module is programmed to turn on solenoid 5 and then turn it off. This solenoid drives the sample inject valve. The implication of this is that for manual IC operation one must reset (the RST key) the pump program and then start it when ready to inject. This is the same procedure the computer uses to control injections.
2) The position of the sample select valve should be noted. The currently defined positions are as follow; 1 = DDW, 2 = sample stream, 3 = span solution and 4 = manual inject port.
3) The peristaltic pump can be used to pull solutions (samples or standards) through the system or it can be disconnected in order to manually inject samples.

The current operating parameters are:

regenerant - 0.025 N H_2SO_4
eluent - 0.0056 M $NaHCO_3$ / 0.0048 M Na_2CO_3
gradient pump mixture - 60% eluent / 40% DDW
flow rate - 2.5 ml/min.

APPENDIX B

The operation of the analytical chemistry subsystem during the course of a single exposure experiment is as follows:

1) Manual calibration of the pH meter and micro pH combination electrode using standards solutions of appropriate pH and ionic strength;
2) Calibration of the IC using three to five standard solutions of appropriate concentration ranges introduced into the sample handling system via the manual sample port with distilled water flushes between each standard solution;
3) Automatic IC analysis of collected fogwater samples for sulfate, nitrate, and HMSA at a predetermined interval and continuous pH determinations;
4) Automated span calibrations at predetermined intervals and at the end of the experiment to verify the stability of the IC calibration; and
5) Manual analysis of integrated samples collected downstream of the peristaltic pump for ammonium concentration.

Operating and maintenance instructions or the Dionex IC and the Beckman pH meter are contained in their respective manuals.

Introduction to the ACQUIRE Program

The ACQUIRE program is intended to be used as part of the entire acid fog system, however it can be used as a stand alone system to control and acquire data from the IC. This documentation assumes the user (also referred to as the operator) is somewhat familiar with the MS-DOS operating system and IBM-PC hardware. Excellent documentation for MS-DOS and the IBM-PC is contained in the appropriate manuals. Documentation for the instrument interface hardware (manufactured by Strawberry Tree Computers, Inc.) is contained in the Strawberry Tree manual and the reader will be referred to that manual as required. Operating procedures for the DIONEX IC are contained in the DIONEX manuals and a brief description of the modifications to the IC for the ACQUIRE program is in appendix A.

The following are conventions used for the ACQUIRE program:

1) (text) - means to insert the appropriate text (such as a filename) in place of (text).
2) <cr> - means to press the RETURN key.
3) <esc> - means to press the key labeled 'ESC'.
4) 'RUN' or 'IC RUN' refers to one complete IC analysis.
5) 'EXPERIMENT' refers to a series of related IC runs.

The ACQUIRE program is a data acquisition and control program for the Dionex IC. It utilizes the Strawberry Tree Analog Connection Jr. hardware and driver software. The majority of the operating parameters are user specified and stored in setup files (see discussion of 'SETUP MODE').

The program writes data files of the form ICRNnnn.PRN and PHRNnnn.PRN to the working directory C:\UCSFNEW where nnn refers to the run number. Runs within an ACQUIRE session are sequentially ordered. A command called FINISH UP, within the ACQUIRE program, will automatically save these files to a data archival directory that is a subdirectory of C:\ARCHIVE. After saving, the program does not automatically delete these files from the working directory. This is to prevent accidental deletion of valuable data.

However, to start the ACQUIRE program, the working directory must be clear of these data files. Thus, the experimenter must delete all files of the form ICRNnnn.PRN and PHRNnnn.PRN before starting ACQUIRE. If old data files exist, the program will not start. The best time to do this deletion is immediately after confirming a successful save to the archival directory at the end of an experiment.

To start the program type

ACQUIRE (setupfilename)<cr>

where (setupnamefile) is the name of the file that contains the operating parameters. You will then be presented with the main menu screen. The menu and each command within it is described below.

MAIN MENU

1) START IC RUNS
2) START CALIBRATION SEQUENCE
3) START AUTO-SPAN
4) FINISH UP
5) ENTER SETUP MODE
6) DOS
7) EXIT PROGRAM
8) ENTER DRIVER INTERFACE
9) BASELINE OFFSET

To select a menu choice press the corresponding number followed by <cr>.

1) START IC RUNS.

This is the portion of the program that controls the IC runs. When entering this mode the program will ask 'ENTER "C" FOR CONTINUOUS OR "M" FOR MANUAL'. Enter the desired choice followed by <cr>. In the continuous mode the program will select the fog collector sample stream and will perform one run after another until it is stopped by the operator. In the manual mode the program will select the manual inject port and will perform one run only. Refer to Appendix A for a discussion of the sample stream select valve. To exit from the continuous mode press <esc>. A message will appear on the screen to inform the operator that the program will exit at the end of the current run. Before the program will exit from the run mode it will ask 'OK TO EXIT (Y,N)'. Enter either Y or N followed by <cr>.

If continuous mode is chosen, the program will ask the operator 'SAVE DATA? (Y,N)'. If the operator responds Y for yes, the program will save each IC run as it occurs. If the operator responds N for no, no data from any run will be saved. If manual mode is chosen, the program will ask the operator 'SAVE DATA? (Y,N)' at the end of each run. The status of data saving is indicated at the top of the screen by DS for data save and NS for no save. In manual mode this indicator displays the result of the operator's last choice. It will not affect his or her option to save at the end of each run.

While the option to not save data is convenient, it is also potentially dangerous. It is the operator's responsibility to verify that data is being saved, as indicated by DS at the top of the screen, during important experiments.

2) START CALIBRATION SEQUENCE

This mode will perform a four point calibration and is very similar to the run mode. Standard #1 is distilled water that should be connected to sample port 1. Standard #4 is the span solution. A syringe containing the span solution should be installed in sample port 3. Standards #2 and #3 will be sampled from the manual inject port. The program will prompt the user for the values of the various standard solutions. The standards should be entered in ascending order for the calibration routine to function correctly (i.e. 3mM, 5mM, 10mM). The program will then inform the operator at the appropriate time to load the various standards. The program reads in the last available calibration numbers every time it is started such that it is not necessary to run a calibration sequence for every experiment as long as the operating parameters for the IC have not changed. The calibration routine can be exited by pressing <esc>; however, this is not recommended as it could have undesirable effects on the calibration curve.

3) START AUTO-SPAN

This routine will perform automatic distilled water and span solution runs. No operator intervention is required other than to ensure adequate quantities of distilled water and span solution are present. This routine can be exited by pressing <esc>. Auto zero/span runs can also be performed at various user specified intervals (see SETUP MODE).

4) FINISH UP

This routine should be run at the end of each experiment to create an archival directory for the data files. The program will ask the operator for an archival directory name for the experiment. If the operator does not wish to chose a name, the program will provide a default name. This name has the form YYMMDDHH.mm where YY is the year, MM the month, DD the day, HH the hour, and mm the minute the experiment ended.

Whichever name is chosen, the program will create a subdirectory of C:\ARCHIVE, e.g., C:\ARCHIVE\YYMMDDHH.mm, and save all data from the experiment, including relevant calibration data, in this directory. The program will also ask 'SAVE DATA TO DRIVE A? (Y,N)'. By entering Y for yes, a backup of the experimental data will be copied to floppy disk in drive A:. The backup data will be stored in a subdirectory having the same name as that used on the hard disk.

The data files are written in a form compatible with Chromatachart ASCII. Chromatachart ASCII is a software package that can be used to perform a detailed analysis of an IC run.

Another file, RUN.LOG, contains data values for all of the parameters that ACQUIRE is responsible for during a fog chamber run. The time interval for writing this data is user definable (see SETUP MODE). Each line of the file contains: the time the data was saved, the integrated values for the three user definable IC peaks, the pH value and analog inputs 3 through 8. The analog inputs are not defined by ACQUIRE and can vary depending on how the acid fog system is configured. RUN.LOG is not saved during archival by FINISH UP, since this information is sent to the IBM-AT system and saved on that system with other fog experiment data during the course of each run.

5) ENTER SETUP MODE

The setup mode is used to create or edit setup files that contain all of the user definable parameters for the ACQUIRE program. The main menu in the setup mode contains four options; 1) load a setup file, 2) save a setup file, 3) view/edit the currently loaded setup file or 4) exit the setup mode. Note that the setup mode has no effect on the parameters in memory but rather works with setup files stored on disk. In order to edit an old setup file the operator must; load the old file, make whatever changes are necessary and then save the file with the old name. In order to create a new file the users must; load an old file, make the desired changes and then save the file with a new file name. The user has the option of loading the changes into memory when exiting the setup mode.

THE VIEW/EDIT MENU

1) - > COMMENT = (text) This is a comment line that could contain a brief description of this setup file (i.e. SETUP FILE FOR UCSF HIGH DENSITY FOG EXPERIMENT)

2) - > IC PEAK NAMES = (text) The names the ACQUIRE program uses for the three peaks it can integrate and identify are defined here.

3) - > pH DISPLAY MIDDLE VALUE = n The pH graph can display a range spanning 2 pH units. The value of the middle unit is defined by 'n'.

4) * > RANGE VALUES OF A/D CHANNELS n n n n n n n n Note that menu choices with an asterisk should not normally be changed. The values 'n' are the current range settings for channels 1 - 8. See the Strawberry Tree manual appendix I under the 'r' command for a description of these values.

5) * > MUX DELAY FOR A/D CHANNELS (MILLISECONDS) n n n n n n n n This is the time delay the program will use before reading each analog input. See the Strawberry Tree manual appendix I under the 'D' command.

6) * > DIGITAL I/O SETUP (0=INPUT,1=OUTPUT) n n n n n n n n n n n This tells the ACQUIRE program whether a digital port is an input or output. See the Strawberry Tree manual for details.

7) - > # OF A/D SCANS PER SECOND = n The ACQUIRE program will take readings 'n' times per second. The normal value is 2.

8) - > IC RUN TIME (MINUTES) = n This is the length of each IC run in minutes. This value should be large enough to ensure that all ions in a sample have completely eluded.

9) - > TIME INTERVAL FOR IC LOGGING (SECONDS) = n 'n' is the number of seconds between storing raw IC values to disk. The normal value is .5 seconds.

10) - > TIME INTERVAL FOR PH LOGGING (SECONDS) = n 'n' is the number of seconds between storing pH values to disk.

11) - > TIME INTERVAL FOR DATA TRANSFER (SECONDS) = n 'n' is the time interval between logging of data to the 'RUN.LOG' as

well as the interval between sending the data to the IBM-AT. The normal value is 1 minute.

12) -> TIME INTERVAL FOR AUTO ZERO/SPAN RUNS (MINUTES) = n The ACQUIRE program will perform auto zero/span runs every 'n' minutes. To disable auto zero/span runs set 'n' equal to a very large number (i.e. 1000).

13) through 18) These are the start and end times (seconds from the start of each run) that the ACQUIRE program uses to identify IC peaks as named by #2 above. Peaks that occur outside of these 3 windows are ignored. As an example; peak #1 may be defined as 'NO3' and have a start time of 90 and an end time of 120, peak #2 is defined as 'SO4' and have a start time of 150 and an end time of 210, peak #3 is undefined and has a start time of 220 and an end time of 300. This example assumes a run time of 5 minutes.

19) - > CHANGE A/D SCALE/OFFSETS This choice has a sub-menu that allows the user to change the scale or offset values for each of the analog inputs. The voltage read in by the program will be multiplied by the scale and added to the offset. These should not be changed for the IC (channel 1) and should only be changed for the other channels if a recalibration of the analog card is required.

To exit the VIEW/EDIT menu type '0'<cr>. To select a menu item type the corresponding number followed by <cr>. After selecting a menu choice the program will ask 'ENTER NEW VALUE(S)'. Type in the new value (if more than one value is needed as, in the mux delay, separate the values with spaces) followed by <cr>. When entering new IC peak names the program will prompt for each name separately. Enter the name followed by <cr>.

6) DOS

This routine allows the user temporary access to the operating system to perform MS-DOS operations without exiting the ACQUIRE program. This could be useful for example to format a floppy disk before running 'FINISH UP'. To exit MS-DOS and return to the ACQUIRE program type 'EXIT'<cr>.

7) EXIT

This will exit the ACQUIRE program. If 'FINISH UP' has not been run the program will ask 'FINISH UP NOT RUN - OK TO EXIT (Y,N)'. Respond with either 'Y' or 'N' followed by <cr>.

8) ENTER DRIVER INTERFACE

This routine is intended for advanced users and is used primarily for testing and debugging purposes. It allows the user to issue commands directly to the driver software. The driver software commands are discussed in the Strawberry Manual in appendix I. One command 'V' will display the analog input voltages on the screen for each channel. The display is updated every second and can be exited by pressing <esc>. To exit the driver interface type 'X'<cr>. The 'V' and the 'X' commands are not discussed in the Strawberry Tree manual and are not driver commands but rather are commands to the ACQUIRE program.

9) BASELINE OFFSET

This routine activates the Dionex Auto-Zero function. Choosing option 9) will cause the Dionex to adjust its output reading to zero for the conductance of the solution currently flowing past its detector cell. This is useful for analysis of low level concentrations when the conductance peaks from the sample are on the same order of magnitude as the background conductance. However, care must be exercised. If the peaks are too small in relation to the background conductance (i.e. the baseline), then baseline drift will cause the program to produce inaccurate concentrations. For very low level analyses, when baseline drift can be significant, a more sophisticated peak detection and integration package, such as Chromatachart ASCII, should be used.

APPENDIX C
FOG Program Data File Format

The data file that can be stored on floppy disk after each run of the FOG program is a binary file. Each record in the file is 371 bytes long. The first record contains the setup constants needed for PDPA calculations. The remaining records contain the time history data for the experiment in the following format:

Byte No.	Length	Type	Description
1	2	Integer	Hour when data was taken
3	2	Integer	Minute when data was taken
5	2	Integer	Second when data was taken
7	2	Integer	Millisecond when data was taken
9	4	Real	Number Concentration
13	4	Real	Mass Median Diameter
17	4	Real	Liquid Water Content
21	4	Real	Number Median Diameter
25	4	Real	NMD Geometric Standard Deviation
29	4	Real	MMD Geometric Standard Deviation
33	2x68	Integer	Particle Velocity Counts Array
169	2x68	Integer	Size Distribution Array
305	2x8	Integer	Bad Sizing Array
321	4	Integer	Running time in milliseconds
325	11	Character	Time from IC program
336	4	Real	Nitrate Concentration
340	4	Real	Sulfate Concentration
344	4	Real	HMSA Concentration
348	4	Real	pH
352	4	Real	Chamber Inlet Temperature
356	4	Real	Chamber Outlet Temperature
360	4	Real	Chamber Air Flowrate
364	4	Real	Pre-Filter Delta Pressure
368	4	Real	HEPA Delta Pressure

Appendix 3

Post-Installation Performance Testing and Calibration of the Fog Generation and Monitoring Systems

Initial performance tests of the fog generation and monitoring systems after installation at UCSF indicated that the optimum location and number of nozzles/screens in the fog generator for the production of a given median droplet size would have to be determined through additional testing. For example, the results of the initial tests demonstrated that the use of a large number of screens (in an attempt to generate droplets of small size) would cause solution to become trapped on the upper screen, which, in turn, would cause diversion of air flow and thus limitation of the particle sizing effect of the screen assembly. The blower flow rate and the temperature of the solution in the storage tank were also noted to be critical variables with regard to the particle size and liquid water content (LWC) of the generated fog.

Approximately 60 days of multi-hour operation of the fog generation and monitoring systems were required to establish the nozzle, screen, and blower flow rate parameters that would allow the reproducible generation of the fog conditions utilized in Project 3 of this report (i.e., a "low" LWC fog of relatively large particle size and a high LWC fog of equal particle size). The lowest LWC for which we could maintain a median particle diameter in the 6-7

micron range was 0.5 g/m^3, which, in fact, is a relatively dense fog by ambient standards.

Because we recognized that the phase/Doppler particle analizer (PDPA) tended to significantly underestimate LWC, we employed a gravimetric method to measure the actual LWC's of the generated fogs at several time points during exposures and to roughly calibrate the PDPA readings for continuous on-line monitoring. For the low LWC fogs (0.5 g/m^3) generated for Project 3, the PDPA LWC readings were in the range of 60-70% of the gravimetric measurements. For the high LWC fogs (1.8 g/m^3) used in the same project, the PDPA readings were 40-50% of the gravimetric measurements.

The modified Cal Tech string fogwater collector frequently captured an insufficient volume of water to allow continuous monitoring of sulfate concentration when low LWC fogs were generated in the chamber. Thus, sulfate concentrations were measured by eluting fogwater from the filters used for the gravimetric measurement of LWC. Several different types of filters were tested before a glass fiber type (Gelman Sciences, Ann Arbor, MI) was selected both for its durability and lack of interference with the measurement of sulfate concentration. The original program written to automatically operate the ion chromatograph did not allow sufficient sensitivity of sulfate measurement to accurately display concentrations in the range of what was eluted from the filters. Thus, we required the ion chromatography

subcontractor, Environmental Research Technology (Calabasas, CA), to rewrite the operating program to accommodate our need for greater sensitivity of sulfate ion measurement.

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This study was built on earlier work examining the effects of acidic fog on human subjects with asthma. Mouthpiece exposure studies on asthmatic subjects showed that both nitric and sulfuric acids potentiate the bronchoconstrictor effects of fog water, and that these acids appear to be similar in this respect. This work resulted in the exposure chamber at the University of California, San Francisco being extensively modified, based on improvements recommended in an earlier investigation, thus allowing human subjects to be exposed to rigorously controlled and monitored test fogs. This study used the chamber to first examine the effects of fog without acid, and then the effects of fog with acid, on exercising subjects with asthma.

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Asthma
Respiratory Diseases
Fog (acidic)
Health
Public Health Effects
Public health--polution (air)
Monitoring--environmental (air)
Chamber--Exposure

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Acid Fog
Acid Aerosols
Health Effects (of acid fog)
Nitric acid
Exposure chamber
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