A PORTABLE COMPUTER CONTROLLED MULTI-SIZE RANGE AEROSOL COUNTING SYSTEM FOR USE IN UNDERGROUND MINING ENVIRONMENTS

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MRL 88-083 (J) c.2 Jan. 1988

Published in Applied Occupational and Environmental Hygiene. Volume 6, No. 3 pps 189 to 196; March 1991.

A portable computer controlled multi-size range, aerosol counting system for use in underground mining environments

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Abstract

Respirable particulate control is a major concern in the underground mining environment. The Elliot Lake Mining Research Laboratory recognized a need for, and had developed, a real-time particle counter to further their dust control studies. Extensive modifications to a commercially available 'clean-room' aerosol counter have customized a unit for use in underground environments.

The particle counter uses near forward light scattering to count particles into six threshold size ranges, five of which start in the respirable range. Applications of the counter include: i) characterizing dust from different mining operations; ii) evaluating the efficiency of dust removal/suppression methods; iii) determining dust transportation/ sedimentation characteristics of mine ventilation systems; and iv) quantifying size dependent characteristics of other dust/particulate measurement methods.

The aerosol counter has the following specifications: threshold size ranges of 0.5, 1.5, 2.0, 3.5, 5.0 and 10.0 μm (optical) diameter; maximum count of $4x10^5$ particles/L without dilution; and normal sample flow rate of 2.8 L/min with optional 100:1 dilution. A rechargeable hand-held computer provides on-line remote control and logging facilities, and off-line communicates with a standard PC computer which analyzes data with an electronic spread sheet.

To date, two particle counters have been used in the evaluation of a dust filtration unit and a dust transportation study. Evaluation of two similar filter units highlighted the size dependency of the filter units and

how aerosol mass distribution by size has a significant effect on the unit's bulk efficiency. Such is the potential of the units in mining environmental dust control studies.

Introduction

The Mining Research Laboratory at Elliot Lake has been investigating airborne particulates since the early 1960s. Of late a requirement for a real time aerosol counter has become apparent.(1) A major interest of the Laboratory has been in measuring and quantifying mineral dusts generated by mining operations that may be injurious to health with long term inhalation exposure. These form five major categories for investigation:(2)

1. Instrument calibration and design, such as the CAMPEDS two-stage personal impactor;(3)
2. Establishing measurement techniques and analysis methods, including the following;
3. The development of direct on filter analysis by X-ray diffraction for quartz;(3)
4. Promoting, designing and evaluating particulate control in the mining environment; and
5. General investigations of dust underground.

In all the above, the primary concern has been with dust of the respirable size range. between 0.5 and 10.0 μm.

Presently, a major thrust is being carried out into the control of dust produced from underground operations. Prior to obtaining optical particle counters, (OPCs), particulate control assessments have been performed mostly with gravimetric samplers that normally collect the whole respirable range. Some use has been made of light scattering monitors, cascade samplers and konimeters. The light based monitors typically provide a real-time history of dust concentrations for the respirable range. The cascade samplers provide size distribution information but only as a time-weighted average (TWA). A konimeter is a useful engineering tool in that it effectively takes an instantaneous sample of which the particle number concentration can be counted.

Formerly, the OPCs were laboratory based clean-room aerosol counting systems which were redesigned and modified for use in underground environments. Specific modifications include: a) size reduction to improve and allow portability; b) optional battery operation to provide power independency; c) protection against the mining environment; d) increased maximum loading of the sensing chamber to handle high concentrations; and e) provision of data logging facilities. This instrument combines the real-time capability of the light based monitors, the size differentiation of cascade samplers and pure particle counts of the konimeter. With data reduction the instrument could also provide both real-time and TWA gravimetric and particle number concentrations, and mass distribution by size information.

The real-time measurement applications of an OPC in mining are where there is a need to investigate the size dependent characteristics of dust clouds; these include:[1]

i) categorizing dust producing operations by their dust characteristics;

ii) assessing dust removal/suppression methods such as water sprays and filters;

iii) investigating dust transportation. pick-up and deposition by a mine airstream; and

iv) evaluating the measurement instruments used to evaluate a miner's dust exposure.

The redesigning and modifying of two former HIAC/ROYCO Model 4102 light scattering particle counting systems was performed by Mono Research Laboratories Ltd., Brampton, Ontario.[4]

In the following sections the basic clean-room laboratory-based OPC, modifications to adapt it to the mining environment, examples of usage and a discussion of its performance are presented.

The Unmodified 4102 OPC

System Configuration

The 4102 system configuration (Figure 1) consists of an optical sensor, electronic analyzer, output device and optional input/controlling device. Briefly, the units function as follows: a pneumatic system draws an airstream through the optical sensor, which converts scattered light from particles in the airstream into electronic pulses, then the analyzer counts and sizes each particle's pulse into one of six diameter groups and the count and size data are logged on a computer or printer.

System Optics

The 4102 system is a near forward scattering light instrument with sheath optics (Figure 2). Light from a standard tungsten filament or quartz halogen source is focused through a defining aperture and passes as a sharply defined beam through a sensitive volume. On an aerosol passing through the small sensitive volume (0.5 x 1.0 x 2.0 mm), each particle of the aerosol scatters a pulse of light over a large solid angle. The near forward component of the scattered light is collected and relayed to a photomultiplier (PM) tube which converts it to an electronic pulse. A light trap collects and absorbs direct light passing through the aerosol when no particles are present.

The typical dynamic range of a near forward scattering technique detector is 40:1, which corresponds to an 0.5 to 20 μm diameter detection range.

System Electronics and Input/Output

The 4102 electronics and input/output options are shown in Figure 1.

The electronic pulses from the PM tube (~40 μs duration) pass through the analog to digital converter to the microprocessor. Here the pulses are counted and sized according to amplitude into 1 of 6 threshold diameter groups. The microprocessor is also responsible for numerous other operations, including controlling input/output modules, internal communications and self-checking of the system.

The input/output modules communicate with the external devices. These may be purely passive data printers, or interactive controlling/data logging computers.

System Pneumatics

The 4102 pneumatic system draws 2.8 L/min (0.1 cfm) from the inlet (Figure 3). This airstream is contained by a 32 L/min column of sheath air. An 0.45 μm absolute filter ensures the sheath air is effectively particle free and able to prevent sampled particles from contaminating lenses in the system.

Figure 3 also depicts a diluter that may be incorporated at the inlet port as it now exists. This again contains an absolute filter. The inclusion of a diluter was one of the major modifications to the system.

Calibration Standards and Techniques

Primary calibration of light scattering instruments is generally performed with monodispersed spherical latex particles.[5] The size distribution property reported by an instrument is the equivalent optical diameter based on the projected area of a spherical particle of known refractive index. For correlating between instruments intended to monitor a polydispersed environment a secondary calibration procedure is also utilized.[6]

4102 Limitations and Specifications

The 4102 in its unmodified state has limitations when considering it for use in an underground environment. The maximum concentration limit of 4 x 10^5 counts/L/min, or total count of 1 x 10^6 counts may be insufficient for some mining operations.

The 4102 system does not acommodate any memory for data storage. Although the system program functions are non-volatile, the data is volatile and could be readily lost during power failure. In addition, the system cannot perform multiple runs and upload data from a remote site.

The 4102 is not readily portable as purchased. It consists of three boxed elements and is not suited to harsh handling. Unmodified, it may be susceptible to stray electro-magnetic noise and is 110 VAC dependent.

Despite the above limitations, this unit can measure the highest concentration of all the near forward light scattering instruments being manufactured. It has adjustable and programmable sampling, delay and stabilization times, it is a true six-channel analyzer and contains numerous programmable functions. The 4102 is already user friendly, has a membrane keyboard and RS-232 communications port for computer control and data logging facilities.

Most of the above limitations have been removed through extensive modifications and development of software and hardware to control the system.

Modifications to the 4102 OPC

Electrical and Electronic Modifications

Repackaging for portability and general protection necessitated the relocation of most of the circuit boards and wiring harnesses, and removal of most of the external wiring. Additional filters were also required to reduce line noise.

Redesigning power demands required various interlocking switches, relays and time delay circuits to be included. These were required to ensure a correct start-up sequence; allow remote activation of pumps when controlled by an external computer; and to smooth the high instantaneous current provided from the remote power supply and inverter.

For survey areas where 110 VAC is unavailable it was also necessary to design and fabricate a rugged inverter with high efficiency rechargeable batteries and a custom charging system.

Pneumatic Modifications

As shown in Figure 2, the main change to the pneumatics was the inclusion of an optional venturi style diluter. The present flow disc in the venturi port provides a dilution ratio of 100:1. The dilution air is prefiltered and the airstreams mix under turbulent conditions.

Modifications for Computer Interfacing and Control

Optimizing the use of the OPC required extensive modifications to allow automatic/remote control and data logging facilities from a portable self-contained hand held computer (a MEMO unit). This provided a non-volatile memory that could store the data from numerous tests.

Specific software was created for communications and file management between both the MEMO and the particle counter, and between the MEMO and an IBM PC or compatible computer.

Data Analysis and Presentation

Once the data is on a PC it can be readily included in an electronic spreadsheet, such as Lotus 1-2-3, with minimal restructuring. The spreadsheet provides both graphical presentation of results and easy manipulation of data. For most applications typical data output representations are: the basic real-time history of pure particle counts for any size range; a derived real-time history of the total particle number concentration (ppcc); and real-time history of the concentration in gravimetric terms, typically mg/m^3; and a history of the percentage mass distribution by size. The latter two require a volumetric treatment of the primary data. The mass distribution by size data are also normally reduced to an average from which a mean optical volumetric diameter (MOVD) and its geometric standard deviation (GSD) can be derived. Such presentations are given in the following sections. These are the standard output of an electronic spreadsheet and the optimum presentation of data has not yet been finalized.

Field Studies Using the Modified OPCs

To date, the OPCs have been employed in five underground tests, and each occasion has been valuable in showing minor modifications necessary to produce the optimum units. The studies were performed in the following locations:

1. Two evaluations of the counters in a conveyor way where broken ore was being transported from a crusher to an interim storage bunker.(7) One of these specifically looked at dust transportation and/or sedimentation.
2. Two investigations in an underground ore crushing room,(8,9) one of which was the evaluation of the particulate removal efficiency of a wet filtration unit attached to the crusher.
3. One evaluation of a wet filtration unit attached to an orepass into which broken rock is dumped from train cars.(10,11,)

The next section presents some of the results of the evaluation of two similar 'water scrubber' type dust collectors at two different mining operations. (2 and 3 above). In each the OPCs monitored the intake and exhaust air of a Mark III Precipitaire dust collector.

Collector 1 - Orepass Location

The orepass collector evaluation results, Figure 4 a-f, were obtained with OPCs operating under the following conditions: i) the OPCs minimum thresholds were 0.5, 1.5, 3.0, 5.0, 10.0 and 15,0 μm; ii) they sampled continuously at 2.8 L/min; iii) counted for 30 sec in each minute; and iv) used no dilution. The OPCs were controlled locally through the membrane keyboard and data were logged on a printer. The dust collector was also evaluated on a gravimetric basis, concurrently, using two-stage impactors.

The basic time history of the number of particles measured at the collector inlet and outlet, Figure 4a, is indicative of the general dust production cycle and conditions of the area. The vertical separation of the two inlet and outlet traces is representative of the good collection efficiency for the 3.0 to 5.0 μm size range. Similar traces could be drawn for the other five size ranges.

The primary peaks of the time history traces all correspond with ore dumping operations. During the first half of each trace there are distinct secondary and tertiary peaks, at about 7 minute intervals.

On occasion, the inlet counter became saturated with particles and resulted in coincidences in the sensing volume. The diluter was not used as the 100:1 ratio was too extreme. No saturation was encountered at the outlet counter and this trace can be assumed to be fully representative of the conditions at the collector exhaust. Data collected at the inlet have been edited in subsequent derived results to remove the saturated conditions.

The dust collector outlet data have been reduced to two concentration formats in Figures 4b and c, ppcc and mg/m^3, respectively. Again both traces show peaks, to a maximum 300 ppcc or 1.5 mg/m^3, occurring at dumping times. The peaks are relatively short-lived and would bias any assessment if taken in isolation. Between peaks the concentration decays to acceptable levels and produces a TWA of ~70 to 90 ppcc or 0.2 to 0.3 mg/m^3 depending on whether a non-operational period is included. A parallel gravimetric analysis gave 0.13 mg/m^3. The difference in concentrations is discussed later.

Unique to a collector or filter evaluation the inlet/outlet data can provide, through a volumetric treatment, the time history of the collector's overall volumetric efficiency (Figure 4d). For the majority of the evaluation period this varied between 70 and 95%. All the values significantly lower than this correspond with saturation occurring in the inlet counter and are not as such representative. Calculating the efficiency for each of the six size ranges has provided an overall efficiency curve (Figure 4e). As is the nature of this type of wet dust collector, it is least efficient for small size particles and very efficient for larger size particles. In this instance the OPCs show the collector to be 45% efficient for particles 0.5 to 1.5 μm optical diameter and >95% for particles larger than 3.0 μm.

The OPCs show the collector to have a TWA overall removal efficiency of 82% by volume and 57% by particle number. The volume efficiency compares well with that from a gravimetric method of 84%.[10]

The OPC derived particle volumetric or mass distributions by size are given in Figure 4f for the inlet and outlet of the collector. These indicate a reduction in the mass mean diameter (MOVD) as the cloud passes through the collector. This is a pure reflection of the preferential removal of larger particles over smaller ones by the collector.

Collector 2 - Crusher Location

The previous test with the OPCs highlighted that few particles of greater than 10 μm were being counted and greater detail was needed at smaller sizes. The crusher collector evaluation results, Figure 5a-f, were obtained with OPCs operating under the following conditions. The thresholds were redefined as 0.5, 1.5, 2.0, 3.5, 5.0, and 10.0 μm; they sampled at 2.8 L/min, counted for 48 sec in each 2-min period, and used no dilution. Throughout, the OPCs were operated in their fully automatic mode with computer control and data logging. A gravimetric analysis was also performed on the dust collector using 8-stage cascade samplers.[8]

A basic time-history of the particles counted at the collector inlet and outlet, Figure 5a, is again indicative of the general dust production cycle and conditions of the area. Compared with the dumping operation the crusher produces high counts for a longer duration. In this instance the peaks rapidly decay both in the inlet and outlet on the cessation of crushing. This demonstrates that the collector and its infrastructure are well designed to minimize the crusher contribution of dust to the mining atmosphere.

Again the good vertical separation of the two traces is an indication of the collector efficiency for the 3.5 to 5.0 μm size range. Saturation also occurred, on occasion, in the inlet OPC, but the dilution option was not used because it made the unit too insensitive at other times. The dust collector outlet data reduced to a concentration format are presented in Figure 5b and 5c. At this location the collector exhaust air is cleaner than with the previous unit at the orepass as shown by: a) the TWA concentrations were reduced from 98 to 72 ppcc or from 0.27 to 0.14 mg/m^3; and b) the maximum concentrations were reduced from 300 to 250 ppcc, or from 1.5 to 0.85 mg/m^3.

The dust collector removal efficiency time history, (Figure 5d), shows variations between 80 and virtually 100% removal. The lack of significant low values and the generally higher overall efficiency of this unit is a function of larger particles being more numerous. In the collector efficiency by size range analysis, (Figure 5e), this unit seems more efficient in all ranges than the previous unit at an orepass, however, for the large sizes this can be attributed to calculating with larger initial inlet numbers. Also shown is the collection efficiency of the unit as derived with cascade samplers and the two curves show reasonable agreement.

For this wet collector, the OPCs show it to be >86% efficient at removing particles larger than 2.0 μm and >96% efficient at 3.5 μm and larger. Overall the particle counters gave a removal efficiency of 92% by volume and 51% by number, while the gravimetric samplers exhibited the unit to be 85% efficient at collecting particles.

The OPC derived volumetric or mass distributions by size of the clouds entering and leaving the collector are distinctly different. Figure 5f shows the inlet distribution to be broad with a large MOVD, whereas the outlet has a small MOVD comparable with that from the orepass unit. For the outlet distribution virtually all counted particles are in the first detection size range. This significant reduction in mass mean diameter emphasizes the collector preference for removing large particles and leaving an aerosol more concentrated in smaller particles to be exhausted.

Discussion

Through investigations and OPC trials to date, the only shortcoming of the instruments is the dilution unit. At high dust production mining operations, the dust clouds generated proved to be too concentrated for the units to measure at their normal sampling flow rate, which resulted in saturation of the inlet unit and an invalid count. However, on dilution, at 100:1 ratio, the units could readily handle the concentration, but detail for particles larger than 3.5μm was limited. This is being corrected by changing the air regulating orifice in the diluter. The optimum dilution ratio is being finalized and will probably be ~20:1.

The data manipulation and presentation performed with a PC still needs improvement. At present the analysis of the large data files generated is very cumbersome and time consuming. Until protocols for data analysis and presentation have been finalized and the associated program macros completed, all decisions have to be made by the analyst and most data manipulation operations made through the keyboard.

Field trials with the particle counters have demonstrated the unit's versatility and possible applications in future work. The trials on the collectors show how the data from the counters can be presented in six different formats depending on requirements. The main advantage of the units is their ability to provide real-time information immediately on the particle counts at different sizes. This is easily converted to particle concentration as measured by konimeters. Through numerical methods the data can also provide the mass concentration and the mass size distribution on a real-time basis and in terms of a time-weighted average.

When compared with gravimetric determinations of TWA mass concentration, the results of the OPCs were significantly higher, but this could be a result of: i) omitting a shape factor correction; ii) not correcting the total masses into their respirable mass concentration; and iii) differential sampling efficiencies of the OPC and gravimetric sampler within the measured range.

The dust collector study demonstrated how the unit can be used to assess dust removal methods and their efficiency dependence on size. It also provides valuable information on the character of dust producing operations. This includes: dust mass distribution; dust production duration; how long the operation affects an area after its cessation; and how efficiently ventilation and suppression, or removal methods, are at controlling the dust contribution to the mine atmosphere. Such information is essential, firstly to gain a greater understanding of dust and its control in the mining environment, and secondly, as a consequence to reduce the inhalation health risks and workers exposure.

For example, consider the described investigation of two identical water type collection units operating at different dust producing operations. Here the optical counters have shown the collector overall mass removal efficiency to vary from 82% at an oredump up to 92% at a crusher, purely because the crusher produces a coarser dust and the collector's removal efficiency is size dependent. Although not the case here, a collector only 82% efficient may not be good enough for its designed duty. Therefore, consideration must be given to the size distribution of the product to be removed before employing such a water type collector, and this can be readily provided by a particle counter.

Conclusion

The development of a portable computer controlled multi-size range real-time aerosol counter for underground use has been successful. The two HIAC/ROYCO 4102 optical particle counters, as modified by Mono Instruments Ltd., have been proven to work under mining conditions and be able to count typical high dust concentrations.

The evaluation of the two dust collectors at common underground mining operations have demonstrated the potential of the OPC. It is expected that the OPCs will prove to be invaluable as an engineering tool in future dust studies performed by the Mining Research Laboratory, Elliot Lake.

Acknowledgement

The authors would like to thank the management of Rio Algom Ltd., specifically the ventilation departments of Stanleigh and Quirke Mines, for providing test sites for the aerosol counters, and also for their help and

cooperation afforded throughout.

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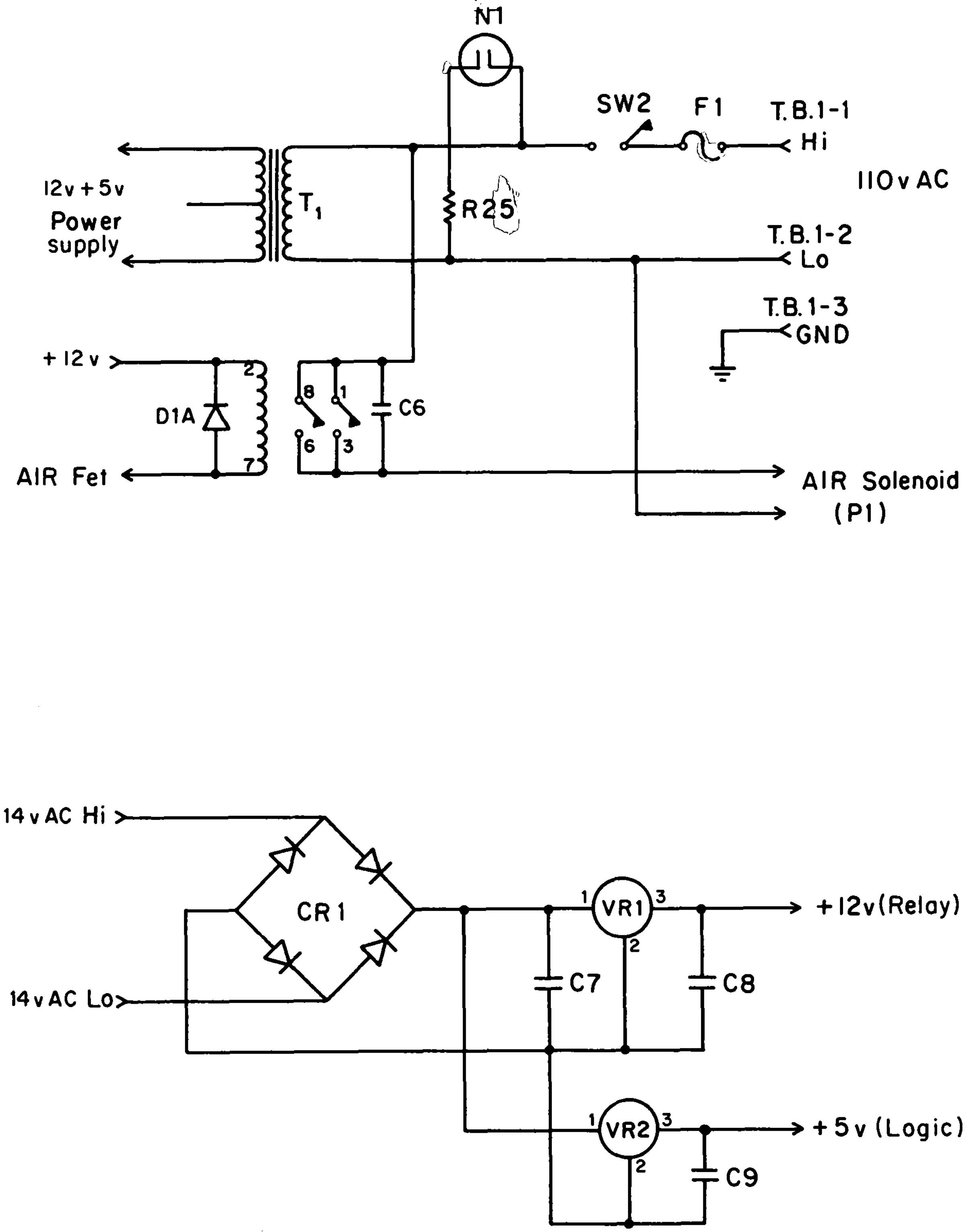


Fig. 5. Power supplies in control box

Figure Captions

Figure 1 -- Original configuration of a HIAC/ROYCO model 4102 aerosol counting system.

Figure 2 -- Optical system of the HIAC/ROYCO 4100 series instruments.

Figure 3 -- The OPC pneumatic system and optional diluter.

Figure 4 -- Optically derived performance data and dust characteristics of a wet dust collector at a mine orepass: a) comparative collector inlet and outlet counts; b) total particle count concentration at the outlet; c) mass concentration at the outlet; d) total volumetric removal efficiency; e) size differentiated particle removal efficiency; and f) volumetric size distributions at both the collector inlet and outlet.

Figure 5 -- OPC data for the dust characteristics and performance data of a dust collector at an underground crusher: a) comparative collector inlet and outlet counts; b) total particle count concentration at the outlet; c) mass concentration at the outlet; d) total volumetric removal efficiency; e) size differentiated particle removal efficiency; and f) volumetric size distributions at both the collector inlet and outlet.

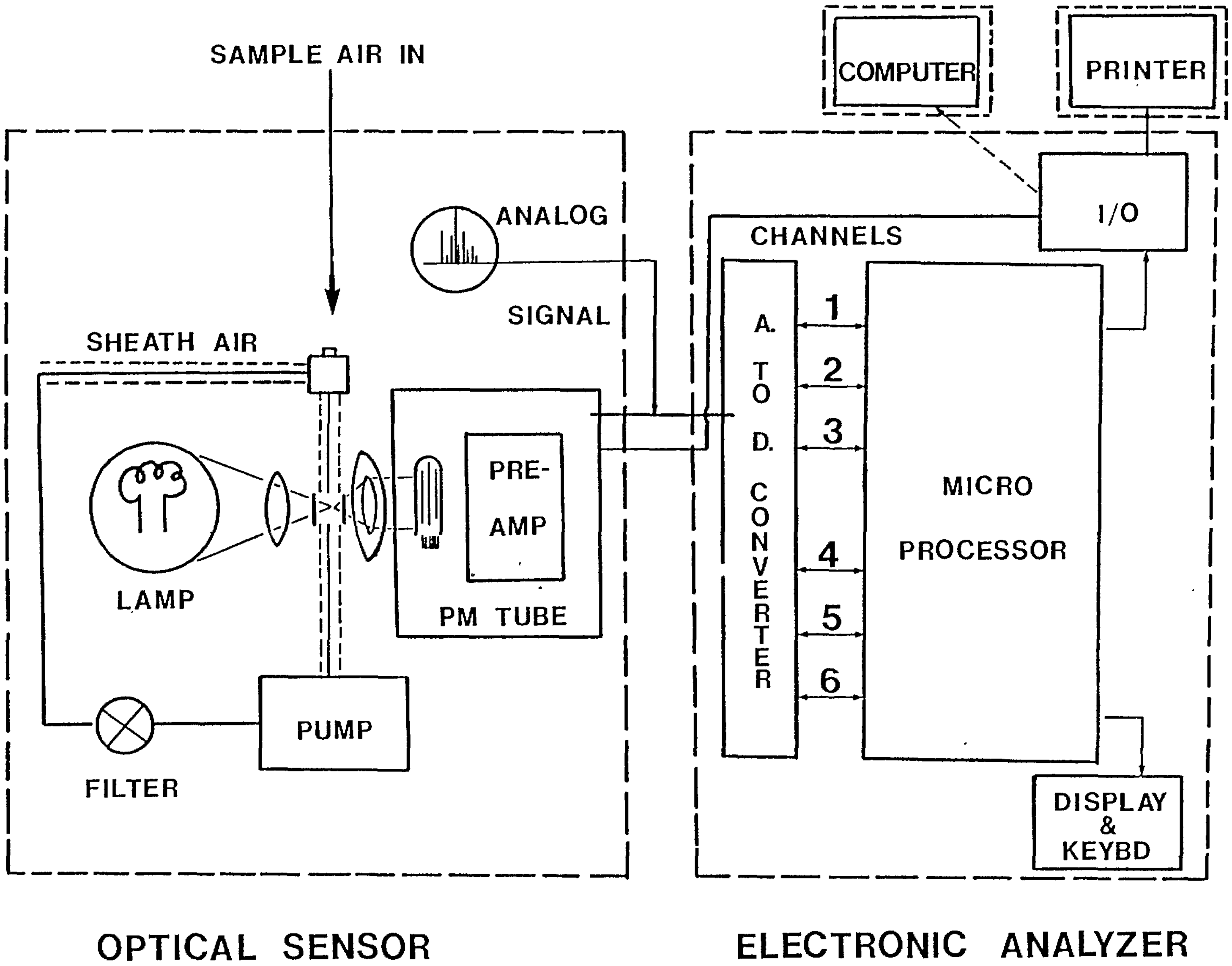
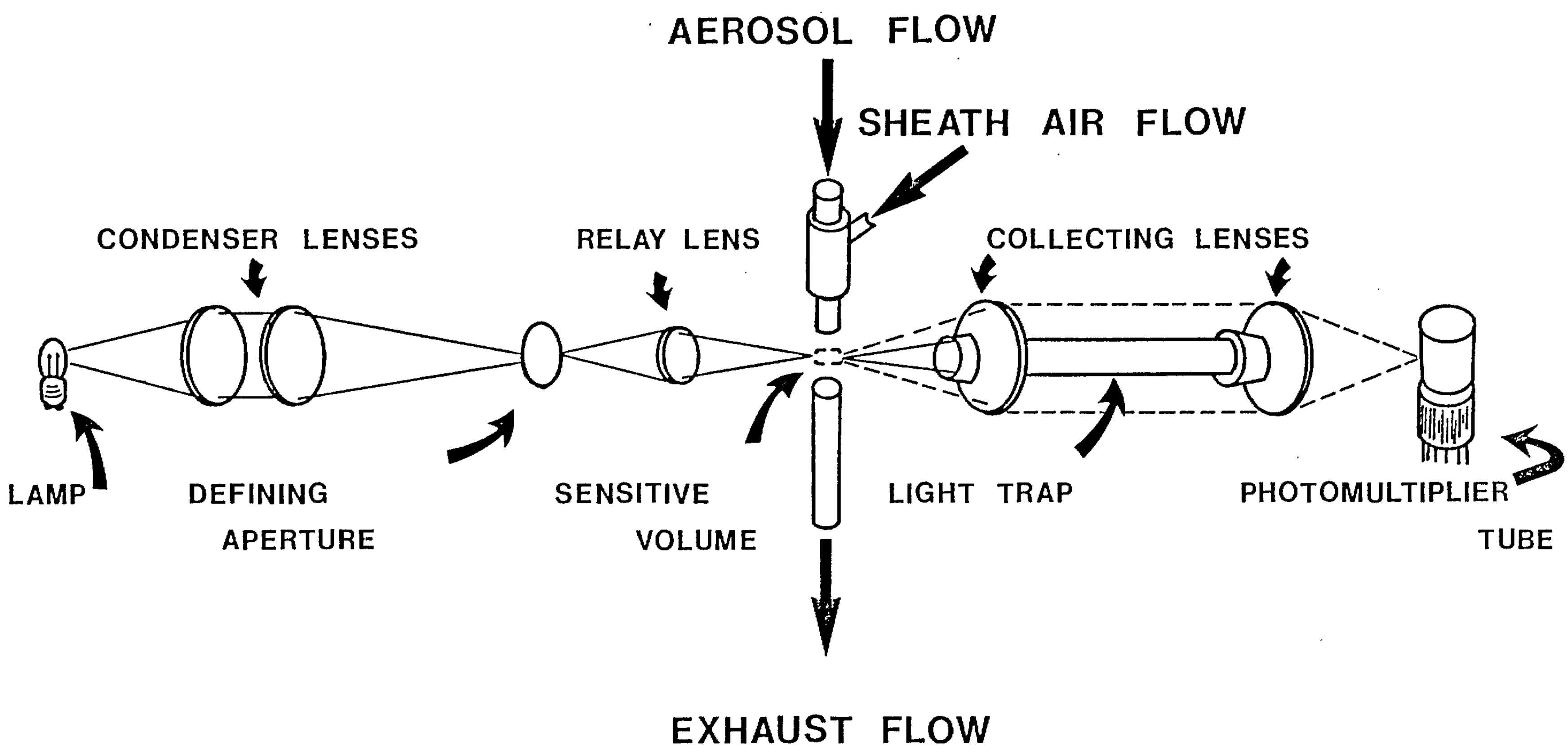

SAMPLE AIR IN
COMPUTER
PRINTER
ANALOG
SIGNAL
I/O
CHANNELS
SHEATH AIR
A. TO D. CONVERTER
1
2
3
4
5
6
PRE-AMP
PM TUBE
MICRO PROCESSOR
LAMP
PUMP
FILTER
DISPLAY & KEYBD
OPTICAL SENSOR
ELECTRONIC ANALYZER

Figure 1.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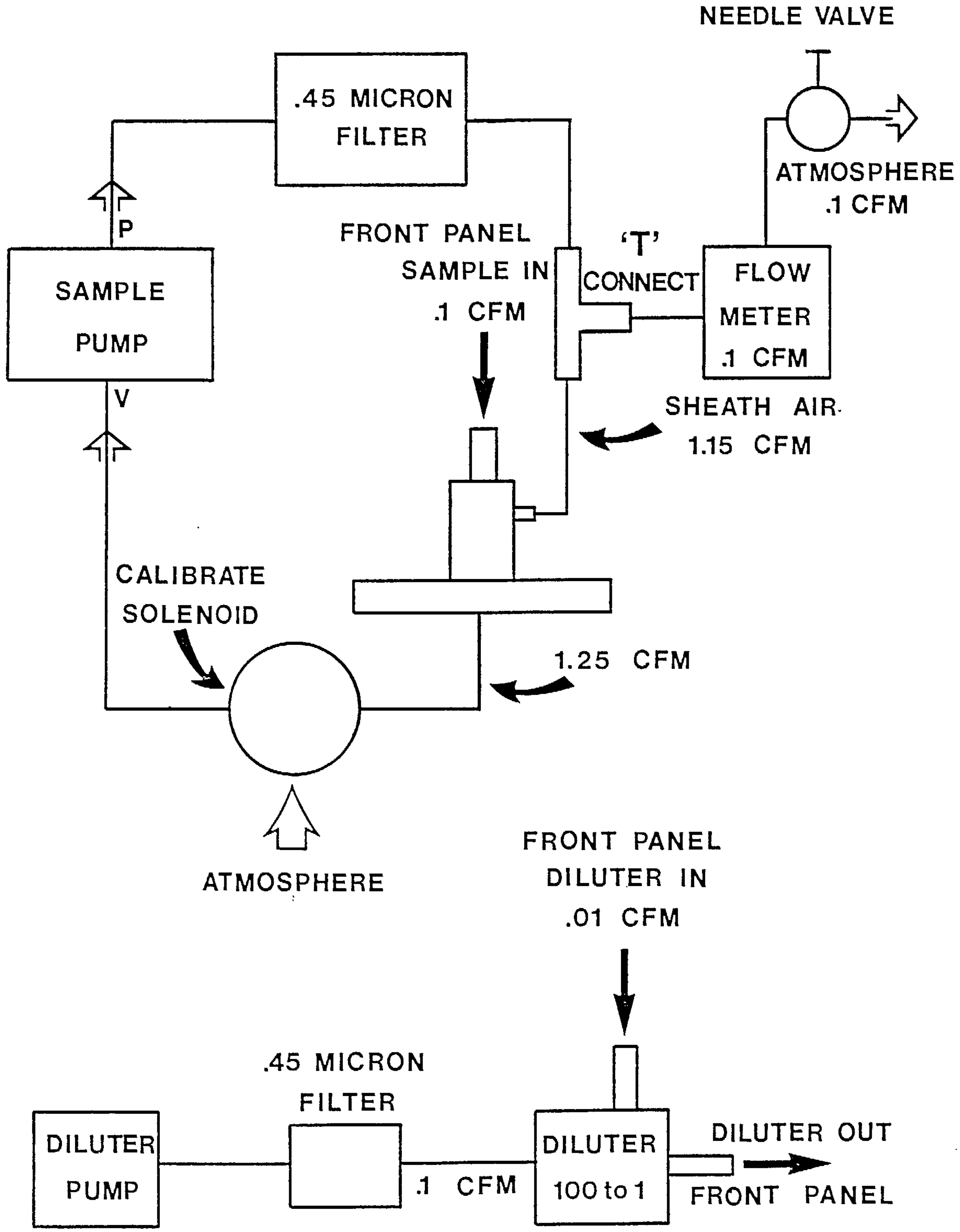
SHEATH AIR FLOW
CONDENSER LENSES
RELAY LENS
COLLECTING LENSES
LAMP
DEFINING
APERTURE
SENSITIVE
VOLUME
LIGHT TRAP
PHOTOMULTIPLIER
TUBE
EXHAUST FLOW

Figure 2.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FILTER
ATMOSPHERE
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FLOW
METER
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SAMPLE
PUMP
V
SHEATH AIR
1.15 CFM
CALIBRATE
SOLENOID
1.25 CFM
ATMOSPHERE
FRONT PANEL
DILUTER IN
.01 CFM
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FILTER
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DILUTER
100 to 1
DILUTER OUT
FRONT PANEL

Figure 3.

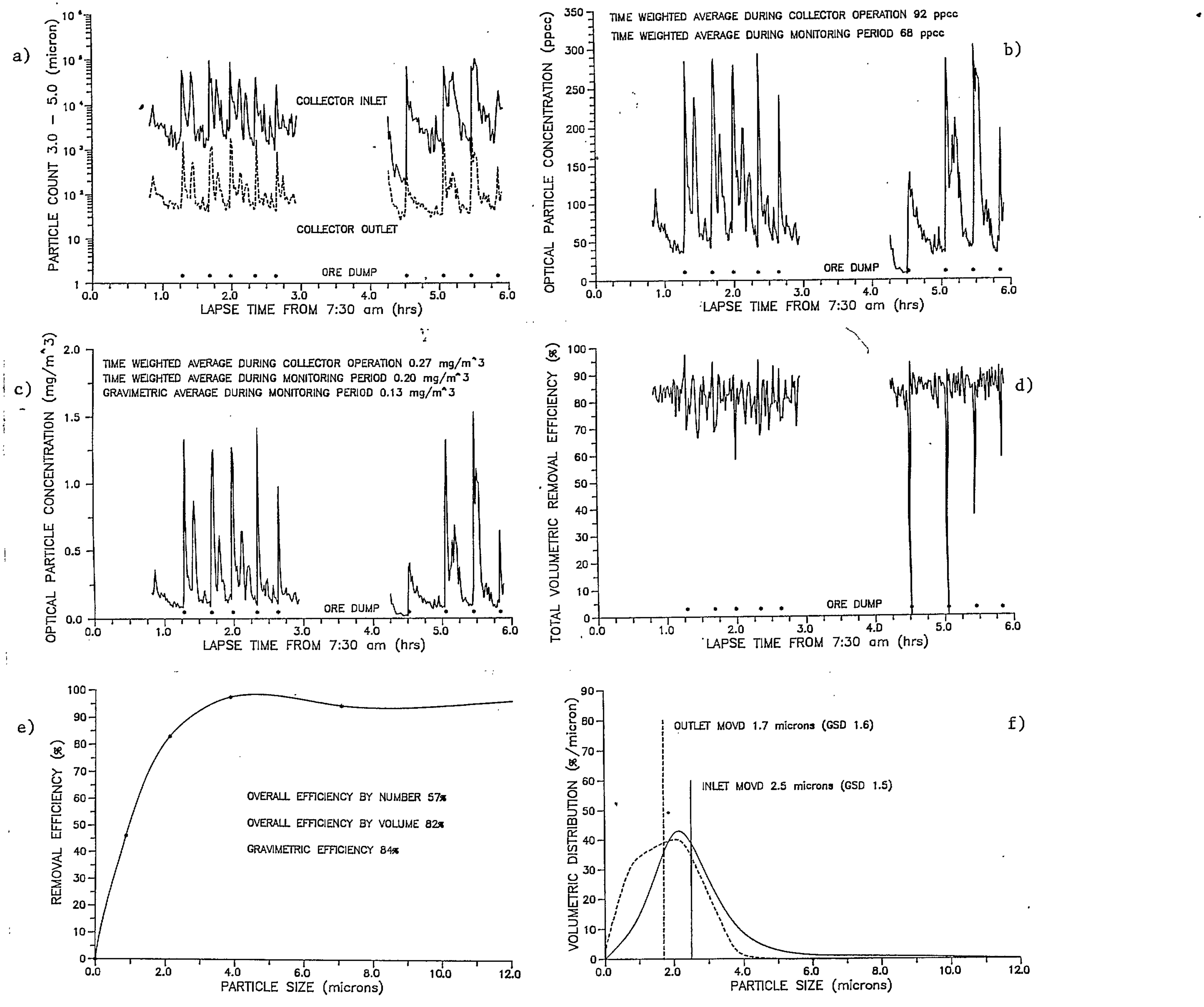
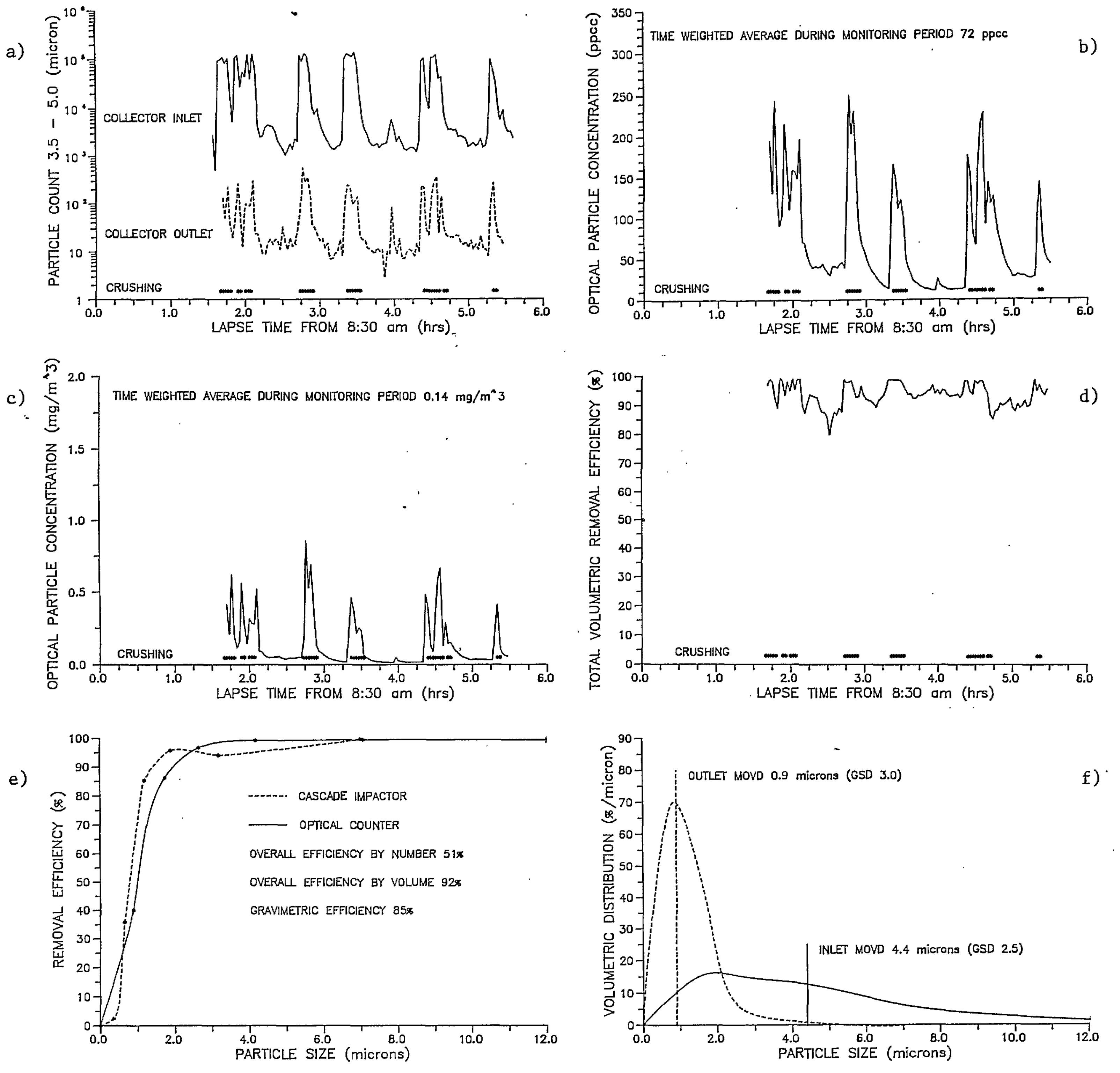

a)
PARTICLE COUNT 3.0 - 5.0 (micron)
COLLECTOR INLET
COLLECTOR OUTLET
ORE DUMP
LAPSE TIME FROM 7:30 am (hrs)
b)
TIME WEIGHTED AVERAGE DURING COLLECTOR OPERATION 92 ppcc
TIME WEIGHTED AVERAGE DURING MONITORING PERIOD 68 ppcc
OPTICAL PARTICLE CONCENTRATION (ppcc)
ORE DUMP
LAPSE TIME FROM 7:30 am (hrs)
c)
TIME WEIGHTED AVERAGE DURING COLLECTOR OPERATION 0.27 mg/m^3
TIME WEIGHTED AVERAGE DURING MONITORING PERIOD 0.20 mg/m^3
GRAVIMETRIC AVERAGE DURING MONITORING PERIOD 0.13 mg/m^3
OPTICAL PARTICLE CONCENTRATION (mg/m^3)
ORE DUMP
LAPSE TIME FROM 7:30 am (hrs)
d)
TOTAL VOLUMETRIC REMOVAL EFFICIENCY (%)
ORE DUMP
LAPSE TIME FROM 7:30 am (hrs)
e)
REMOVAL EFFICIENCY (%)
OVERALL EFFICIENCY BY NUMBER 57%
OVERALL EFFICIENCY BY VOLUME 82%
GRAVIMETRIC EFFICIENCY 84%
PARTICLE SIZE (microns)
f)
VOLUMETRIC DISTRIBUTION (%/micron)
OUTLET MOVD 1.7 microns (GSD 1.6)
INLET MOVD 2.5 microns (GSD 1.5)
PARTICLE SIZE (microns)

Figure 4

Figure 5.



a)
COLLECTOR INLET
COLLECTOR OUTLET
CRUSHING
PARTICLE COUNT 3.5 - 5.0 (micron)
LAPSE TIME FROM 8:30 am (hrs)
b)
TIME WEIGHTED AVERAGE DURING MONITORING PERIOD 72 ppcc
OPTICAL PARTICLE CONCENTRATION (ppcc)
CRUSHING
LAPSE TIME FROM 8:30 am (hrs)
c)
TIME WEIGHTED AVERAGE DURING MONITORING PERIOD 0.14 mg/m^3
OPTICAL PARTICLE CONCENTRATION (mg/m^3)
CRUSHING
LAPSE TIME FROM 8:30 am (hrs)
d)
TOTAL VOLUMETRIC REMOVAL EFFICIENCY (%)
CRUSHING
LAPSE TIME FROM 8:30 am (hrs)
e)
REMOVAL EFFICIENCY (%)
CASCADE IMPACTOR
OPTICAL COUNTER
OVERALL EFFICIENCY BY NUMBER 51%
OVERALL EFFICIENCY BY VOLUME 92%
GRAVIMETRIC EFFICIENCY 85%
PARTICLE SIZE (microns)
f)
VOLUMETRIC DISTRIBUTION (%/micron)
OUTLET MOVD 0.9 microns (GSD 3.0)
INLET MOVD 4.4 microns (GSD 2.5)
PARTICLE SIZE (microns)