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The Standard Instrument Calibration Aerosol Test System

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ABSTRACT

A system for testing personal "respirable" samplers in a well characterized coal dust environment is described. Components of the system, contained in one cabinet, include a Wright Dust Feed mechanism, tritide charge neutralizer, aerosol chamber, electrostatic precipitator sampler, and a GCA Respirable Dust Monitor, in addition to air flow plumbing and controls.

Employment of this test system to evaluate the performance of personal "respirable" particulate air sampling instruments required variations in aerosol mass concentration with respect to time and space to be less than ±10%. Up to four personal "respirable" dust samples can be simultaneously operated within the coal dust cloud. More than 80 tests of 3 or 4 samplers each showed that variation of total or respirable mass concentration is ±5% within the aerosol chamber. Aerosol aerodynamic size distribution measured with Andersen cascade impactors showed the dust cloud size to be stable within ±6% throughout periods of operation up to 8 h.

I. INTRODUCTION

The health hazard due to inhalation of industrial aerosols can be accurately evaluated only if the dust, mist, or other particulate material is well characterized in terms of its physical and chemical properties. Physiologic response to particles deposited within the respiratory tract depends on various factors including chemical and physiological solubility; and particle concentration, shape, size, and surface area.[1] These properties may be estimated from careful analysis of the aerosol of concern; however, the validity of this analysis depends upon the similarity between the sample collected and material actually deposited within the respiratory tract. Both theoretical and experimental studies have shown that insoluble particles greater than 10 μm in aerodynamic diameter are of little concern as an inhalation hazard because they are eliminated from the inspired air before entering the lower respiratory tract.[2] Penetration into and deposition in the lungs is a function of the aerodynamic diameter of a particle, which is related to the particle microscopic diameter, shape, and density. Criteria relating respiratory tract penetration to aerodynamic size distribution of polydisperse aerosols have been established to assist industrial hygienists evaluate the hazard due to coal and silica dusts.[3,4] Air sampling instruments designed to evaluate compliance with criteria defining lung deposition as a function of particle aerodynamic size[5] must be initially calibrated and periodically retested in an environment

simulating actual worker exposure conditions. This report details the instrumentation developed to produce, control, and monitor a test environment simulating potential occupational exposures, and measure performance of air sampling instruments for a coal dust or other dry dust cloud.

The Standard Instrument Calibration (SIC) System is designed primarily to check the calibration of personal dust samplers used to estimate workers' exposure to "respirable" airborne dusts, such as coal dust, silica, and radioactive particulates. The unit can continuously generate a reproducible coal aerosol in which 10-mm nylon cyclone-filter personal samplers can be operated to determine if the cyclone sampler satisfies criteria [4] for "respirable" dust sampling. The coal dust cloud generated has specific size characteristics, and the cyclone sampler collects only the "nonrespirable" portion of dust while the "respirable" portion is collected on a backup filter. Gravimetric analysis of dust on this filter, and a knowledge of the aerosols size parameters determine the collection characteristics of the personal sampler as compared to the ACGIH "respirable"dust criteria.[4] A "standard" test coal dust with specific, well characterized properties was developed for use with the SIC System in a complementary development program conducted at the Los Alamos Scientific Laboratory, and sponsored by NIOSH.[6,7]

Three aerosol test systems were constructed and tested under an interagency agreement between the Atomic Energy Commission and the National Institute for Occupational Safety and Health (NIOSH). Presently, one unit is in use at each of three laboratories: a) the Engineering Laboratory, Division of Laboratories and Criteria Development (DLCD), NIOSH, Cincinnati, Ohio, b) the NIOSH Testing and Certification Laboratory (TCL), Morgantown, WV, and c) the Industrial Hygiene Group, Los Alamos Scientific Laboratory (LASL). Both NIOSH and LASL have evaluated each test unit and suggested improvements or modifications to be incorporated in the subsequent units. Thus while the three units are generally similar, they are not identical in all respects, and where these differences are important to performance, they are noted.

II. SYSTEM COMPONENTS

Essential components of the SIC unit (Figs. 1-5) are 1) an aerosol or dust chamber, 2) a Wright Dust Feed (WDF) mechanism to generate or disperse the dust, 3) an aerosol electric charge neutralizer, 4) a GCA Corporation Respirable Dust Monitor (RDM) to periodically monitor aerosol mass concentration, and 5) a point-to-plane electrostatic precipitator (ESP) to obtain samples for electron microscopy.

A. Aerosol Chamber

The chamber (Fig. 5) confines the aerosol in a region of uniform mass concentration, and provides various sampling instruments access to the aerosol. A 25-liter polyethylene chamber, 25-cm diam by 46-cm high with four openings around the periphery in addition to top and bottom openings, serves to contain the aerosol. Aerosol from the generating system enters through a mixer (Fig. 6) at the conical entrance to the chamber. Clean dilution air also enters the mixer through several converging nozzles to mix with and dilute the aerosol to a desired concentration. At the top of the chamber a Lucite plate, 1 cm thick, seals the chamber and permits viewing the interior during operation (Fig. 4). This transparent plate contains 5 holes which serve as passthroughs for 4 personal samplers and an exhaust tube. Aerosol is exhausted through a baffled 2.5-cm diam Tygon tube to four high efficiency respirator filters in parallel. Four peripheral sampling ports, plus the four top ports, permit withdrawal of aerosol samples or insertion of sampling probes into the test aerosol environment through rubber stopper seals.

A bypass flow outlet on each side port (Fig. 7) permits the same amount of aerosol withdrawal at each port even though the sampling devices employed may require diverse flows. For example, if the largest aerosol sample to be withdrawn is 5 l/min, at one port, bypass air withdrawn from each of the other ports will be 5 l/min less the sampling flow rate from that particular port. Thus, the total flow from each port will be 5 l/min even though some of the sampling instruments may draw considerably less than this. This provides symmetrical sampling conditions from the relatively small chamber.

B. Wright Dust Feed (WDF) Mechanism

Dispersal of dust into an air stream is accomplished by this device.[8] Bulk coal dust is pressed into the WDF cup (Fig. 5) at pressures up to 700 kg/cm^2 to form a coherent, uniform compact. In operation, the cup and compact, which are inverted and threaded firmly to a rotating base, slowly descend onto a stationary scraper blade which continuously removes dust from the compact surface. Compressed air entering the cup through an orifice entrains and removes particles at a uniform rate. Both the air flow and dust cup rotation can be accurately varied to provide a wide range of aerosol concentration. Dust output may be calculated from a knowledge of blade advance rate, dust compact dimensions and porosity, and particle density.

C. Aerosol Charge Neutralizer

As dust particles are generated in the WDF and introduced into the air stream, they acquire an excess of electrical charge which will affect their behavior and the properties of the dust cloud as a whole. Before the aerosol is introduced into the experimental chamber the overall electric charge of the cloud is neutralized by passing the aerosol stream through an intense ion field created by radioactive β^- emission from tritium. A stainless steel foil, held in a tubular configuration, contains 200-mCi tritium on its inner surface as titanium tritide (Fig. 8). The chemical stability of the titanium tritide minimizes problems associated with radioactive contamination. If the foil is washed following deposition of particulates on the foil, the wash water will contain less than 0.02 μCi/ml which constitutes no health problem. However, to keep the release of radioactive materials as close to zero as possible, this wash water is handled as "contaminated material". A cylindrical brass case encloses the tritide foil, distributes aerosol flow through an annulus and past the foil, and prevents personnel contact or exposure to the tritium.

D. GCA Respirable Dust Monitor (RDM)

This sampler (Figs. 1 and 3), designed specifically for use with coal dust,[9] provides a means for continuously determining aerosol mass concentration within the chamber during one minute sampling intervals at a flow rate of 2 l/min. The instrument consists essentially of an impactor, β^- counter, associated power supply, sampling pump, and electronics. In operation the instrument impacts coal dust particles greater than 0.5-μm diameter onto a Vaseline coated Mylar collection foil which is located between 100 μCi of ^{14}C and a counter. Attenuation of the β^- radiation by the coal dust is measured and displayed as mass concentration. If a cyclone presampler is placed in the flow stream ahead of the RDM, the "respirable" dust passing the cyclone may be measured directly. The RDM model installed in the SIC System is capable of measuring coal dust concentrations from 1.0 to 50 mg/m^3 with ± 25% accuracy at the 95% confidence level. Although the unit is self-contained and portable, it is used as a stationary instrument in SIC.

E. Electrostatic Precipitator (ESP)

A point-to-plane precipitator, similar to that previously used at LASL,[10] is used to obtain particle samples directly on electron microscope grids for size analysis (Fig. 5). A grid is mounted directly on the planar electrode, separated from the vertical

needle electrode by approximately 3 cm. The precipitator housing is made of Lucite and directs the aerosol flow(4 l/min)between the electrodes. An ac high-voltage power supply (capable of producing a corona discharge at 10 kV and 5 mA, and controlled by a current limiting resistor designed to reduce the high-voltage hazard) provides a 9-kV ac potential across the ESP electrodes.

III. SYSTEM OPERATION

As in most aerosol generation and test systems, proper performance of the SIC System requires careful attention to preparation and operation procedures. Critical among the procedures is preparation of the WDF powder compact. Since output of this device largely determines aerosol concentration stability with respect to time, poor technique in pressing powder into the cup can produce fluctuations in concentration. Excessively porous or nonuniform compacts may be eroded rapidly by the air stream, or if the compact surface is very hard, it may not be cut uniformly by the scraper blade. The latter condition is controlled by placing a 10-lb lead weight (Fig. 5) on the dust reservoir to prevent dense compacts from lifting the dust cup which descends by screw action and its own weight. Generally, the optimum compacting load depends upon the size distribution, moisture content, and composition of the bulk dust. Pressures between 350 and 700 kg/cm^2 have proven satisfactory with the bulk coals used at LASL. Dust compacts pressed at these pressures form weak but coherent bodies held together by mechanical interlocking and adherence of particles. Dust is scraped from the compact by breaking the interlocking forces and,in general, particles adhering together are separated by the turbulent, high shear air forces as they leave the WDF. This shearing action generates a charge nonuniformity which is neutralized to a Boltzmann distribution by the tritium source before the aerosol is used in experiments.

The prototype test unit utilized a tritium neutralizer with an activity of 4 Ci. It was desirable to decrease the amount of radioactive material in subsequent SIC units to permit its use in facilities whose AEC license limits the amount of radioactivity which may be handled. The minimum activity required to neutralize particles at expected concentration and flow rate was determined both theoretically and experimentally as described in the Appendix. It was calculated and confirmed that less than 150-mCi activity was sufficient to neutralize the charge on an actual coal dust aerosol. Thereafter, the charge neutralizers were modified to contain 200 mCi of tritium.

Air flow control is provided by regulators, gauges, and flowmeters on a front panel (Fig. 3) of each unit. Compressed air at 30-50 psig enters through a pressure type air filter, is reduced in pressure, and distributed to flowmeters (Fig. 9) at 20 psig. Air flow to the WDF is normally 30 l/min and the normal dilution air flow is 90 l/min. But depending upon the dust concentration and flow velocity required, either flow can be widely varied. Air flowing through the WDF drops in pressure from 14 psig at the inlet to slightly above ambient at the exit. The aerosol then passes through the neutralizer and is diluted before entering the chamber.

As aerosol enters the chamber from the dilution mixer it is deflected by a Stairmand baffle to prevent a center jet entering the upper chamber. Aerosol flow rates of 60 to 120 l/min produce an average air velocity within the cylindrical section of the chamber of 3.5 to 5.0 cm/sec and the turnover is 2 air changes/min. The chamber's low flow velocity permits sampling from an essentially static environment without concern for isokinetic sampling. Either straight or 90° probes may be used to conduct aerosols from each of the side ports through "in line" 25-mm filter holders connected directly to the probes at the chamber port. Polyvinyl

chloride, 0.8-μm pore size, membrane filters have been used to collect samples at 1 to 2 l/min for 12 to 15 min.

Although dust concentrations within the chamber may be gravimetrically determined within 20 min using membrane filters, it is desirable to continuously monitor the concentration by a faster, less tedious method. Two commercial fast response instruments were evaluated. One unit, manufactured by Thermo-Systems, Inc. (TSI), deposits particulate matter from the aerosol stream by electrostatic precipitation onto a vibrating quartz crystal, and periodically measures change in the harmonic frequency of vibration caused by the deposit mass.[11] This change is referenced to a similar, non-collecting crystal and digitally printed at regular intervals as the difference in vibrational frequency between the two. Mass concentration may be calculated from known constants plus the change in frequency. This quartz crystal particle mass monitor proved to be marginally useful in the aerosol units due to a) crystal overload and b) concentration measurements consistently lower than that indicated by membrane filter samples. Crystal overload occurs because the outer layers of a dry coal dust deposit do not adhere sufficiently well to be detected as a weight increase. The onset of this phenomenon is dependent upon the particulate material but occurs with coal dust in less than 2 min at 4 μg/l concentration. This requires continual cleaning of the crystal collection surface. Low concentration measurements, consistently 25% below those determined by filter samples, (Fig. 10) appeared to be due to losses in the sampling system. Shortening the sampling tube to 10 cm long versus the normal 46-cm length decreased the line loss slightly so that the particle mass monitor results were approximately 15% lower than gravimetric results. Tests of ESP collection efficiency showed that nearly 100% of the particles were deposited; consequently, low concentrations appear to be a function of line loss.

Because of the problems associated with use of the TSI instrument, a GCA Corporation Respirable Dust Monitor (RDM) was evaluated and selected as a replacement. The RDM suffers some drawbacks, but is simpler to operate and can function at higher mass concentrations, which makes it more suitable for routine monitoring. Calibration of the RDM agreed with a GCA supplied standard sample; however, the indicated dust concentration was higher than obtained by simultaneous mass measurements using membrane filters (Fig. 11). RDM measurements were adjusted to correspond to the mass indicated by these filters (Fig. 12) by correcting the instrument calibration, which appears to drift with time, or use; that is, recalibration to correspond to mass filter concentrations was necessary after approximately 100 RDM readings. Individual readings from the instrument varied considerably, as indicated by vertical data range bars, producing an average coefficient of variation of 27.1%. It should be noted, however, that variations in mass concentration recorded by the RDM may be valid since filters average out fluctuations in concentration over a 15-min sampling period as compared to the 1-min cycle time of the RDM. Some sampling line loss was also observed with the RDM, so that the instrument performed best when placed very near the aerosol source.

IV. PERFORMANCE

The three aerosol test systems were similar in performance characteristics. Slight differences between the units are generally due to different test conditions such as concentration level, number of samplers used, etc.[7] since relatively few measurements were made on an undisturbed cloud. Samples for aerodynamic and microscopic size determination, personal sampler comparison, and mass determination were often taken simultaneously. Withdrawal of more than 10% of the total aerosol flow at one sampling port, as with the Andersen Impactor, caused a disruption of the cloud

uniformity which persisted for up to 30 min after the sampling ceased.

Start up of the units with a new dust plug produced the highest instability of concentration which lasted up to 2 h, (e.g., Figs. 10 and 11). Restart with the same plug resulted in less severe variation which persisted less than 30 min. Due to start up instability, no sampling other than mass monitoring was performed during the initial 2 h of operation. After the initial period of instability in aerosol mass concentration, the units provided an aerosol stability of $\pm$11% or better with stability defined as the variation of mass concentration with time at a single location as measured periodically by membrane filters. Uniformity of mass concentration at different sampling locations within the units was likewise $\pm$11% or better. Uniformity is defined as the time independent variation of concentration measured simultaneously by three or more separate membrane filter samplers at different peripheral ports. These parameters were measured during experiments in which no other samples were withdrawn and the chamber was not disturbed. Mean values of concentration obtained in individual dispersion experiments from filter, Thermo-Systems particle mass monitor (PMM), and GCA respirable dust monitor (RDM) measurements are tabulated in Table I. Filters 1, 2, and 3 represent samples taken simultaneously at positions 6 inches apart within the chamber. Each concentration is the average of 5 or more determinations, except for the RDM where each concentration is the average of 6 individual samples, so that each tabulated concentration for this instrument represents a minimum of 30 readings. Mass concentration stability and uniformity are shown in the last two columns, and asterisks denote runs made for the purpose of establishing performance under optimum conditions, i.e., no disturbance of the cloud. As discussed in the previous section, values determined by the RDM and PMM instruments are an average of 25.4% and 6.5%, respectively, lower than membrane filter determinations. These variations in mass concentration and the inconsistency between RDM and PMM and membrane filter samples are detailed in Figs. 10-12 as a function of elapsed time during typical runs.

Physical size distribution of the dust cloud was measured by standard electron microscope techniques applied to samples collected by the point-to-plane ESP. An ionizing voltage of 9 kV deposited particles directly on 3-mm, carbon coated, electron microscope grids from an aerosol flow of 4 l/min. In addition to providing sizing information, electron microscopy in conjunction with optical microscopy of membrane filters showed that the chamber aerosol is not agglomerated.

A knowledge of the aerodynamic properties of the dust cloud is essential in testing performance of personal samplers. An Andersen Impactor operated at 28.3 l/min was employed to separate the dust into an aerodynamic spectrum. The impaction plates were covered with preweighed, 76-mm diam, polyvinyl chloride, membrane filters to provide low tare weight collection surfaces, which also served to minimize particle rebound losses.[6] Sufficient mass was collected in 1/2-h sampling periods to permit size analysis by weight utilizing a Mettler microbalance with a precision of $\pm$5 µg. The data were then used to compute and plot a cumulative size distribution on log-probability graphs. Almost all dusts used proved to be log-normally distributed. Generally, either 2 or 3 Andersen Impactor samples were collected in the course of each dispersion experiment (Table II). Each value of mass median aerodynamic diameter (MMAD) and geometric standard deviation (σ_g) is the mean of the determinations; the coefficient of variation indicates the size distribution is quite stable throughout a run. Because many dusts were employed during evaluation of the SIC System, overall comparison of size distribution is meaningless. Generation of aerosols from the same bulk dust showed reproducibility from run to run of $\pm$6.5% in MMAD as indicated by the average of the coefficients of variation for all Andersen Impactor data.

TABLE I

AEROSOL TEST SYSTEMS MASS CONCENTRATION PARAMETERS

Run	Mass Concentration (µg/l)						
	Filters			TSI PMM	GCA RDM	Stability, %[a]	Uniformity, %[b]
	1	2	3				
Unit 1							
F-63[c]	4.1	4.0	4.0	2.8		6.3	6.7
64[c]	2.9	2.8	3.0	2.5		10.2	8.3
65[c]	2.2	2.2	2.2	1.6		12.0	6.1
67	2.1	2.2		1.9		17.2	
Unit 2							
F-77	2.0	2.3	2.0			16.1	13.5
78	3.1	3.4	3.2	2.1	3.9	15.9	13.8
79[c]	3.8	3.5	3.8	2.2	2.3	10.1	3.9
80	2.6	2.8	2.6	1.9	2.7	23.6	24.0
81	1.6	1.6		1.8	1.4	18.0	
82	3.4	3.1		1.8	3.1	20.2	
Unit 3							
84[c]	2.5	2.7	2.3	1.5		11.2	11.6
87	2.7	2.8		2.2	2.6	18.2	
88	3.4	3.3			2.1	8.2	
89	4.1	4.0			3.7	10.4	
90	2,3	2.4			2.5	17.2	
92	1.7	1.7	1.7			18.9	12.1
93	1.5	1.6	1.6			15.3	10.8
94	0.8	0.9	0.9			40.4	21.1
95	3.3	3.5	3.4			11.0	6.9
96	2.9	3.0	2.8			11.0	9.0
97	3.3	3.3	3.4			12.8	9.5
98	3.1	3.4	3.4			17.8	8.7
99	3.5	3.4	3.4		3.6	13.0	6.4
101	4.1	4.0	4.0		3.3	8.9	4.6
102	4.0	4.3	4.1		3.1	8.1	7.1
103	3.9	4.0			2.7	3.3	
104	4.7	4.7			3.0	5.8	

[a] Variation of Mass Concentration at 1 Location with Respect to Time.

[b] Variation of Mass Concentration Measured Simultaneously at Three or More Locations.

[c] Test Runs Under Optimum Conditions (Constant Aerosol Flow, No Chamber Disturbances, Cloud Stabilization Time of 2-1/2 Hours Before Measurements Started).

TABLE II

AERODYNAMIC PARAMETERS AND CYCLONE PERFORMANCE

		Andersen Impactor			10-mm Nylon Cyclones			
Run	Dust	MMAD	Coef. Var.	σ g	Penetration	σ	Coef. Var.	No. of Samplers
		μm			%			
95	NA-1:18	4.0±0.1		1.8±.1				
96	NA-1:18	3.7± .1		2.1±.1				
98	NA-1:18	4.5± .1		2.1±.1				
Avg	NA-1:18	4.0± .4	0.10	2.0±.2				
99	B-23-31	3.5± .1		1.9±.1				
100	B-23-31	3.6± .1		1.9±.1				
Avg	B-23-31	3.6± .1	0.04	1.9±.1				
101	B-21-24	3.7± .1		2.0±.1				
102	B-21-24	3.6± .1		1.9±.1				
103	B-21-24	3.6± .1		1.9±.1	42.7	4.0	0.09	6
Avg	B-21-24	3.6± .1	0.03	1.9±.1				
104	B-3-1	4.3± .2		1.9± 0	35.6	3.3	0.09	6
105	B-3-1	4.2± .3		2.0±.5	37.2	7.4	0.20	6
106	B-3-1	4.0± .6		2.0±.1	36.2	5.2	0.14	6
107	B-3-1	4.0± .4		1.9±.1	34.9	4.6	0.13	4
108	B-3-1	4.0± .1		2.1±.1	31.9	3.9	0.12	5
Avg	B-3-1	4.1± .3	0.07	2.0±.1	35.2	4.9	0.14	
109	B-5-1	3.8± 0		2.2± 0				
110	B-5-1	4.0± .3		2.1±.1				
111	B-5-1	3.8± .3		2.2± 0				
112	B-5-1	3.7± .2		2.0±.1	42.0	8.7	0.21	7
113	B-5-1	3.7± .2		2.1±.1	37.5	2.5	0.07	6
114	B-5-1	3.6± .3		2.1±.1	47.7	3.3	0.07	10
Avg		3.8± .2	0.06	2.1±.1	42.4	4.8	0.11	
116	SC-3	3.8± .3	0.09	2.2±.2	46.2	3.1	0.07	6
Mean Variation			0.06				0.12	

Table II also details performance measurements made using 10-mm nylon cyclones. Three cyclones were suspended into the chamber, about 10 cm apart, and operated at 1.7 l/min for periods from 3/4 to 4 hours. Respirable dust passing the cyclone was collected by 47-mm Gelman, type VM-4, membrane filters. These particular filters have a high resistance to flow, but have a very low, stable tare weight. This low tare weight, combined with a balance precision of ± 5 μg, produced a mass sensitivity of less than 2%. Agreement between cyclones (Table II) as defined by an average coefficient of variation,

(mean variation), was ±12%.

Additional results were obtained by NIOSH during a study on charge effects[12] which employed the prototype SIC unit to provide a uniform coal dust aerosol. Four 10-mm cyclones suspended within the aerosol chamber sampled at flows of 1.72±0.02 or 2.00±0.02 lpm as controlled by critical orifices installed for these experiments. Cyclones made of different materials were utilized in 83 sampling runs under various combinations of cloud charge and cyclone charge. Results from this study concerning charge effects will not be discussed here, but results concerning the uniformity of mass concentration are pertinent. In the normal mode of operation, that is, with a charge neutralized cloud the chamber uniformity averaged 5.2% as determined from the coefficients of variation of membrane filter mass determinations and 4.2% as indicated by cyclone "respirable" dust data for each run.

V. SUMMARY

The SIC aerosol test system provides a realistic, well characterized coal dust for the simultaneous testing of 4 coal mine personal samplers. The unit generates an actual coal dust atmosphere to simulate the effects of particle density, sphericity, and surface characteristics,as well as concentration and size distribution of dust existing within a mine.

The aerosol is generated by a Wright Dust Feed mechanism at a uniform rate,with few particulate agglomerates, and with a stable size distribution. After passing through a charge neutralizer and mixer-diluter, the aerosol enters the chamber where the velocity is reduced to produce laminar flow conditions. Mass concentration variation is less than ±10% from point-to-point within the chamber. Control of this chamber variable is critical because any nonuniformity indicates a false variation in collection efficiency between the cyclone samplers being tested. Mass concentration measurement of the aerosol is provided primarily by accurate gravimetric measurement of samples collected on membrane filters. In addition, an immediate indication of concentration is obtained from a fast response sampling instrument.

Another parameter of importance in personal sampler tests is the aerosol aerodynamic size distribution and the stability of that distribution throughout a test. While the aerosol size distribution is controlled primarily by the bulk dust size distribution, it is also affected by fluctuations in air flow, particulate charge, and velocity and residence time in the chamber. Aerodynamic sizing of samples from the SIC System indicate the variation of this parameter to be less than ±6%.

The Standard Instrument Calibrator units have been employed to test personal samplers and found satisfactory for this purpose. In addition to personal sampler testing the SIC units have also been utilized in an investigation of charge effects on 10-mm nylon cyclones,[12] a "standard test coal dust" development project,[7] and a test program to determine the operational characteristics of personal sampler pumps.[13]

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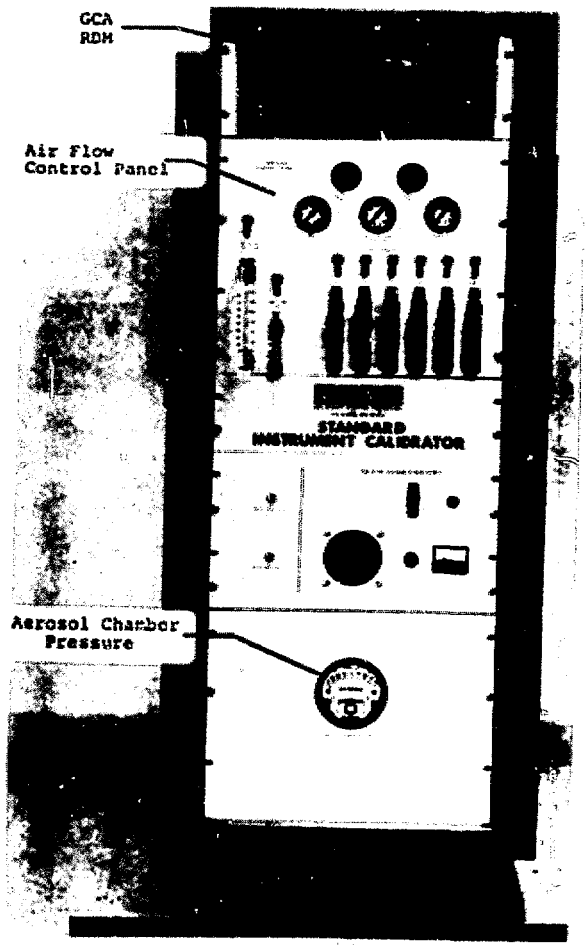

Fig. 1. Standard Instrument Calibration System (SIC), (front).

Fig. 2. Standard Instrument Calibration System (SIC), (rear).

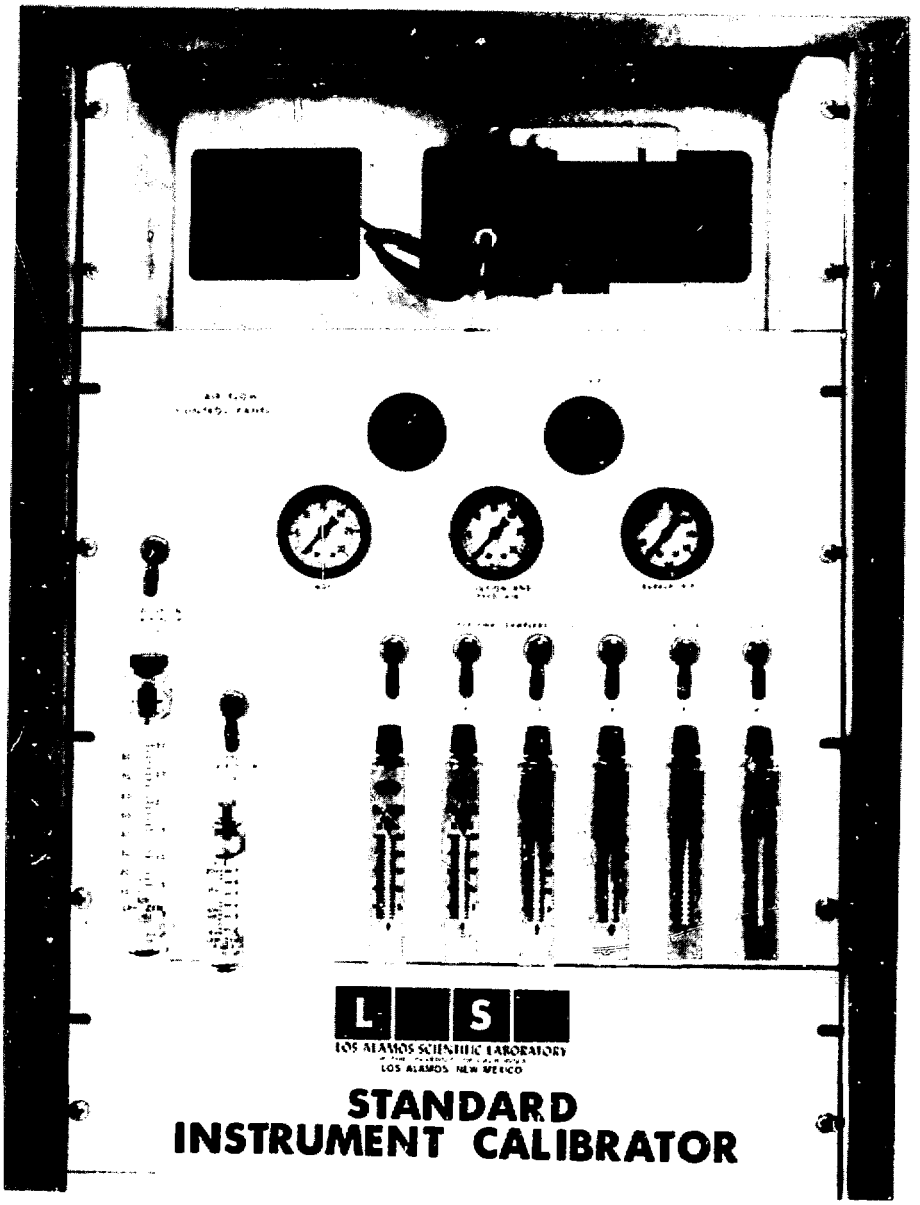

Fig. 3. SIC Upper Section, (front).

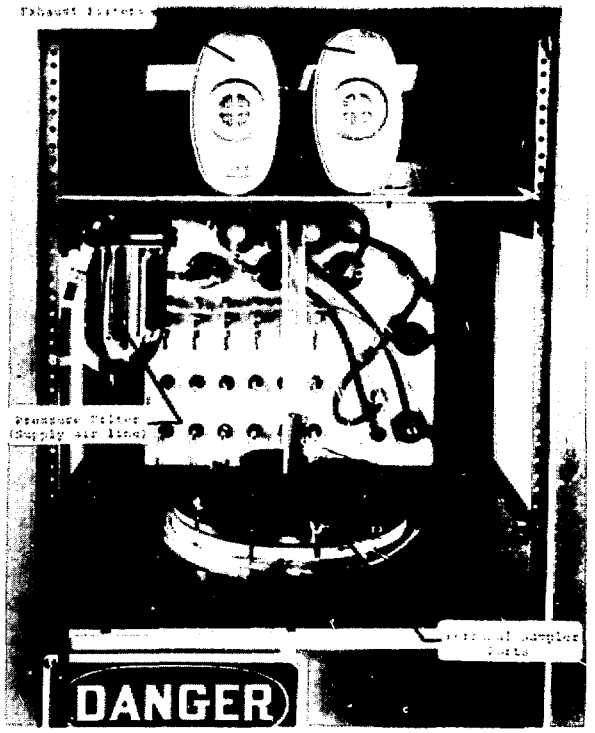

Fig. 4. SIC Upper Section, (rear).

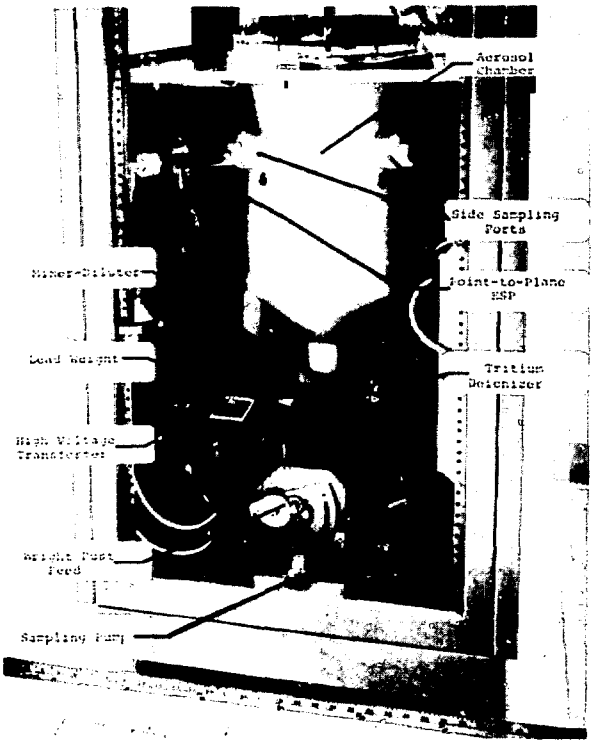

Fig. 5. SIC Lower Section, (rear).

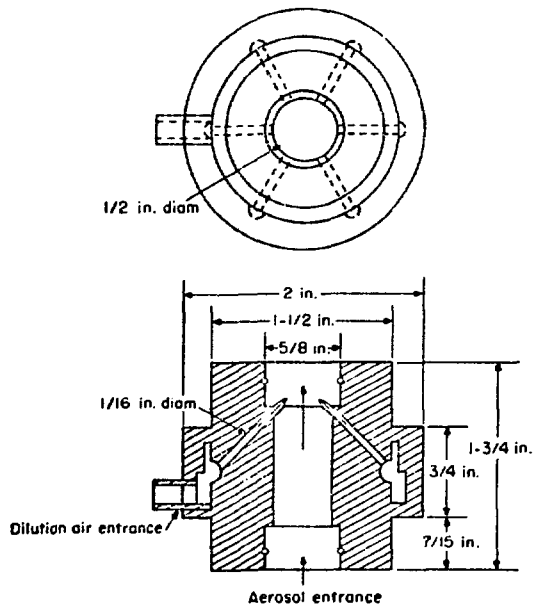

Fig. 6. Aerosol dilution-mixer device.

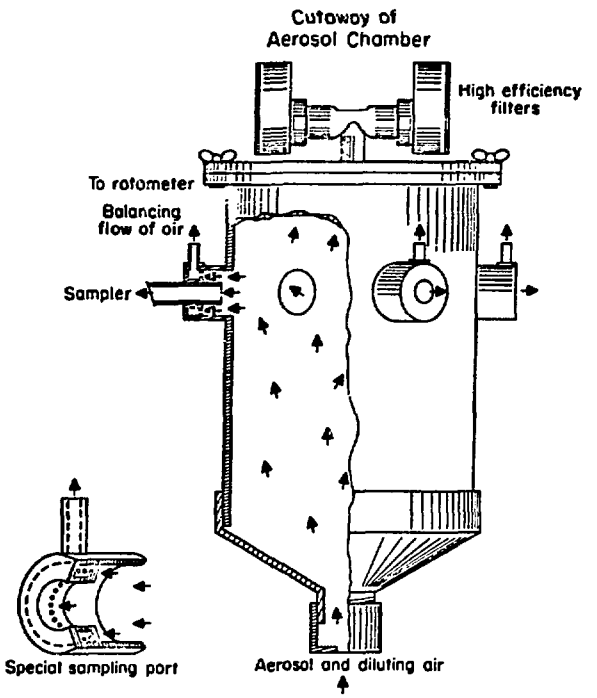

Fig. 7. Cutaway of aerosol chamber and special sampling port.

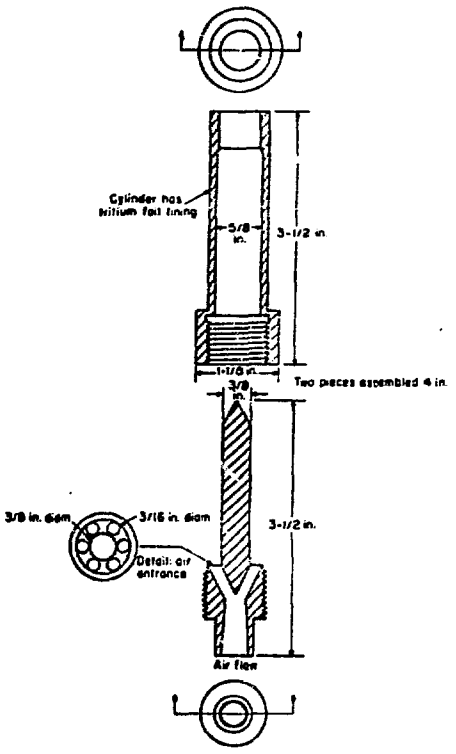

Fig. 8. Aerosol Charge Neutralizer Detail.

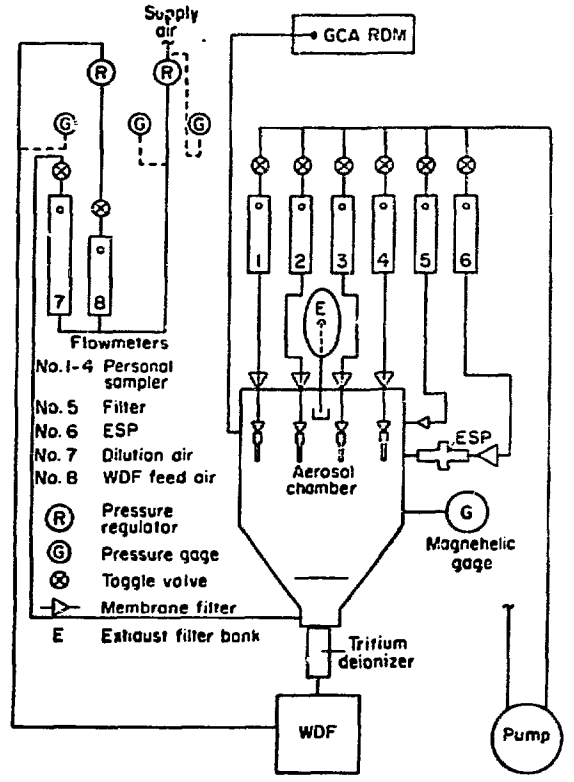

Fig. 9. Air Flow Schematic.

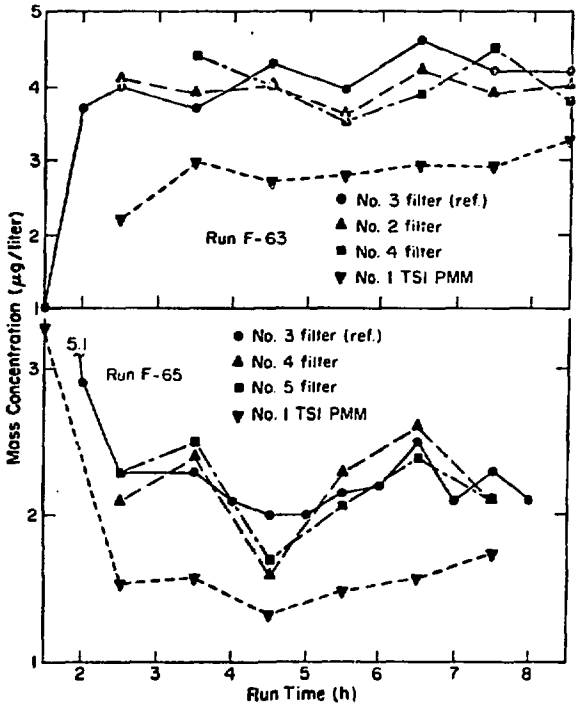

Fig. 10. Mass Concentration Data Plot.

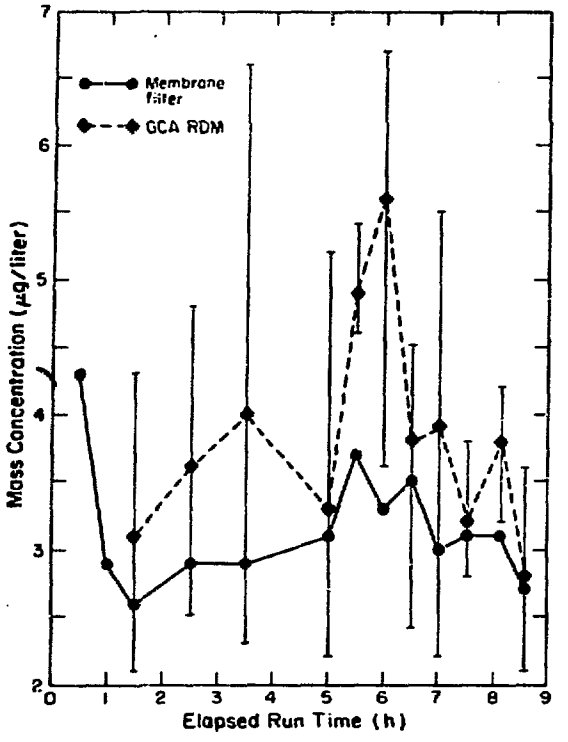

Fig. 11. Mass Concentration in SIC chamber, dispersion run F-78.

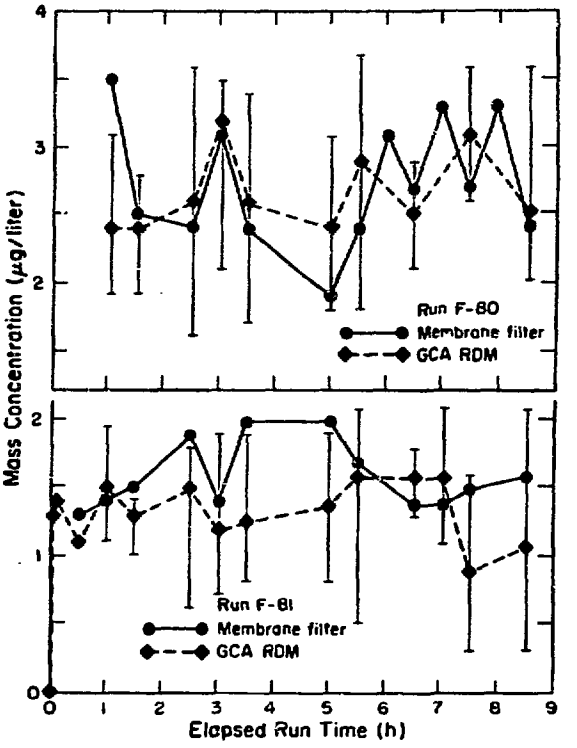

Fig. 12. Mass concentration in SIC chamber, dispersion runs F-80 and F-81.

APPENDIX

ELECTRIC CHARGE ON COAL AEROSOL

No information was found concerning the charge carried by coal aerosols when generated from the Wright Dust Feed; therefore, it is assumed that the charge is given by $|\bar{\sigma}|=25D$, where $|\bar{\sigma}|$ is the number of electron charges on a particle of diameter D expressed in microns.

Using the maximum design conditions of 30 l/min flow through the WDF plus 90 l/min of dilution air, and 6 µg/l dust concentration within the chamber the concentration of aerosol leaving the WDF is 24 µg/l (2.4×10^{-5} g/l). Converting this mass concentration to generator mass output gives 1.2×10^{-5} g/sec leaving the WDF (and passing through the neutralizer).

Assuming the aerosol is log normally distributed with an MMAD = 3.75 µm and σ_g = 2.0, calculation of count parameters using the Hatch and Choate relation,[1] 1.3 g/cm^3 particle density,[2] and spherical particle shape, results in CMD = 0.78 µm, σ_g = 2.0. The diameter of average mass is then given by:

$$\ln D_m = \ln \text{CMD} + 3/2 \ln^2 \sigma_g$$

$$D_m = 1.60 \text{ µm} .$$

From the density and calculated volume the particle of average mass is found to be 2.80×10^{-12} grams. The number of particles generated is then 4.30×10^{6} particles/second. The average number of charges per

particle is given by:

$$|\bar{\sigma}| = 25\ \bar{D}$$

where $\ln \bar{D} = \ln \text{CMD} + 1/2 \ln^2 \sigma_g$.

Substituting the values of CMD and σ_g:

$$|\bar{\sigma}| = 24.8$$

and the charge generated every second is then $1.06 \times 10^8 |e|$/second.

Now considering the available ionization to neutralize charge on the particles, the average energy of the ^3H beta decay is 5×10^3 ev with 32 ev being required to form an ion pair in air. Assuming that 50% of the β^- decays are toward the metal, the number of ion pairs produced per second for each curie of ^3H is given by:

$$1.65 \times 10^{10} \frac{\text{dis.}}{\text{sec-Curie}} \times 5 \times 10^3 \text{ ev} \times \times \frac{1}{32} \frac{\text{ion pair}}{\text{ev}} = 2.58 \times 10^{12} \frac{\text{ion pair}}{\text{Curie-sec}}$$

These ion pairs are formed in a dense path, so recombination will be quite high. Assuming conservatively that 99.9% of the ion pairs recombine, then 2.58×10^9 ion pairs/sec-Curie will be available to discharge the aerosol.

Finally, the required amount of ^3H is given by:

$$\frac{1.06 \times 10^8 |e|/\text{sec}}{2.58 \times 10^9 |e|/\text{sec-Curie}} = 4.11 \times 10^{-2} \text{ Curies}$$

or, 41.1 millicuries is required for neutralization of the aerosol charge.

The experimental arrangement shown in Fig. A-1 determines the approximate amount of tritium needed to eliminate charge on the coal aerosol. Ion collector voltage was

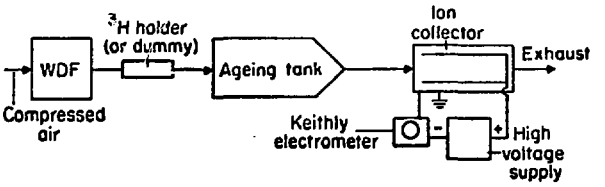

Fig. A-1 Electric charge experimental apparatus.

maintained constant at 1500 volts (E = 1500 V/cm) and the current measured as the amount of ^3H was decreased by covering it with thin cardboard. The current did not increase until more than 96% of the ^3H had been covered. The current measured with 3.1% of the tritium available was 25% of the current measured with no ^3H available. (The zero tritium level was determined using an empty tritide holder.) The current readings were the same for all measurements made with more than 3.1% of the ^3H available, and amounted to 8% of the current measured with the ^3H foil removed. This indicates that if more than 125 mCi (3.1% of the 4 Ci tritium source) is available, the test aerosol is adequately discharged. To provide excess capacity, a 200 mCi source is recommended for the SIC aerosol charge neutralizer.

REFERENCES

1. T. Hatch and S. P. Choate,"Statistical Description of the Size Properties of Non-Uniform Particulate Substances," J. Franklin Inst., 207, 369 - 387, March, 1929.

2. H. J. Ettinger, C. I. Fairchild, L. W. Ortiz, and M. I. Tillery, "Aerosol Research and Development Related to Health Hazard Analysis, Quarterly Report, January 1 through June 30, 1973," LA-5359-PR, August, 1973.