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Los Alamos, New Mexico 87544

IN REPLY
REFER TO: H-5

February 15, 1973

Mr. Robert P. Carter
Industrial Hygiene Engineer
Aluminum Company of America
ALCOA Building
Pittsburgh, Pennsylvania 15219

Dear Mr. Carter,

The work presented at the Denver local AIHA meeting has not yet been published. I am enclosing a copy of a recent Progress Report since a portion of the activities described at the meeting are detailed in this report. We anticipate preparing a formal paper covering our work with asbestos for presentation at the May AIHA meeting. When a copy of this paper is available I will forward it to you.

Sincerely,

Harry J. Ettinger
Alt. ~~Group~~ Leader
Industrial Hygiene Group

HJE:js

Enc. Progress Report (1)

411084 1733

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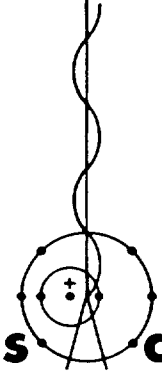
LA-5182-PR

PROGRESS REPORT

Aerosol Research and Development Related to Health Hazard Analysis

Quarterly Report

July 1 through December 31, 1972



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UNITED STATES
ATOMIC ENERGY COMMISSION
CONTRACT W-7405-ENG. 36

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This report presents the status of the Aerosol Research and Development program. The four most recent reports in this series, all unclassified, are:

LA-4911-PR	LA-4936-PR
LA-4912-PR	LA-5016-PR

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LA-5182-PR
Progress Report
UC-41
ISSUED: February 1973

Aerosol Research and Development Related to Health Hazard Analysis

Quarterly Report

July 1 through December 31, 1972

Work performed by
Aerosol Studies Section
Industrial Hygiene Group

Harry J. Ettinger, Project Manager
Charles I. Fairchild
Lawrence W. Ortiz
Marvin I. Tillery

This work supported by the National Institute for Occupational Safety and Health, Cincinnati, Ohio. Project R-072.

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AEROSOL RESEARCH AND DEVELOPMENT RELATED TO HEALTH HAZARD ANALYSIS
JULY 1 THROUGH DECEMBER 31, 1972

by

Harry J. Ettinger, Project Manager
Charles I. Fairchild, Lawrence W. Ortiz, and Marvin I. Tillery

ABSTRACT

Final development and documentation of the dispersion filtration technique for the preparation of asbestos standard filter samples has been completed and transferred to the NIOSH Testing and Certification Laboratory. Quality control monitoring of these samples indicates the magnitude of variations in fiber count which may be expected. Work to generate fibrous glass aerosols for calibration of the 10 mm cyclone was reactivated. Sampling at 1.7 lpm, these cyclones exhibit a well defined aerodynamic cut off for fibers greater than 2.2 μm (diameter).

The Standard Instrument Calibration (SIC) system developed to provide a coal dust aerosol for the testing of coal mine personal samplers was completed and shipped to the NIOSH Testing and Certification Laboratory. Coal grinding experiments have established a relationship between grinding conditions and product specific surface. Using these as a guide, air dispersed dusts appear to have predictable aerodynamic size characteristics.

Initial studies with the LASL Spiral Centrifuge Aerosol Spectrometer indicate increases in aerodynamic diameter of as much as 30% for submicron polystyrene latex (PSL) particles under high humidity conditions. Subsequent experiments using a horizontal elutriator indicate no effect when the temperature is kept constant throughout the experimental apparatus. Reevaluation of the Spiral experiments indicate that the change is the result of water condensation on the PSL caused by a decrease in temperature during sampling.

SUMMARY

Development of a liquid slurry filtration technique to provide standard asbestos filters for the NIOSH certification program was completed. Detailed instructions for preparation of these standards were prepared for NIOSH, and the person responsible for continuing this certification program was trained at Los Alamos. Future standards will be prepared at the NIOSH Laboratory in Morgantown, West Virginia. Over 400 filter standards were prepared for distribution by NIOSH to the various states participating in the certification program. Extensive quality control monitoring of these standards

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was carried out at Los Alamos requiring considerable asbestos fiber counting by several members of the section. These count data indicate variations up to ± 50% under optimum conditions. NIOSH was advised of the apparent limitations inherent in this technique.

Work with the fibrous glass aerosol, temporarily deferred at the request of NIOSH was reactivated. The fibrous aerosol system was tested using a new glass fiber provided by Owens Corning. While aerosol mass output varies with time, the system produces a uniform concentration throughout the aerosol test chamber, and should satisfy the requirements for cyclone calibration. The fibrous aerosol ranges in diameter from 0.06 to 3.4 μm, covering the range of "respirable" fibers as defined by Timbrell. A limited number of cyclone comparison experiments indicate that the mass of fibers passing the cyclone is reproducible. Limited sizing data indicates a possible aerodynamic size cut off as no fiber larger than 2.2 μm has been observed on the downstream side of a 10 mm nylon cyclone operating at 1.7 lpm.

Construction, calibration, and performance testing of the Standard Instrument Calibration (SIC) System was completed, and the unit shipped to the Testing and Certification Lab (TCL) in Morgantown, West Virginia. This unit, which is similar to the Prototype Standard Instrument Calibration System (PSIC) sent to Cincinnati in July, will be used to check the performance of coal mine personal air sampling instruments. Several improvements over the prototype unit were incorporated into SIC, with the two major changes being 1) replacement of the TSI Particle Mass Monitor with a GCA Respirable Dust Monitor (RDM), and 2) replacement of the 4 Ci tritide aerosol charge neutralizer with a redesigned more efficient 200 mCi neutralizer. Installation of the RDM provides SIC with a fast response compact mass measurement instrument designed specifically for use with coal dust. Reduction of tritium activity was necessary to satisfy the requirements of TCL's radioactive materials license. Theoretical calculations confirmed by experimental data show that 200 mCi of tritide provides adequate charge neutralization. A detailed operation, calibration, and maintenance manual was prepared for the PSIC and SIC systems.

To produce a bulk coal dust by micronizer (fluid energy) grinding an empirical relationship has been established between grinding pressure, grinding time, and product specific surface as measured by air permeability. To minimize the time variable, a new powder feed system was employed to decrease grinding time from approximately 4 minutes to 24 ± 5 seconds per 100 g of coal. Additional data will be developed to determine the reproducibility of grinding by this method.

Aerodynamic sizing of dispersed coal dusts was emphasized, with simultaneous use of the following aerodynamic sampling instruments: 1) Andersen Impactor, 2) Andersen mini-impactor, 3) LASL modified mini-impactor, and 4) Lovelace Aerosol Particle Separator (LAPS). Agreement of aerodynamic size has been within ± 15% of the mean of the 4 determinations; however, σ_g determined aerodynamically, varied from 2.1 to 3.5. Such aerodynamic sizing, as well as electron microscopy indicated that the mass median aerodynamic diameter (MMAD) of dusts dispersed from coarse bulk powders (low specific surface) was little different from that of fine bulk powder; that is, as the specific surface decreased by a factor of 4 the MMAD increased by only 15%. In two experiments, removal of a deagglomeration baffle from the Wright Dust Feed (WDF) aerosol outlet produced an increased MMAD.

The experimental program to evaluate changes in particle aerodynamic size under high humidity conditions was continued using the LASL Spiral Centrifuge Aerosol Spectrometer and a specially designed horizontal elutriator. Initial data using the Spiral with three different polystyrene latex aerosols showed significant changes.

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Reevaluation of these data indicates that the test system produced a 5° C temperature decrease in the humid air stream passing through the Spiral resulting in sufficient water vapor condensation to account for the indicated increase in apparent aerodynamic size. The horizontal elutriator was constructed to permit its operation under constant temperature conditions, and the humidity generation system was modified to minimize any temperature increase in the experimental test system. Triplicate tests using 1 μm polystyrene latex (PSL) show no increase in apparent aerodynamic size as previously indicated by tests using the Spiral.

I. FIBERS

A. Standard Asbestos Filter Samples

Work during the first half of this six-month period was devoted to final development and documentation of a standard procedure for preparation of asbestos standard filter samples for the NIOSH Proficiency Analytical Testing (PAT) program. Final development of the liquid slurry technique was completed to permit use of UICC chrysotile. This modification permits use of a basic material with reproducible characteristics, eliminates milling bulk asbestos, and simplifies preparation of these standards. Particulate background material is aluminum oxide. Test procedures were standardized and detailed instructions for preparation of these standards were prepared for NIOSH, details of which are described in the Appendix to this report.

Seven sets of standards were prepared during this period. Each set consisted of four different concentrations with approximately 15 filters per concentration (approximately 420 filter standards). A continuing quality control monitoring procedure was developed, and eight filters from each set were reserved for counting at Los Alamos. Data from these samples counted by four trained people indicate variations up to ± 50% (Table I). To provide additional quality control information for NIOSH, a complete series of 10 "identical" standards were also counted. These data summarized in Table II, show variations of less than ± 10% for any one counter, and ± 20% for all counters.

The NIOSH employee responsible for continuing this asbestos proficiency program visited Los Alamos for special training in preparation of these standards. Future standards are being prepared at the NIOSH Laboratory in Morgantown, West Virginia, with LASL providing fiber counting to assist in their development of a quality control program.

Evaluation of the dispersion filtration technique indicates that the method is capable of producing fiber/particulate loaded membrane filters in a controllable and predictable fashion. This, however, can only be quantitated when fiber counts are assessed by a single counter. Fiber count results obtained under conditions where several trained counters use the same optics, and count the same wedges indicate variations as large as ± 50% are possible, with typical variations on the order of ± 30%. Typical fiber count results for a series of standard asbestos samples obtained by multiple counters appears in Table I. When additional variables are introduced (counters of varied experience, different sample wedges, different optics) unpublished count data contributed by other counting facilities participating in the NIOSH PAT program indicate variations as large as several fold.

The two most important single variables inherent in the technique of fiber counting appear to be the quality of optics available (The number of fibers detectable can be direct function of the optical resolution of the microscope in use) and the attitude and experience of the counter. A detailed list of the variables of concern would include the following:

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TABLE I

ASBESTOS COUNT DATA SERIES 149-152

Counter	Asbestos Count Data Series 149-152							
	149		150		151		152	
	13-A	15-A	13-B	15-B	13-C	15-C	13-D	15-D
Ortiz	843	706	863	961	1294	1255	2176	2294
Fairchild	667	863	804	1255	1373	1216	2157	1882
Gettemy	784	1000	1216	1627	2725	2216	3118	3039
Ettinger	647	470	471	627	902	804	1431	1353
Average:	735	760	839	1118	1574	1373	2221	2142
σ:	94	227	305	426	795	598	692	711
Coef.Var.:	0.13	0.30	0.36	0.38	0.50	0.44	0.31	0.33

TABLE II

ASBESTOS COUNT DATA - SERIES 12-E
INDIVIDUAL FIBER COUNT DATA - TEN "IDENTICAL" FILTERS

Counter and Fibers Counted/mm^2 Filter Area

SAMPLE CODE	ORTIZ	FAIRCHILD	GETTEMY	ETTINGER
12-1-E	1379	1655	1138	1241
12-2-E	1414	1517	1172	1069
12-3-E	1586	1621	1207	1276
12-4-E	1310	1690	1103	1103
12-5-E	1414	1655	1103	1172
12-6-E	1310	1655	1207	1172
12-7-E	1345	1966	1138	1207
12-8-E	1345	1793	1276	1069
12-9-E	1241	1945	1138	1138
12-10-E	1310	1621	966	1103
Average:	1365	1712	1145	1155
σ:	94	145	83	71
Coef. Var.:	0.07	0.08	0.07	0.06

Average of four (4) LASL counters: 1344
Standard Deviation: 265
Coef. Variation: 0.20

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a) Quality of optics - As indicated previously, the number of fibers detected is a function of optical resolution.

b) Microscope alignment - Proper illumination and use of a green filter along with critical alignment of the objective phase plate and condenser annulus combine to improve image contrast. Optimum phase contrast correspondingly increases image resolution and hence increases the number of detectable fibers.

c) Coverslip and microscope slide - Microscope phase objectives are generally corrected for specific cover glass thickness and deviations will affect image contrast. Likewise, thick microscope slides (> 1.2 mm) scatter light, reduce optimum phase interference and also reduce image contrast. The net effect is, again, to reduce optical resolution.

d) Quality of microscopic mount - The microscopic mount is an integral part of the optical system and hence can influence fiber counts. Good mounts should be optically clear, free of air bubbles and support the material to be counted in a narrow optical plane.

e) Relative size of counting field - The use of an eyepiece reticule prescribing large counting fields (> 0.005 mm^2 at 400 X) can influence fiber count results by contributing to counter eye fatigue and encouraging a habit of scanning the microscopic viewing field (i.e. When counting over a large area a counter tends to superficially scan the counting field rather than proceed through a careful and meticulous examination of the field simply because he has more area to search).

f) Particulate concentration - High particulate concentrations tend to mask small fibers and make counting difficult and tedious. Lower fiber counts can be expected under these conditions.

g) Fiber concentration - High fiber concentrations make counting difficult and the natural tendency of a counter is to count only fibers that are easily distinguished. Under these conditions the small diameter fibers are frequently neglected.

h) Attitude and experience of counter - As previously mentioned, this variable along with microscope quality is one of the most critical in the overall technique of fiber counting. Fiber count results are a direct function of the care and patience employed by each counter. Strict adherence to predefined criteria, painstaking care, and a thorough examination of each counting field are prerequisites to obtaining meaningful data by the fiber count procedure.

While there are many potential errors inherent in the proposed technique for monitoring airborne asbestos, the most important aspect is that all these variables tend to reduce the number of fibers counted, and thus underestimate the potential exposure hazard. The need for development of alternate techniques to monitor potential worker exposure is apparent.

Two potential objections have been raised concerning use of UICC material for the PAT standards. These objections are that the filters are unrealistic, and too difficult to count. Both complaints relate to the occurrence of fine diameter (< 1 μm) fibers in the UICC material. However these fine fibers are probably also present in samples obtained when monitoring typical industrial exposures. In these instances, the presence of easily counted relatively large diameter fibers may obscure the presence of the finer fibers. At this stage, this speculation is not substantiated but is a reasonable extrapolation based on the characteristics of chrysotile. An important aspect concerning small diameter fibers is that the relative health hazard associated with these fibers is, at present, unknown. Since those fibers are "respirable", they may in fact constitute the greater hazard.

Experiments with UICC Chrysotile "B" using the electron microscope have illustrated the presence of asbestos fibers with

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diameters as small as 250-300 Angstroms. These diameters lie well below the lower limit of resolution of optical microscopes at magnifications of 400 to 500 X. Detection and measurement of these small diameter fibers was accomplished by transferring samples from membrane filters to electron microscope (EM) grids by fusing the collection filter surface with solvent vapor, then replicating the altered filter surface with a carbon/chromium film. Small squares of the shadowed filter are cut and placed on EM grids and, the filter matrix gently dissolved away. The metallic replica is thus left directly adjacent and adhering to the EM grid. While some particle loss is to be expected during this transfer process, it is adequate to illustrate the presence of submicron diameter fibers in UICC chrysotile. Typical electron micrographs are illustrated in Figs. 1 and 2.

B. Respirable Sampling For Fibers

During the latter part of this six-month period work has been directed toward the continuation of the fibrous glass aerosol studies temporarily abandoned in April, 1972. The original intentions of these studies were to include: Generation of a fibrous glass aerosol, aerodynamic classification of said fibrous aerosol, and calibration of a 10 mm nylon cyclone for the sampling of fibrous aerosols to approximate the ACGIH definition of "respirable" dusts.

Recent fibrous aerosol generation experiments have been conducted with a new type of glass fiber supplied by the Owens Corning Fiberglas Corporation (O/C ID Code: E glass AA-12). This material is provided as a mat or batting in bulk form containing fibers ranging in diameter from 0.06 to ~ 6.5 μm. This size range is suitable for aerosol generation purposes as will be explained below. A schematic diagram of the fibrous aerosol generation system currently in use is illustrated in Fig. 3. A large quantity (~ 60 gm) of this new glass was blendorized as a thin water slurry and thoroughly mixed to provide a consistent batch of fibrous glass dust for aerosol generation. The blendorization treatment served to chop fibers and thus reduce fiber length, with diameters remaining unaffected. The resultant aerosol contains fibers with a range of well defined diameters and multiple lengths.

Preliminary generation experiments with this particular glass indicate that the aerosol output is extremely variable with time. Mass concentration variations sampling with open face filters have been observed to range from 28 to 81 μg/l within a 1.5 hour sampling interval (Fig. 4). This apparent shortcoming is not a serious limitation as simultaneous samples taken over short intervals (15 min) indicate that the aerosol mass distribution is relatively uniform throughout the sampling chamber. The average coefficient of variation for simultaneous samples at different sampling locations was ± 11%. The previously noted variation in aerosol output as a function of time is inherent in the design of the generation system. Packing of the fibrous feed plug is difficult to reproduce since a weighed quantity of fibrous glass is compressed, while still wet, to a fixed dimension. Production of the fibrous aerosol is a somewhat arbitrary process, since fibrous bundles are shaved from the compact feed plug and aerosol production is dependent upon the random separation of individual fibers from these shaved bundles by the gentle, but turbulent agitation within the generator chamber. However, the fibrous aerosol produced is well suited for our purposes. Individual fibers with diameters as large as ~ 3.4 μm (3.4 μm physical diameter corresponds to ~ 10 μm aerodynamic diameter) have been observed in the aerosol cloud. The range of fiber diameters available for experimental work, under established generation conditions, extend from an aerodynamic size range of 0.2 to 10 μm (microscopic diameters ranging from 0.06 to 3.4 μm). This range of fiber diameters (0.06 to 3.4 μm) fits well into the class of "respirable" fibers as defined by Timbrell.[1]

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Recent work involving a limited number of experiments conducted with the 10 mm nylon cyclone sampling at 1.7 lpm indicate that the collection characteristics of the 10 mm cyclone for short term sampling (< 90 min) of fibrous glass dusts appear to be experimentally reproducible. Simultaneous sampling of the glass aerosol using two or three identical cyclones resulted in an average coefficient of variation of ± 13% in the mass passing each cyclone. Tabular results for the cyclone sampling experiments appear in Table III. This observation is contradictory to results obtained earlier[2] using a different glass aerosol and long (> 4 hour) sampling times. All cyclone comparisons were made by taking simultaneous samples and monitoring the mass of fibrous aerosol passing the cyclones which was then related to the total challange aerosol as determined by open face filter samples. Limited fiber sizing data indicates that there may be an aerodynamic size cut off as no fibers larger than ~ 2.2 μm (diameter) have been measured (to date) passing the 10 mm nylon cyclone operating at 1.7 lpm. This diameter (2.2 μm) corresponds to an aerodynamic diameter of ~ 7 μm. As an additional note of interest fibers as long as 518 μm (1.1 μm diameter) have been measured on the downstream side of the cyclones.

The above observation (no fibers larger than 2.2 μm have passed the 10 mm nylon cyclone) indicates that the 10 mm nylon cyclone may prove a useful short term sampler for fibrous dusts. There are, however, certain reservations about the cyclone behavior relative to fibers that need to be clarified and will be the major effort during the next quarter.

II. STANDARD INSTRUMENT CALIBRATION (SIC) SYSTEM

Construction, calibration and testing of the SIC system was completed in November and the unit (Figs. 5 - 9) was shipped to the NIOSH Testing and Certification Lab, Morgantown, West Virginia, in December. This unit is similar to the prototype (PSIC) sent to Cincinnati in August, but incorporates some improvements requested by NIOSH.

One major change was replacement of the TSI Particle Mass Monitor (PMM) with a GCA Respirable Dust Monitor (RDM). This latter instrument provides rapid mass measurement and is designed specifically for use with coal dust. The RDM consists essentially of

TABLE III

CYCLONE COLLECTION COMPARISONS

Run No.	Fibrous Mass Passing Cyclone (mg)	Total Challange Aerosol-Fibrous Mass (mg)	Fibrous Mass Passing Cyclone (%w)	Std. Dev. (Mass Pass. Cyc.) (σ)	Coefficient Of Variation $\left(\frac{\sigma}{\bar{x}}\right) \times 100$
1	2.010	5.192	38.7	3.1	7.6
1	2.235	5.192	43.0		
2	0.935	3.754	24.9	5.1	17.9
2	1.205	3.754	32.1		
3	0.367	1.163	31.6		
3	0.470	1.163	40.4	5.1	13.6
3	0.470	1.163	40.4		

Average Coefficient of Variation: $\Sigma \frac{\sigma}{n} \times 100 = \pm 13\%$

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an impactor, β counter, associated power supply, sampling pump, and electronics. In operation the instrument impacts coal dust onto a vaseline coated mylar collection surface, which is located between a β source and a counter. Attenuation of the β 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 read directly.

Upon receipt, calibration of the RDM agreed with a GCA supplied standard sample; however, mass readout of dust concentration in the SIC was considerably higher than obtained by mass measurements using membrane filters (Fig. 10). RDM measurements were made to correspond to the mass indicated by these filters (Fig. 11) by adjusting 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 shown by the Fig. 11 error bars, with an average coefficient of variation of 27.1%. It should be noted that the variations in mass concentration recorded by the RDM may be valid since the filters average out fluctuations in concentration over a 15 min period as compared to the 40 sec measurement time of the RDM.

A second major change involved redesign of the tritide charge neutralizer to permit use of a 200 mCi tritide source in place of the 4 Ci source used in the PSIC system. This modification was incorporated to assure that the tritide neutralizer unit met requirements of TCL's AEC license, which limits its permissible tritium activity to 250 mCi. To insure that 200 mCi activity was sufficient to neutralize the charge on a coal dust aerosol, the activity required at expected concentrations and flows was determined theoretically and experimentally. In the absence of reference data concerning charge carried by coal aerosols, the charge was assumed to be $/\bar{n}_p/ = 25\ D$ where $/\bar{n}_p/$ is the average number of unit charges on a particle of diameter D expressed in microns. If the Wright Dust Feed mass output is converted to number of particles generated per second by assuming the distribution has a count median diameter of 1 μm, and σ_g of 1.8, the total charge can be estimated. When this is equated to the amount of tritium required to neutralize such a charge in the geometric configuration of the deionizer unit, it is found that 15 mCi provides sufficient ion concentration. An experiment, utilizing decreasing amounts of tritium confirmed that less than 150 mCi activity was sufficient to neutralize the charge on an actual coal dust aerosol. A compact case was designed and constructed to further improve the tritide aerosol charge neutralizer.

Additional, less significant improvements of the newer unit included, 1) higher flow rate meters to accommodate personal sampler flow up to 2.5 l/min, 2) larger personal sampler ports in the aerosol chamber, and special clamps to permit quick insertion and positioning of personal samplers within the chamber, and 3) a modified exhaust system which eliminates the need for a pumping system to remove excess aerosol. The inclusion of a method to visually determine initiation of aerosol generation was considered, but visual observation of the coal dust aerosol by scattered light proved to be impractical in SIC due to light absorption by the coal dust. However, it was found that the RDM provided a reliable indication of aerosol generation within 2 min of start up.

Performance of the SIC system was determined in several dust dispersion runs. As a function of operating time, stability of coal dust concentration as measured by average coefficient of variation was $\pm$ 10.1% at four different sampling positions within the chamber. Spatial uniformity of concentration as measured by simultaneous membrane filter samples taken at two, or three locations exhibited an average coefficient of variation of 7.2%. Both the stability and spatial uniformity were determined during

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experiments in which the dust cloud was undisturbed. Additional experiments involving relocation of internal samplers, momentary opening of sampling ports, etc. caused temporary increases of approximately 50% in the above variations.

III. STANDARD COAL DUST AEROSOL

Several comminution experiments utilizing the micronizer fluid energy grinder established that the product coal dust size is strongly dependent upon grinding air pressure, and to a lesser degree upon grinding time. To achieve a uniform feed rate in recent experiments the sloping tray powder feeder was replaced with a vibrated stand pipe feeder. This decreased the time to grind 100 g of coal from 4 $\pm$ 1 min to 24 $\pm$ 5 sec, which resulted in a coarser coal dust (Fig. 12) as well as a 60% increase in the amount of coal recovered as product. Additional experiments are necessary to determine if the new feed method increases the reproducibility of grinding.

The variation in measured specific surface for bulk micronized coal is small, while the calculated specific surface based on size characteristics of the aerosolized dust varies considerably. Calculated specific surface is obtained by substitution of aerosol CMD and σ_g, determined from electron micrographs, into the Hatch and Choate equation for specific surface.[3] Since σ_g can have an error of $\pm$ 15%, the term 2.5 σ_g^2 in this equation may produce a $\pm$ 60% variation in calculated specified surface. This error combined with uncertainties in samling the airborne dust makes precise correlation of the calculated and measured specific surface difficult. Another factor which may account for a major part of the discrepancy between measured and calculated specific surface is the possibility that the size distribution of air dispersed dust is different from that of the bulk dust due to losses, shattering, agglomeration, etc. in the dispersion process. A review of aerodynamic sizing, microscopic sizing, and specific surface measurements indicates that while the bulk powder used for dispersion is made increasingly coarse, the airborne dust exhibits little change in size parameters. Thus, as the specific surface of bulk dust decreased by a factor of 4, the MMAD of the airborne dust increased by only 15%. In two recent experiments the deagglomeration baffle was removed from the exit of the Wright Dust Feed and two dusts which had been previously dispersed with the baffle installed, were dispersed. The size parameters changed significantly (Table IV), but whether this change is due to increased agglomerates in the cloud or an actual increase in the number of large particles is not yet clear. Probably both mechanisms contribute to the greater MMAD when the baffle is removed from the WDF. The first two dusts listed in Table IV (actually the same dust, but different dispersion conditions) are within the range of size distribution desired for the "standard test dust", i.e. 3.75 $\pm$ .25 µm MMAD and $\sigma_g \geq 2$.

TABLE IV

SIZE CHARACTERISTICS OF NIOSH COAL DUST

Dust	Size Parameters			
	Measured			Calc.[d]
	CMD[b] µm	σ_g	MMAD[c] µm	MMD µm
M-17	.40±.04	2.09±.18	3.5±1.4	2.2±1.1
M-17[a]	.53±.03	1.99±.16	3.6± .8	2.2± .6
M-41	.54±.01	1.91±.01	2.8± .3	1.9± .02
M-41[a]	.61±.07	2.00±.08	4.8± .4	2.6± .7

[a] Dispersion from WDF with deagglomeration plate removed.

[b] Average of at least 2 ESP-EM sizing samples.

[c] Average of MMAD obtained from 5 aerodynamic size measuring instruments.

[d] Calculated from $\ln MMD = \ln CMD + 3 \ln^2 \sigma_g$.

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Methods for determination of aerodynamic size characteristics were improved during the period. An Andersen impactor, two Andersen mini-impactors and the Lovelace Aerosol Particle Separator (LAPS) were used during each run to obtain aerodynamic size distributions.

The Andersen impactor provides the most reliable aerodynamic size distribution information. This instrument, operated at 1 cfm air flow, collects sufficient dust on the 75 mm diameter membrane filters used as impaction surfaces in a reasonable period of time to give good mass sensitivity. A plot of the size information indicates a log normal size distribution with little tail off at the extremes (Fig. 13). Greater reliance is placed upon these data than that obtained from other methods for estimating aerodynamic size distribution.

Two Andersen mini-impactors, one of which is a LASL modification of the commercial instrument have also been used, primarily to obtain a calibration of the mini instruments for coal dust by comparison with data from the large impactor. This sampler may be useful in field work, as well as to the TCL for routine monitoring of dust during air sampling instrument tests in SIC. The MMAD obtained from the mini-impactors agrees fairly well with that obtained from the large Andersen, however, the mass sensitivity is relatively poor because the mass of dust collected is only 0.1% of the mass of the plate upon which it is collected and weighed.

Two-stage, 10 mm nylon personal samplers have also been used to obtain estimates of the MMAD of coal dust clouds. If σ_g is assumed to correspond to that determined by the Andersen impactor data, and total mass entering the cyclone is estimated from other data (membrane filters, total mass collected in aerodynamic samplers, etc), then the "respirable" fraction passing the cyclone can be found from gravimetric measurement of total dust and dust on the personal sampler second stage filter. The MMAD of the dust can then be estimated from this information together with parametric curves of cyclone efficiency as a function of MMAD and σ_g (Fig. 14).[4] Knowing the respirable fraction (% passing the cyclone) and σ_g, aerosol MMAD can be estimated. In general, MMAD's obtained by this method has been approximately 25% smaller than those obtained by direct sampling techniques.

Problems with the LAPS still exist since an accurate calibration of our instrument for aerodynamic size greater than 2 μm, has not been obtained, inlet losses are significant, and the laminar flow pattern near the exit filter is distorted. A calibration taken from Kotrappa and Light[5] is being utilized temporarily for aerodynamic sizes greater than 2 μm until PVT latex particles of 6 μm mean diameter are available to calibrate the instrument. Inlet loss in LAPS has averaged about 10% of the total mass collected during a run, as determined from washings. This loss is acceptable so long as a reasonable determination of the mass can be made. For recent LAPS collection runs no final filter has been used in the channel; rather, a membrane filter is placed in the exhaust air line external to the head. Elimination of the filter in the channel appears to have improved the particle deposition pattern in this region.

IV. EFFECT OF HUMIDITY ON AERODYNAMIC PROPERTIES OF NONHYGROSCOPIC PARTICLES

(This Activity Only Partially Supported by NIOSH)

This study was initially carried out using the LASL Spiral Centrifuge Aerosol Spectrometer (Spiral).[6] Aerosols generated from three suspensions of monodisperse polystyrene latex particles (0.3 μm, 0.987 μm and 1.95 μm) were aerosolized with a Retec compressed air nebulizer. The particles were dried by diluting the aerosol with dry air. Electrical charge was eliminated by passing the aerosol through a parallel plate tritium deionizer. A small portion of this aerosol (~0.400 l/min) was drawn into the

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deposition channel of the Spiral which operates by introducing the aerosol into the deposition channel in a thin layer separated from the deposition surface by a much thicker layer of clean air. The centrifugal force caused by rotation of the deposition channel directs the particles across the thick clean air layer to the deposition surface as they travel down the channel. All particles have essentially the same distance to travel across the clean air layer so each particle will be deposited a specific distance down the channel that is characteristic of its aerodynamic size. To study the effects of humidity on aerodynamic size the relative humidity of the clean air layer was varied by passing the elutriating air over warm water. Temperature of the water was adjusted to provide the desired humidity. The results of these experiments are shown in Fig. 15 indicating an increase in particle aerodynamic diameter at high relative humidities. The increase is much greater for the 0.3 μm particles than for the larger particles.

During these experiments there was a change in both relative humidity and temperature of the air between the entrance to the Spiral and the exhaust line. The relative humidity increased about 1.4%, while the temperature decreased from approximately 30° C to 25° C. These changes would cause the condensation of approximately 7×10^{-6} g of water per cubic centimeter of air which will condense on all available surfaces including all particles large enough to provide a nucleation center. The growth of particles significantly larger than the mean free path of the condensing molecules is described by the following equation,[7]

$$S - S_o = \frac{8 \pi D}{\rho} c_\infty t \qquad (1)$$

where S_o is the initial surface area of the particle, S is the surface area of the particle after time t, ρ is the density of the particle, D is the diffusion coefficient of the condensing molecule and c_∞ is the concentration of the condensing molecules far from the particle. In this instance (condensation of water on polystyrene latex) particle density remains essentially constant. Condensation occurs rapidly when super saturation is reached so it seems reasonable to assume that the temperature drop occurs as the air passes through the Spiral inlet thus providing equal growth times for all particle sizes. The measured change in size for large particles can then be used to predict the change in size for smaller particles assuming the change is the result of a condensation process. Based on the Spiral data for the growth of 1.95 μm diameter particles, theory predicts that 0.987 μm particles would grow to 1.082 μm diameter. The observed growth of these particles was to 1.065 μm which is within 1.5% of the predicted size.

Equation (1) must be modified for predicting the increase in surface of particles whose size approaches the length of the mean free path of the condensing molecules.[8] In this case the rate of change of surface is given by

$$\frac{ds}{dt} = \frac{8 \pi D c_\infty}{\rho} \left(\frac{1}{\frac{D}{rv\alpha} + \frac{r}{r+\Delta}} \right) \qquad (2)$$

where r is the radius of the particle; α is the fraction of molecules that strike the particle that condense (assumed to be unity); $v = \left(\frac{k T}{2\pi M_2}\right)^{\frac{1}{2}}$, where k is the gas constant per molecule, T the absolute temperature, and M_2 the mass of the condensing molecule; $\Delta = \lambda \left(\frac{M_1 + M_2}{M_2}\right)^{\frac{1}{2}}$ the average distance traveled by a condensing molecule before it collides with a gas molecule, where λ is the mean free path of the air molecules and M_1 the mass of the "air" molecule. Equation (2) can be solved to relate the change in radius of these smaller particles with the change in surface of the large particles (previously defined by equation (1)) using the following relationship:

$$\frac{8\pi D}{v\alpha}(r_1 - r_o) + 8\pi\Delta(r_o - r_1) + 4\pi(r_1^2 - r_o^2) + 8\pi\Delta^2 \ln\left(\frac{\Delta + r_1}{\Delta + r_o}\right) = \frac{8\pi D c_\infty t}{\rho} \qquad (3)$$

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where r_o is the initial radius of the particle and r_1 is the final radius of the particle. Equating the left side of equation (3) to the change in surface measured in the spiral for 1.95 and 0.987 μm diameter particles would indicate that 0.300 μm diameter particles will increase to 0.499 μm and 0.462 μm respectively. The observed change was to 0.4 μm. However, these smaller particles take longer to deposit, resulting in greater water evaporation from the particles as they travel down the Spiral deposition channel. Therefore, this discrepancy between observed and expected size for 0.3 μm PSL is consistant with the experimental conditions.

To confirm these experimental data and theoretical predictions a new series of experiments were completed using a horizontal elutriator to characterize particle sedimentation velocity. To eliminate temperature gradients most of the apparatus was enclosed in a water jacket. Water was circulated through the jacket and also through a bubbler column where diluting air was humidified at the temperature of the water. Six experiments were conducted by nebulizing an aqueous solution of 1.011 μm PSL particles then diluting the aerosol with humid or dry air. After mixing, the aerosol entered a small chamber (~1.4 liters) located in a large water bath with the horizontal elutriator. The horizontal elutriator sample was drawn from this chamber at a flow rate of approximately 300 cm^3/min. The excess aerosol (~11 l/min) was withdrawn from the chamber through a double walled glass tube containing a wet and dry bulb thermometer. Circulating water from the water bath was passed through the outer annulus of this tube. The pressure in the small chamber was maintained at approximately atmospheric by balancing the intake and exhaust flow rates.

Samples were collected on electron microscope grids placed at 5 cm intervals along the center line on the floor of the elutriator. The number of individual particles deposited on 16 grid openings was determined by scanning the openings in an electron microscope and counting the individual particles. Deposition concentration was then plotted as a function of penetration distance to characterize the sedimentation velocity of the particles. Figure 16 shows the average deposition concentration as a function of penetration distance for all runs. The plotted concentrations are normalized to the average deposition concentration for the first 90 centimeters. Penetration distances were also adjusted according to measured flow rates through the elutriator so each point represents the same deposition time. These data indicate that the PSL particles behave as if they are 11% smaller in the more humid constant temperature environment, opposite to the effect observed in the Spiral experiments which included a 5° C temperature drop.

Several corrections were necessary to establish the correct volumetric flow through the horizontal elutriator which was measured by means of a bubble flow meter connected in series with the elutriator and the suction line. Air flow for the low humidity runs was adjusted assuming the air in the flow meter was immediately saturated at room temperature and that the soap added to the water in the bubble flow meter would not affect vapor pressure. Indicated air flow for the humid runs was low since the circulating water pump heated up the water slightly, causing the experiment to be conducted a couple of degrees centigrade above room temperature. This drop in temperature between the water bath containing the horizontal elutriator and the bubble flow meter caused water to be condensed in the line. By assuming that the air remained saturated but at room temperature it was possible to correct the indicated flow rates. Temperature corrections were also made for all measurements.

These problems coupled with the very long sampling times (~16 hours per sample) and the long sedimentation times (~10 min to maximum penetration) make it impossible to precisely determine the effects of high

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humidity on the aerodynamic properties of nonhygroscopic particles. The results of the horizontal elutriator experiments indicate that there is little or no effect of high relative humidities on the aerodynamic characteristics of nonhygroscopic particles. However, experimental data obtained with the Spiral and the subsequent calculations indicate that large errors can be made in the characterization of small particles in saturated atmospheres if temperature drops of as small as one or two degrees centigrade occur prior to the dynamic characterization of aerodynamic size. Therefore, the sampling instrument should be at the same or a higher temperature then the air to be sampled, and no pressure drops leading to a reduction in temperature should occur before aerodynamic characteristics are measured. This potential problem will arise in instruments that have significant inlet pressure drops such as cascade impactors. The condition will also arise if the aerosol passes through a warm humid environment before reaching the sampling instrument, i.e. characterization of exhaled aerosols with the instrument at room temperature. An error in estimating lung deposition will also occur when sampling in a humid-high temperature environment (such as mining) where the ambient temperature is considerably greater than body temperature.

V. WORK FOR NEXT QUARTER

One major effort during the next quarter will be directed toward aerodynamic classification of the aerosol produced with the new Owens Corning fibrous glass and calibration of the 10 mm nylon cyclone for the sampling of respirable glass fibers.

Major emphasis will also be directed at completion of the "standard" coal dust test aerosol. In addition considerable time will be devoted to the design and construction of two "large" aerosol test systems to be supplied to NIOSH and TCL by July, 1973.

To terminate the humidity-aerodynamic size study, experiments are planned utilizing the Spiral to sample a submicron aerosol under high relative humidity and constant temperature conditions. This same apparatus will then be used to sample several types of fibers.

REFERENCES

1. V. Timbrell, "The Inhalation of Fibrous Dusts," Ann. N.Y. Acad. Sci., 132, 255-273 (1965).

2. Aerosol Research and Development Related to Health Hazard Analysis, Los Alamos Scientific Laboratory Project R-038 Quarterly Report, LA-4936-PR (Jan. 1 - March 31, 1972).

3. 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).

4. O. R. Moss and H. J. Ettinger, "Respirable Dust Characteristics of Polydisperse Aerosols," AIHA J. 31, 546-547 (1970).

5. P. Kotrappa and M. E. Light, "Design and Performance of the Lovelace Aerosol Particle Separator," Rev. Sci. Instr., 43, 1106-1112 (1972).

6. O. R. Moss, H. J. Ettinger and J. R. Coulter, "Aerosol Density Measurements Using A Modified Spiral Centrifuge Aerosol Spectrometer, Env. Sc. Tech. 6, 614-617 (1972).

7. N. A. Fuchs, Evaporation and Droplet Growth in Gaseous Media, Pergamon Press, p. 3 (1959).

8. H. L. Green and W. R. Lane, "Particulate Clouds: Dusts, Smokes, and Mists," E & F. N. Spon Ltd. London, p. 92 (1964).



Fig. 1. Electron Micrographs UICC Chrysotile 'B', Nuclepore Filter Sample. Transferred to EM Grids.

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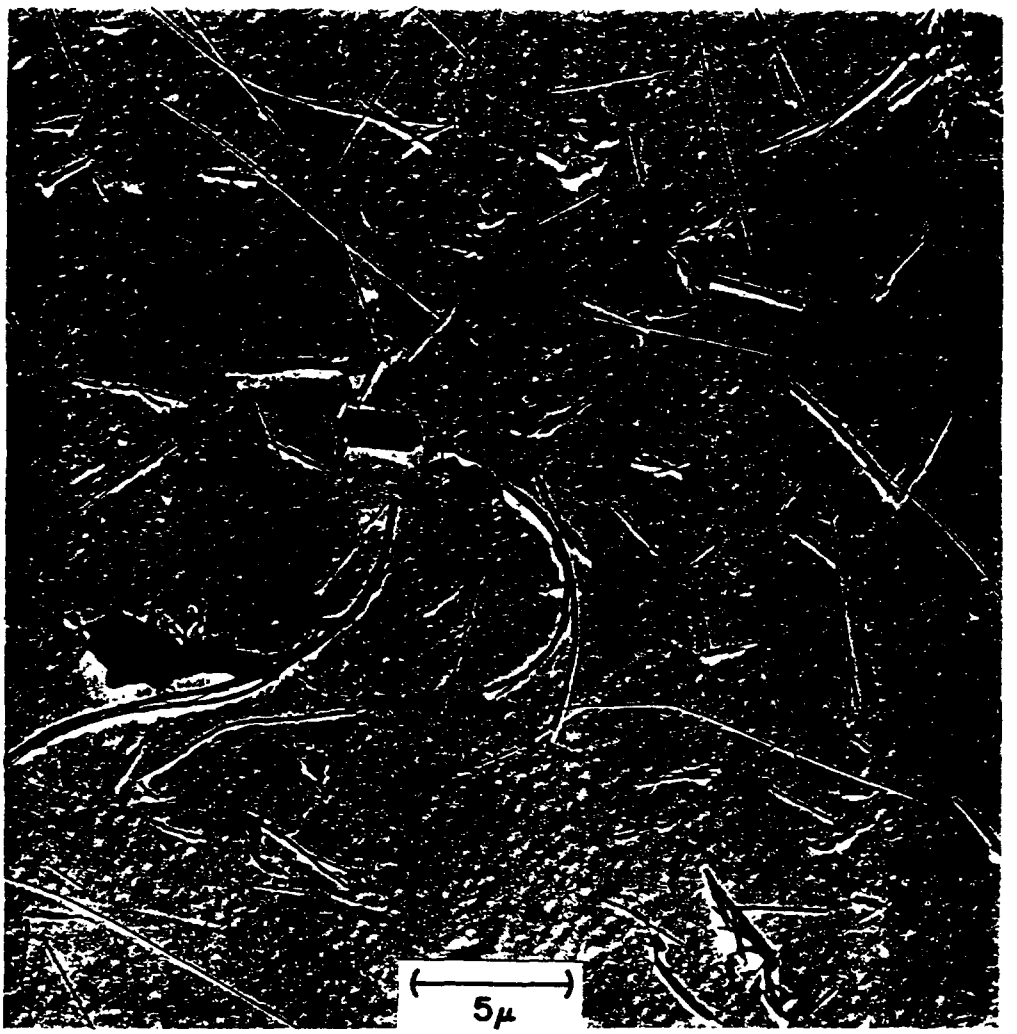

Fig. 2. Electron Micrographs UICC Chrysotile 'B', Millipore Filter Sample. Transferred to EM Grids.

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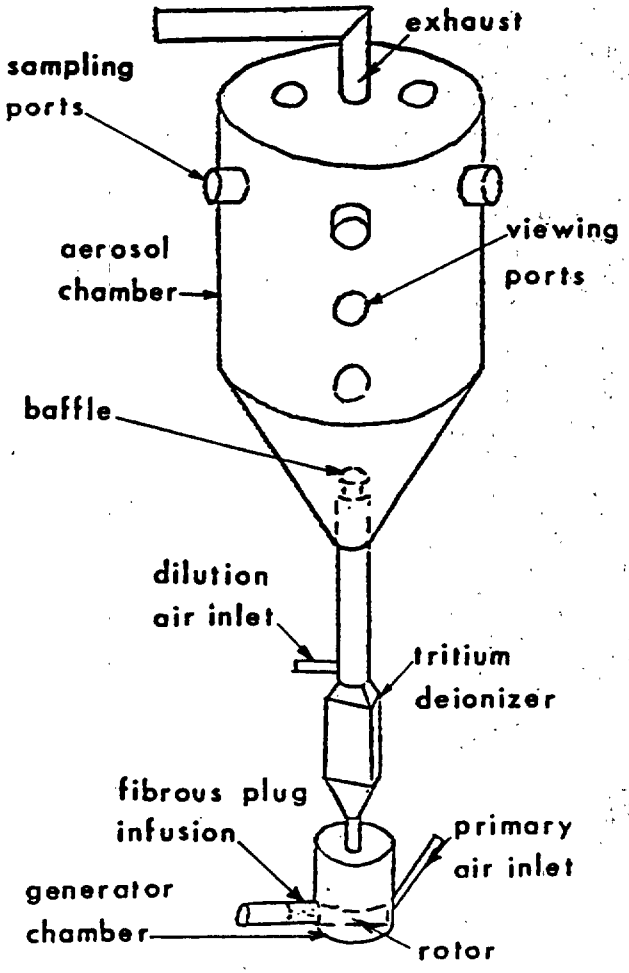

Fig. 3. Fibrous Aerosol Generation System.

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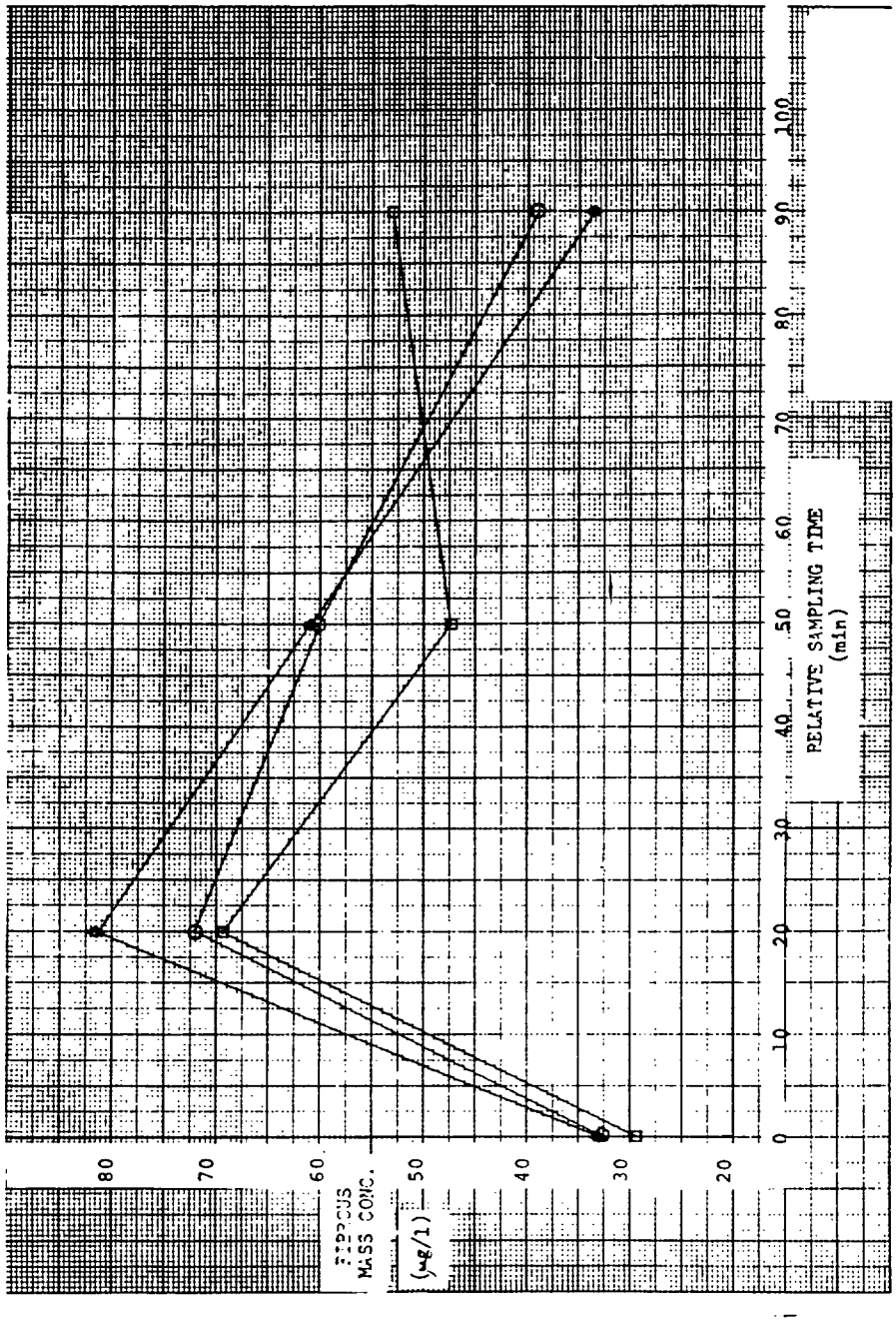

Fig. 4. Fibrous Glass Aerosol: Mass Concentration vs Relative Sampling Time.

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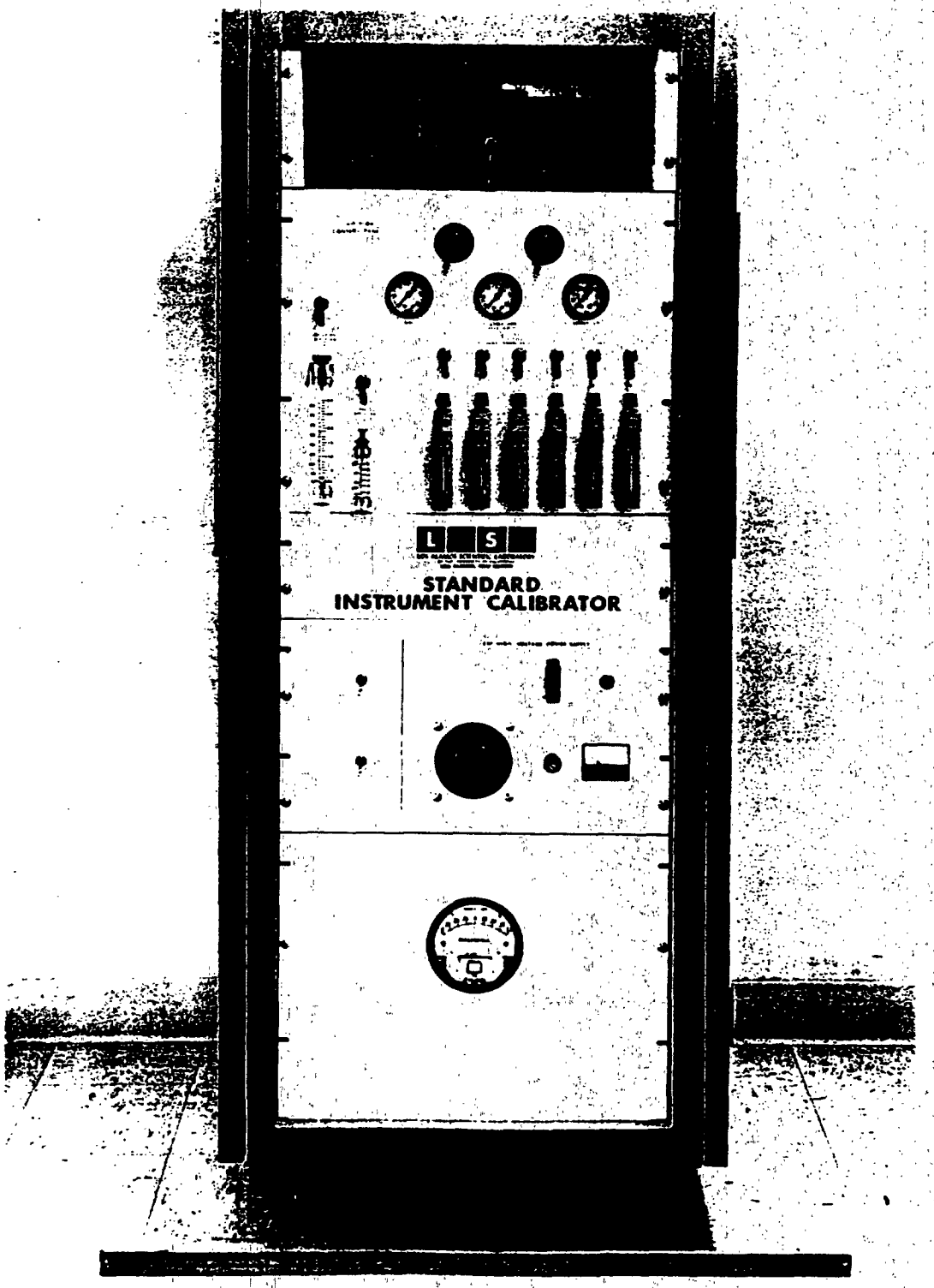

Fig 5. Standard Instrument Calibration System (SIC), (front).

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Fig. 6. Standard Instrument Calibration System (SIC), (rear).

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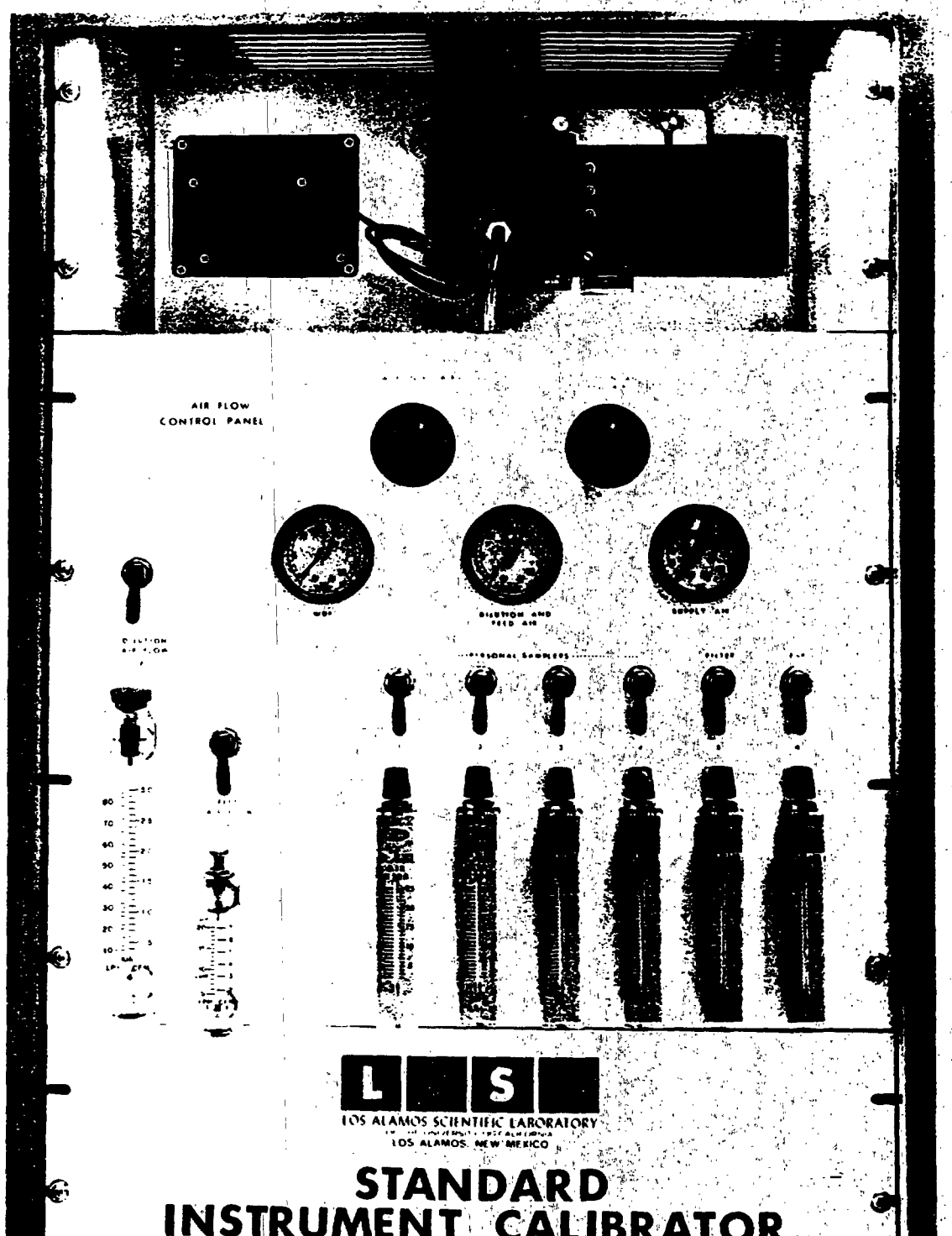

Fig. 7. SIC Upper Section, (front)

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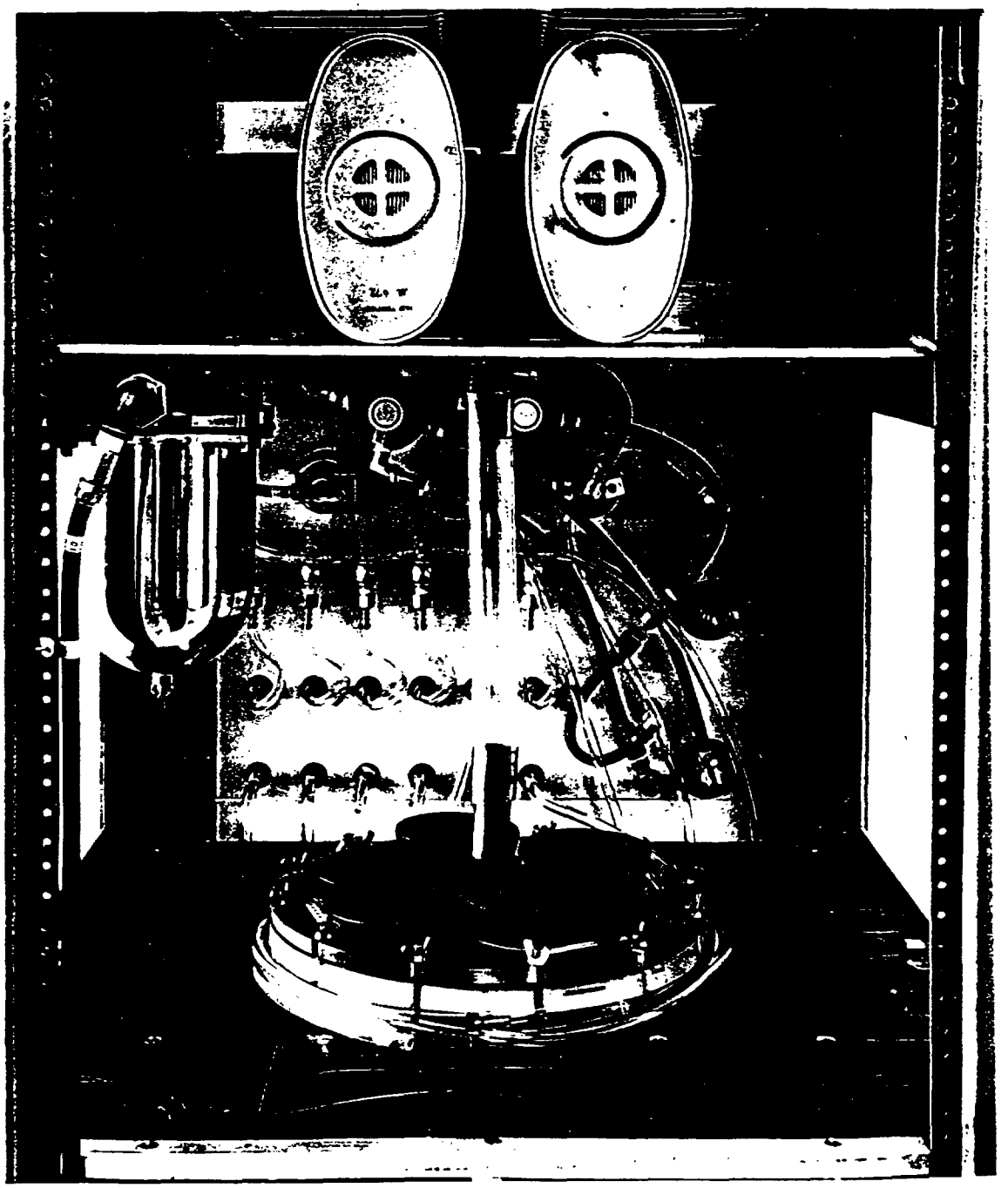

Fig. 8. SIC Upper Section, (rear).

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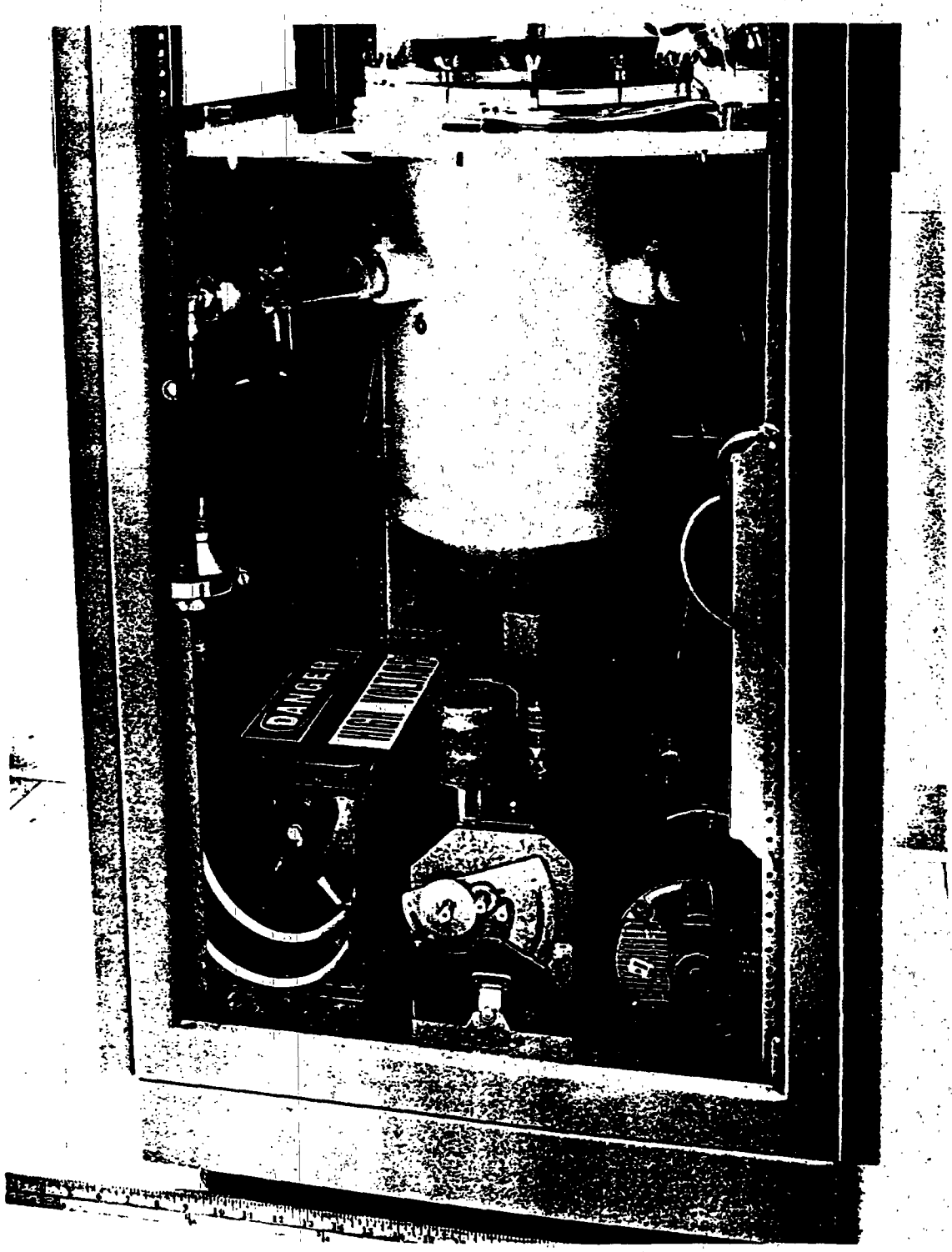

Fig. 9. SIC Lower Section, (rear).

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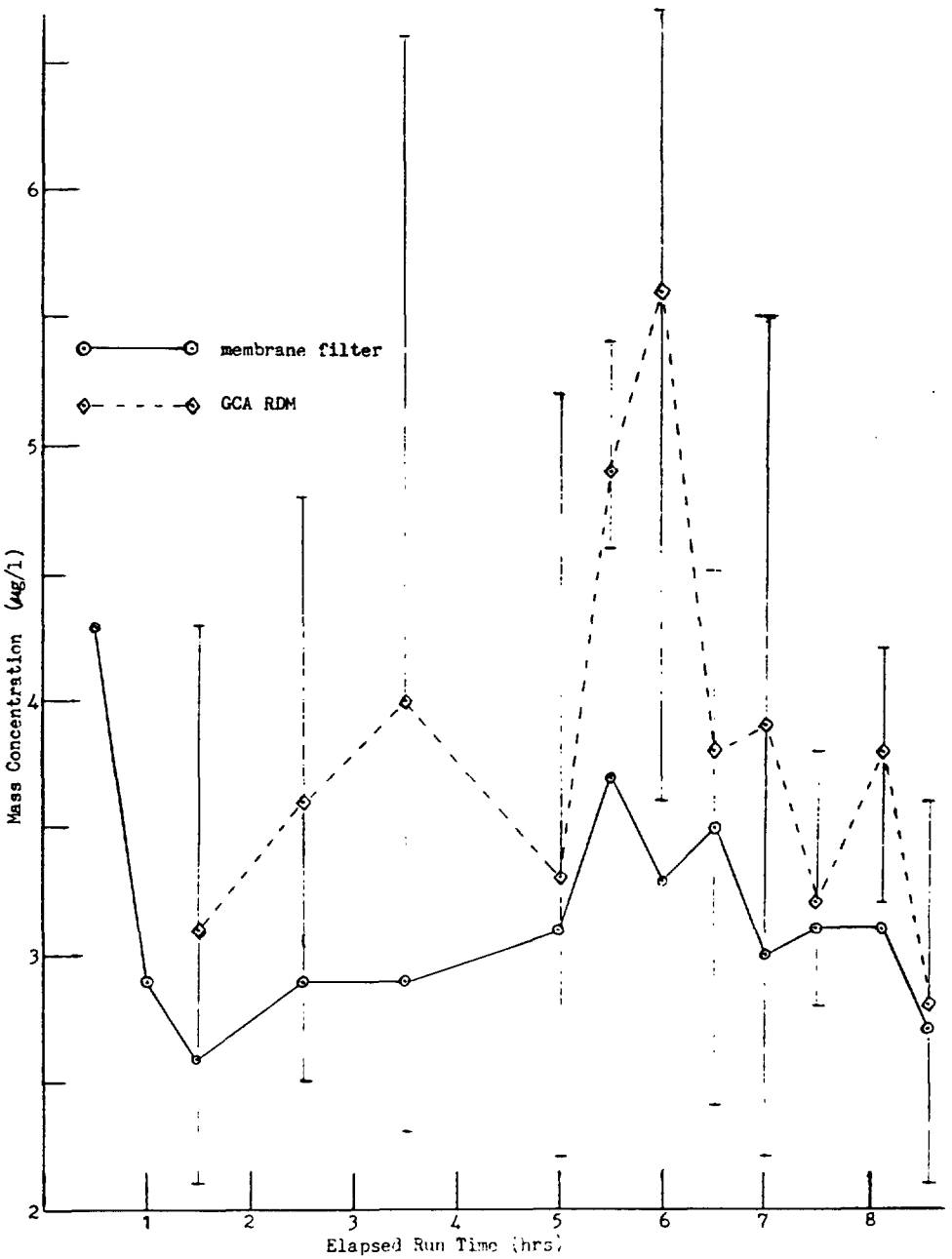

Fig. 10. Mass concentration in SIC chamber, dispersion run F-73.

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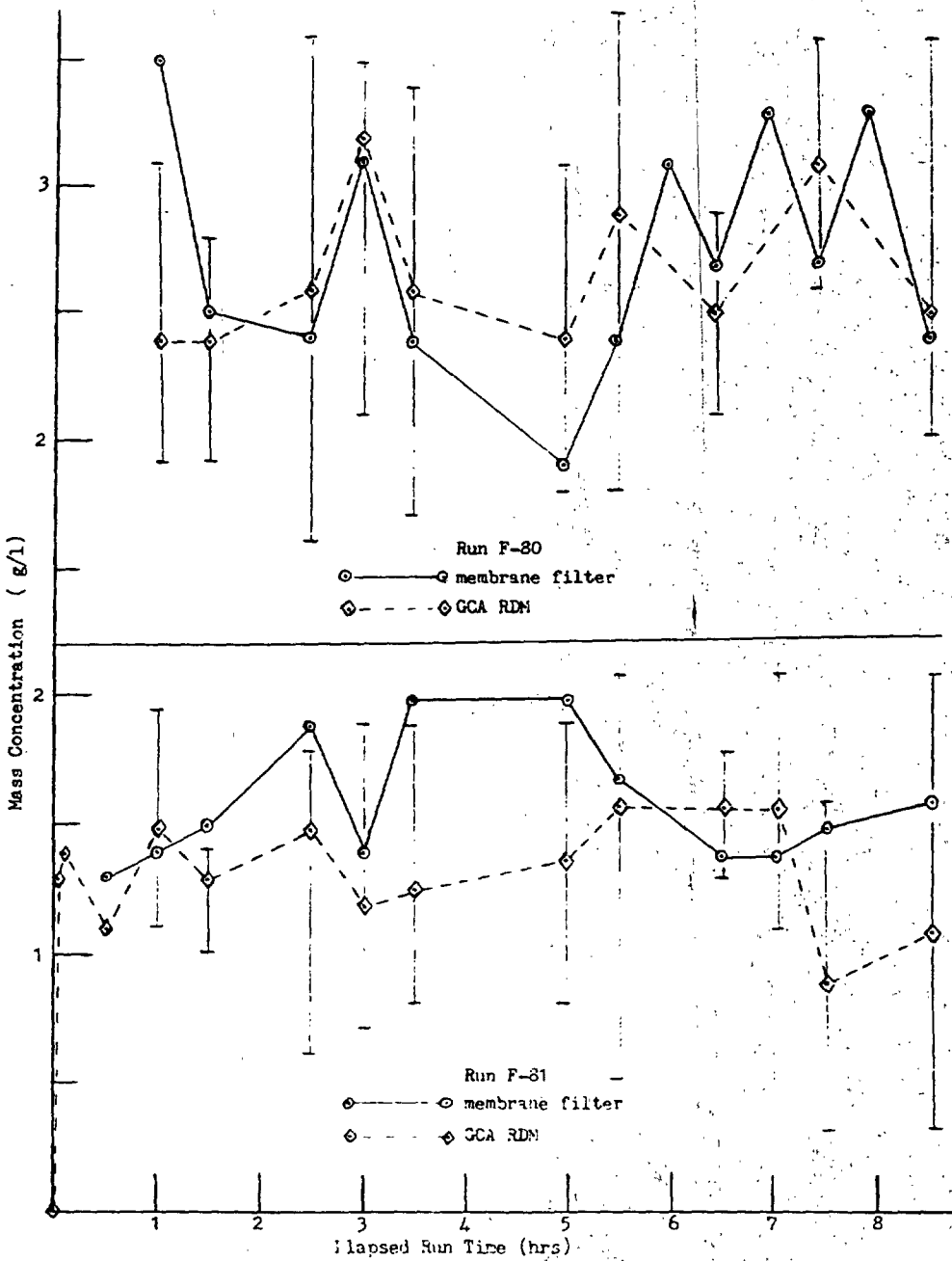

Fig. 11. Mass concentration in SIC chamber, dispersion runs F-80 and F-81.

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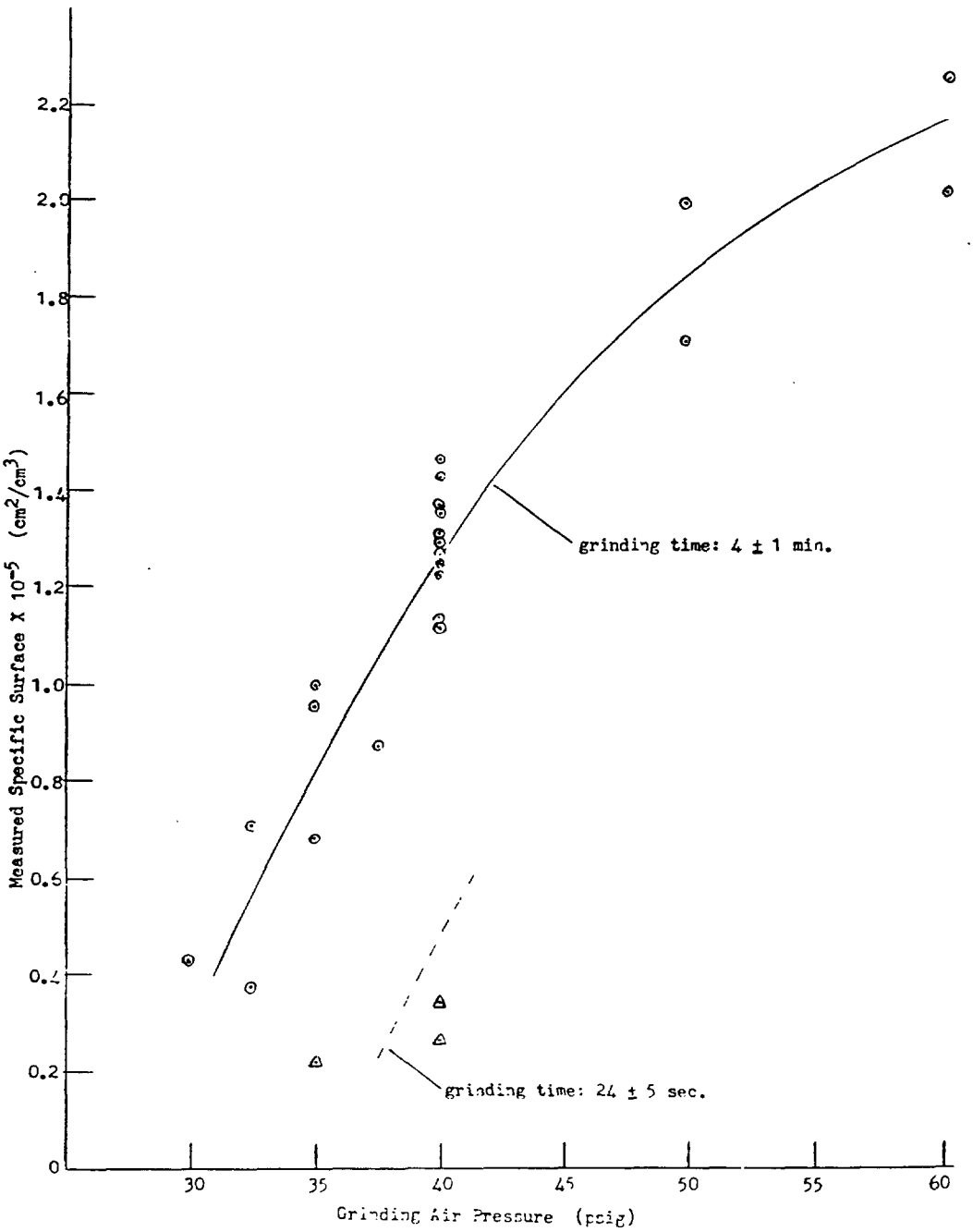

Fig. 12. Specific surface of NIOSH coal dust as a function of micronizer pressure.

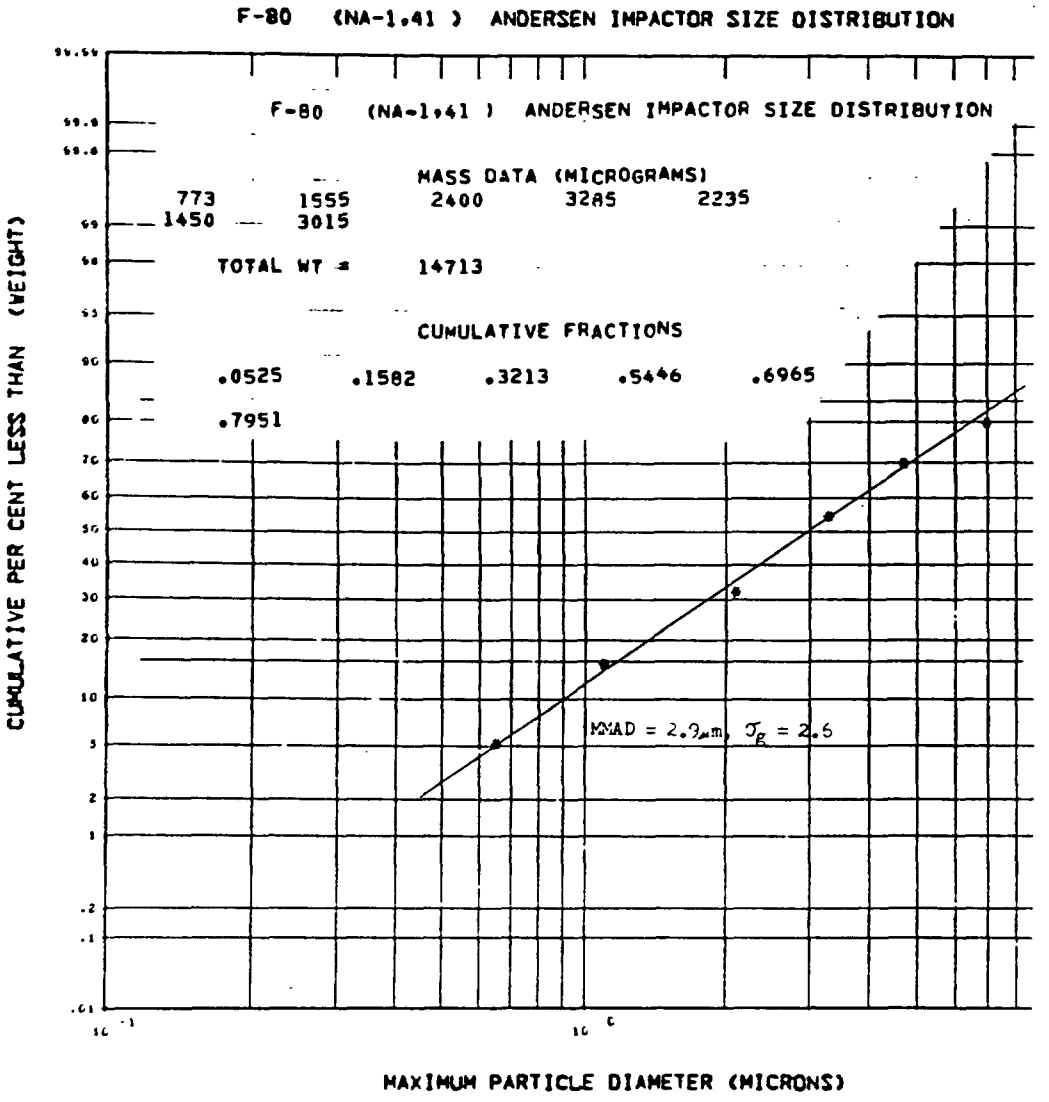

Fig. 13. Typical Andersen impactor aerodynamic size distribution results.

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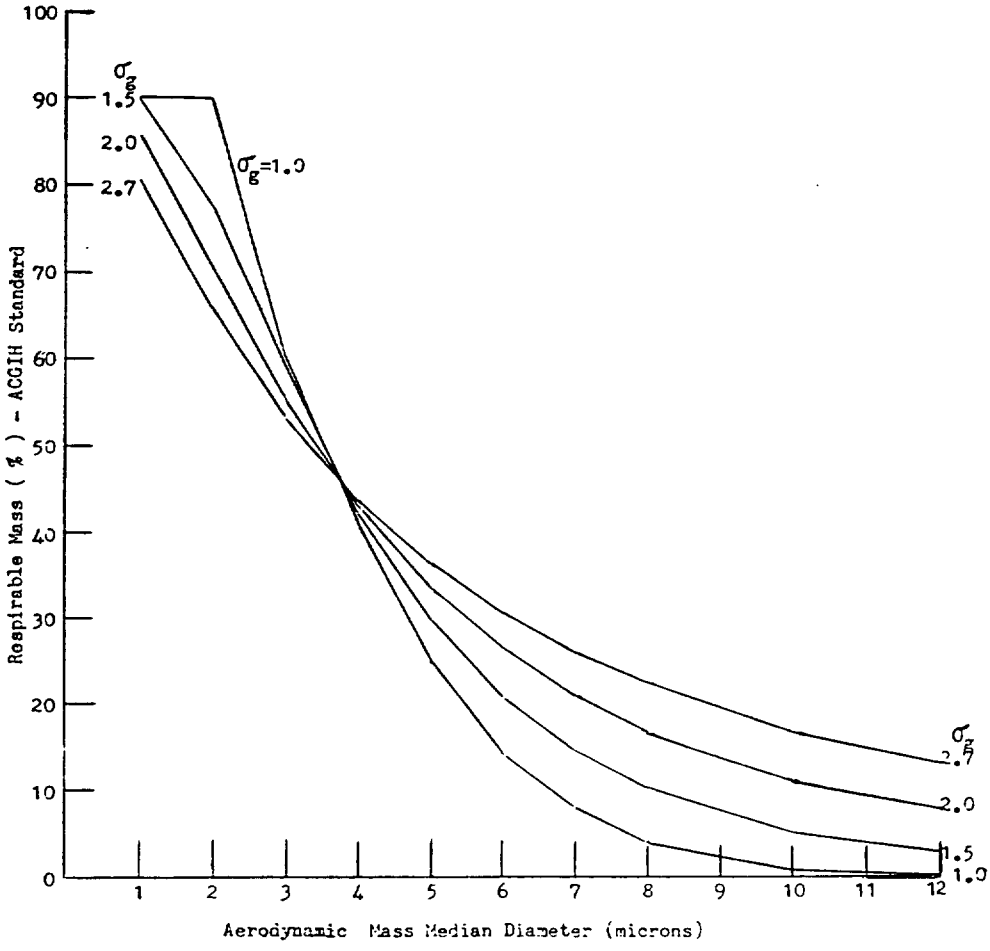

Fig. 14. Respirable mass—ACGIH standard—as a function of aerodynamic mass median diameter for polydisperse aerosols.(4)

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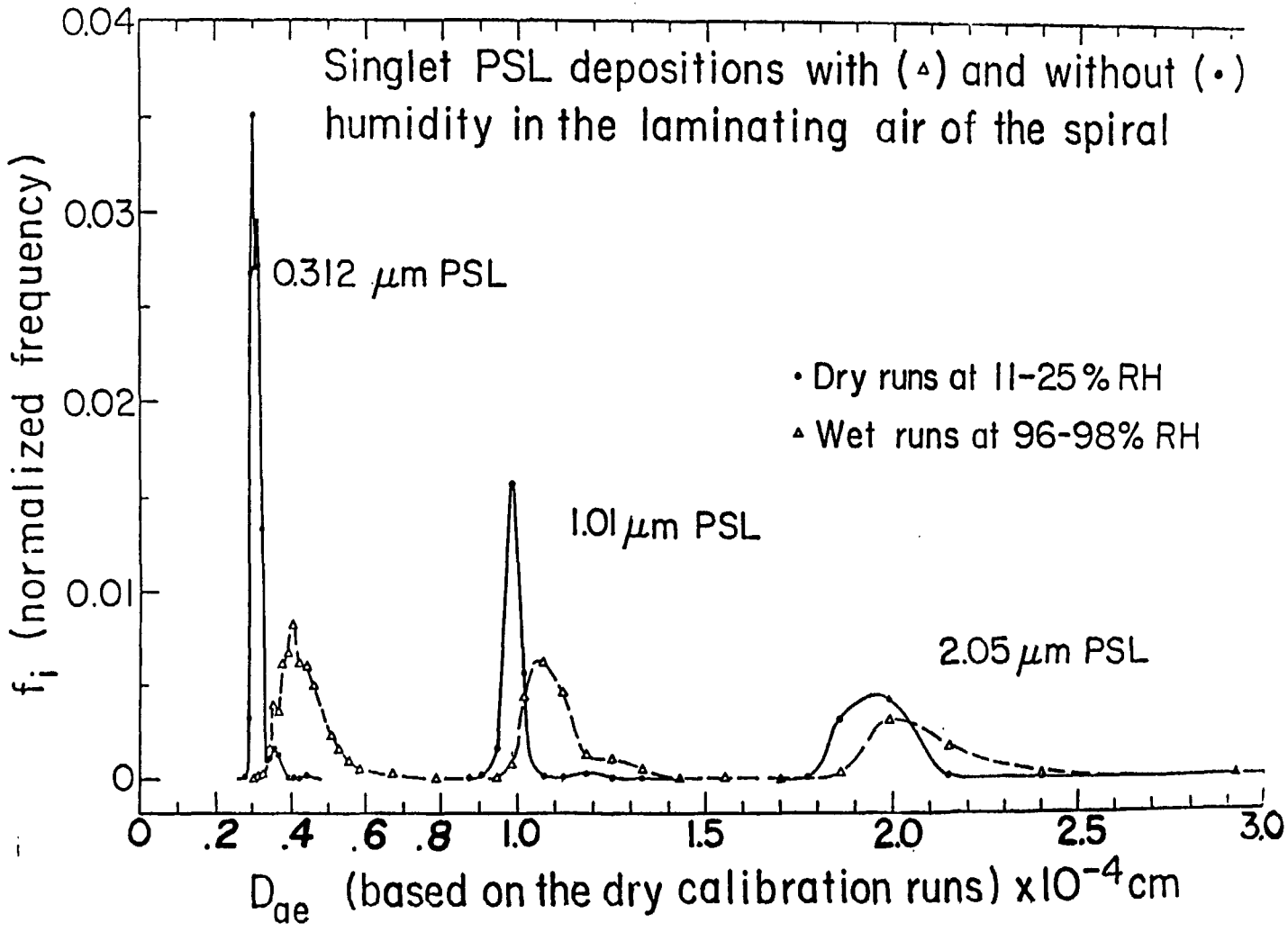
Singlet PSL depositions with (▵) and without (•) humidity in the laminating air of the spiral
0.312 μm PSL
1.01 μm PSL
2.05 μm PSL
• Dry runs at 11-25% RH
▵ Wet runs at 96-98% RH
f_i (normalized frequency)
0.04
0.03
0.02
0.01
0
0 .2 .4 .6 .8 1.0 1.5 2.0 2.5 3.0
D_{ae} (based on the dry calibration runs) x10^{-4}cm

FIGURE 15

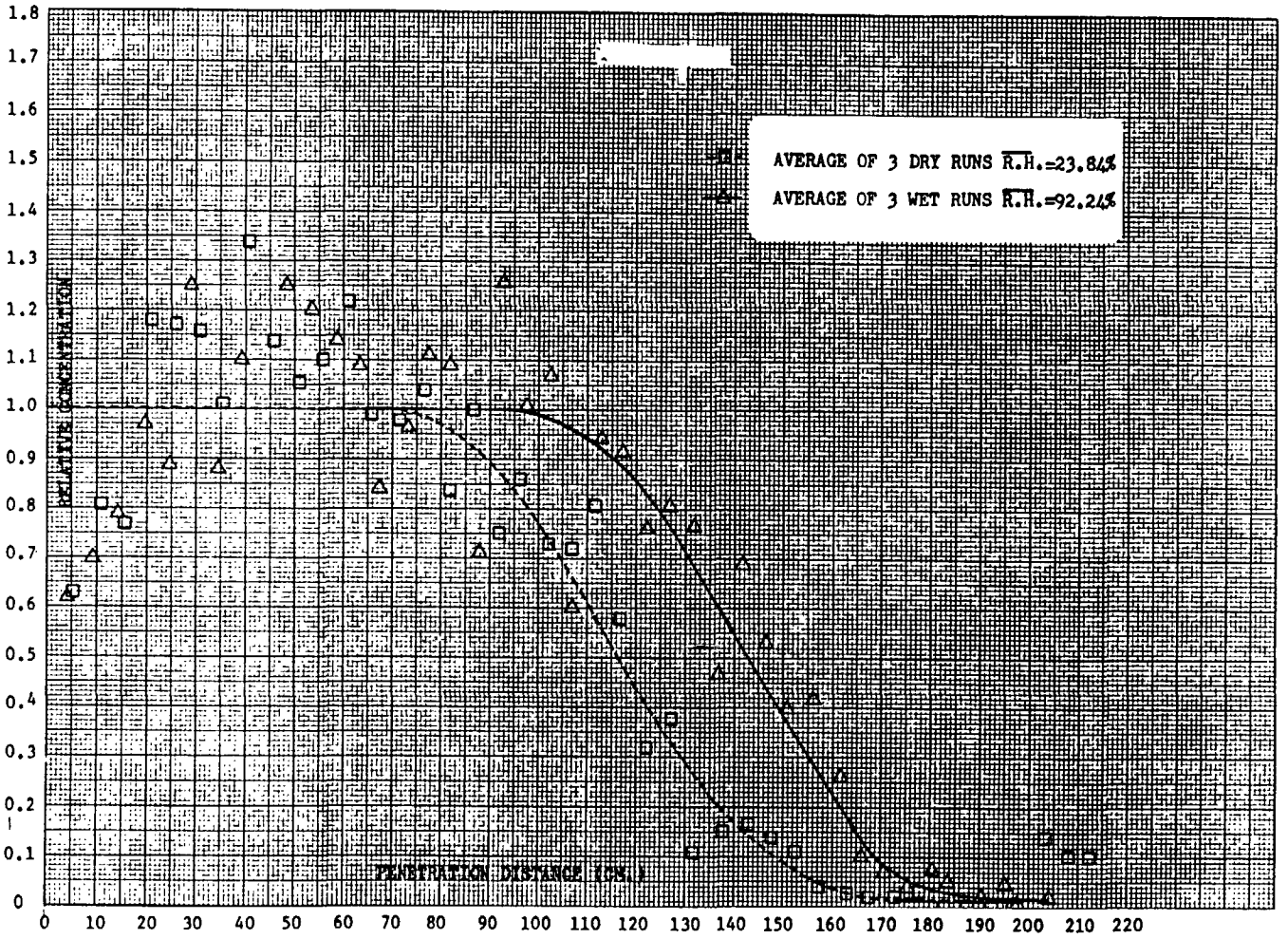

Fig. 16. Deposition of 1.0 Micron PSL along the Horizontal Elutriator

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APPENDIX

PREPARATION OF STANDARD ASBESTOS FILTER SAMPLES

September 1972

A. Materials and Apparatus

1. UICC Standard Reference Chrysotile 'B' - available on request from V. Timbrell, Pneumoconiosis Research Unit, Llandough Hospital, Penarth, Glamorgan CF6 1XW, England.

2. Aluminum Oxide (Al_2O_3) - 0.3 µm mean diameter. Commercially available in bulk form from Buehler Ltd, Evanston, Illinois.

3. Membrane Filters - Millipore AA, 25 mm diameter. (0.8 µm pore size) available from Millipore Corporation, Bedford, Mass.

4. Toluene - Mallinkrodt Analytical Grade.

5. Filter Holders w/Reservoirs - 25 mm, Gelman Instrument Co., Ann Arbor, Michigan, Cat. No. 1112. (A manifold arrangement with several filtration funnels attached makes multiple filtrations convenient. Fig. 1-2).

6. Ultrasonic Bath - Sonicor (SC 150) Sonicor Instrument Corp., Farmingdale, New York, 1-1/2 Gal. capacity, 150 watt output.

7. Syringe Pipettes - large bore (0.8 cm I.D.) graduated, capable of delivering 10 cc with rinse attachment (Fabricated in our local glass blowing facility. Fig. 3).

8. Bottles - reagent type, 2 liter capacity with polyethylene lined stoppers. Corning Pyrex.

B. Procedure

Prepare four dispersions containing UICC chrysotile 'B', each having different fiber concentration levels (0.2, 0.4, 0.6 and 0.8 µg chrysotile/cc) and one dispersion containing Al_2O_3 (3 to 8 µg/cc as desired) using analytical grade toluene as the dispersion medium. Weigh the desired quantities of UICC chrysotile 'B' ($\pm$ 0.01 mg) or Al_2O_3 ($\pm$ 0.01 mg) into a 2 liter container and dilute to a measured volume with toluene. Specific suspension fiber concentrations should be maintained within limits noted in this discussion. Thoroughly disperse each separate suspension by sonication and intermittent vigorous hand shaking. Repeat as necessary until the dispersions are uniform. The relative uniformity of each dispersion is checked by visual observation of Tyndall light scatter within the suspension. A uniform dispersion will appear to have a great many small fibers, with very few large fibrous clumps. Fifteen to twenty minutes of sonication is normally adequate when accompanied by intermittent vigorous hand shaking of said dispersions. Dispersions at these concentrations can be stored several months prior to use in preparation of filter standards.

When properly dispersed, the resultant suspension concentrations are:

Chrysotile 0.2 to 0.8 µg/cc (as prepared)

Al_2O_3 3 to 8 µg/cc (as prepared)

The filtration manifold is detailed schematically in Fig. 1. Photographs of the manifold, and large bore syringe pipette are shown in Figs. 2 and 3.

Shake chrysotile suspension to be filtered, then pipette ten (10) cc into the filter reservoir and filter in a controlled fashion (~ 0.4 - 0.6 cc/sec @ 5"-7" H_2O negative pressure - also see Fig. 1). Rinse the pipette with pure toluene into the filtration reservoir before the reservoir goes dry. (A clean solvent rinse is included in order to wash fibers adhering to the inner pipette walls into the filtration reservoir). Immediately, in sequence and before the filtration reservoir goes dry, pipette 10 cc of the Al_2O_3 dispersion into the funnel. Allow ~ 3/4 of the Al_2O_3 suspension to filter through the Millipore filter and again follow with a clean toluene rinse. Allow filtration to proceed at a slow, controlled rate (0.4 to 0.6 cc/sec) until the filter reservoir is void of liquid. Then

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pull room air (at 20-30 lpm) through the "wet" Millipore filter, to facilitate drying. The air dried, asbestos -Al_2O_3 loaded filter is then removed for counting and/or shipping.

As a practical aid to these procedures, the following details must be observed in order to insure successful operation of this dispersion-filtration technique:

1. Asbestos should be UICC Standard Reference Chrysotile 'B'.

2. Prepare separate stock dispersions (suspensions) for each fiber concentration level desired. As a basis for calculations, assume ten (10) cc as the volume to be filtered.

3. Dispersions must be dilute in order to prevent agglomeration. The chrysotile dispersions must not exceed 1.3 µg/cc toluene. Al_2O_3 dispersions (0.3 µm mean diameter) must not exceed 11.0 µg/cc toluene.

4. Two separate dispersions (Al_2O_3 and asbestos) for each series of "identical" filters must be prepared and these dispersions must be filtered in sequence; asbestos first, followed by Al_2O_3. One solution, containing both materials at the concentrations needed causes extensive fiber/particulate agglomeration and a predictable fiber deposit concentration becomes impossible.

5. Optimum fiber/particulate distribution on the membrane filter is obtained when filtration is limited to small dispersion volumes (20 cc maximum for each).

6. Dispersions must be subjected to sonication during preparation in order to break up loose fiber bundles and particulate agglomerates.

7. Dispersions must be agitated immediately prior to the filtration process. Vigorous intermittent hand shaking throughout a series filtration is adequate.

8. The vacuum filtration funnel (reservoir) must not be allowed to go dry between successive asbestos and Al_2O_3 filtration steps, or fibers already on the filter surface will be washed from their original site and be redeposited in a non-random fashion. Usually this "washing" phenomenon is observed as a concentrated ring deposit on the membrane near the inner walls of the filtration funnel.

Dispersions are not true solutions and must be treated as such. Dilute suspensions, good initial dispersion, intermittent vigorous hand shaking, controlled filtration, sequential application of fibers then particulates, and operator consistency will produce a predictable and controllable fibrous/particulate deposit.

Care and good judgment should be exercised if parameters described in this method are changed.

C. Typical Results

The following table is intended only as a guide for the preparation of loaded Millipore filters and was tabulated using actual samples prepared by the dispersion filtration technique. A moderate particulate background (Al_2O_3 ~ 400 x 10^2 grains/mm^2) was included on these filters using a dispersion concentration of 8 µg/cc.

Dispersion Conc. (UICC Chrysotile 'B') (µg/cc)	Volume Filtered Through 25mm Millipore Filter (cc)	Actual Fibrous Mass Filtered per Millipore (µg)	Fiber* Conc. Measured (Fibers/ mm^2)
0.2	10	2	724
0.4	10	4	966
0.6	10	6	1483
0.8	10	8	2172

*Average of 4 counters on same filter wedge. Phase contrast, 400X.

These typical data, based on the average of four (4) fibrous deposit levels (data from 4 counters each counting the same wedge obtained from two different filters sampled from a consecutive series of "identical" filters) indicate the following semi-quantitative relationship: For each microgram of UICC chrysotile 'B' filtered through a 25 mm membrane (as described above) one may expect ~ 250-350 fibers/mm^2. The higher value occurs at the lower fiber concentrations.

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This relationship is reported as approximate for several reasons: 1) Dispersions are not homogeneous solutions, 2) the particulate background influences the fiber count (i.e. higher particulate densities on the membrane surface tend to mask small fibers and hence lowers the fiber count), and 3) variations are introduced by microscopic techniques and optics used for counting fibers.

Considering that the fibrous deposit is of primary interest, the particulate (Al_2O_3) deposit may be adjusted as desired. Extremely high particulate deposits (on the order of 600 x 10^2 grains/mm^2) should be avoided for the reason previously noted.

The dictated procedure, when followed in a careful and consistent manner, is capable of producing predictable and controllable fibrous/particulate deposits on a membrane surface.

D. Safety Precautions

The inherent hazard associated with human exposure to microscopic asbestos fibers is well documented. Extreme care should be exercised in the handling of liquid asbestos dispersions as well as the dry, milled material. Dispersion preparation (sonication included), filtration and membrane packaging operations should all be carried out in a well ventilated chemical fume hood. Toluene - a flammable and volatile organic solvent - should likewise be accorded similar treatment.

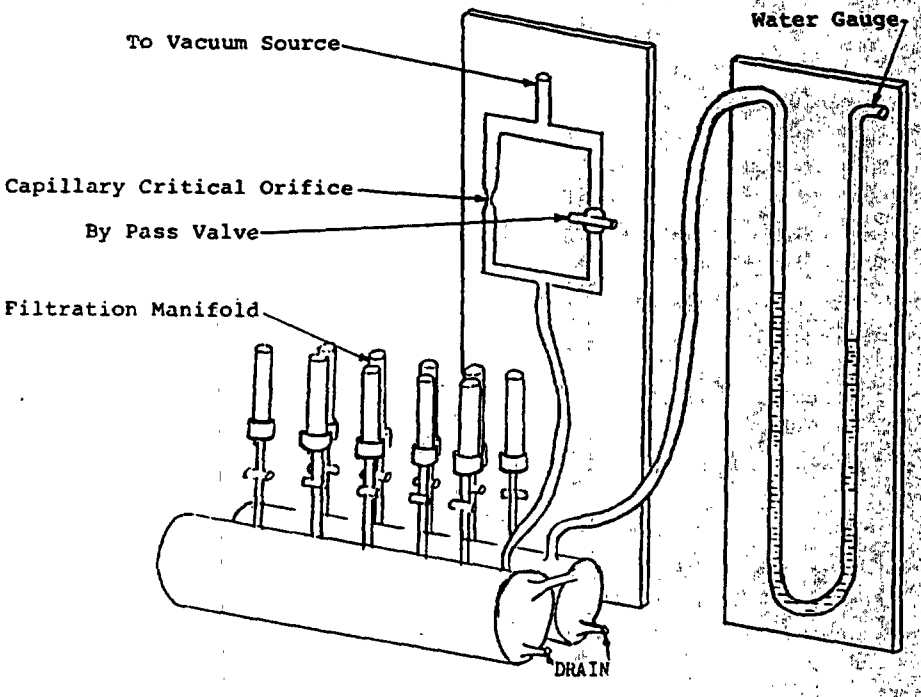

Fig. 1. A small capillary connected in series between the vacuum source and the filtration manifold is used as a critical orifice to help control the filtration rate. A valve bypass allows one to conveniently pull sufficient air through the wet membrane to aid in drying.

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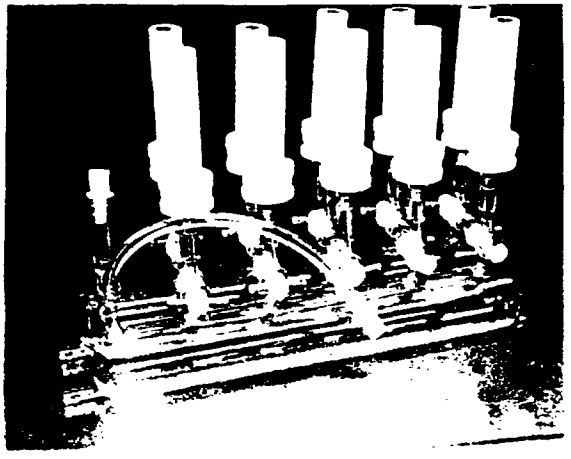

Fig. 2. Filtration manifold.

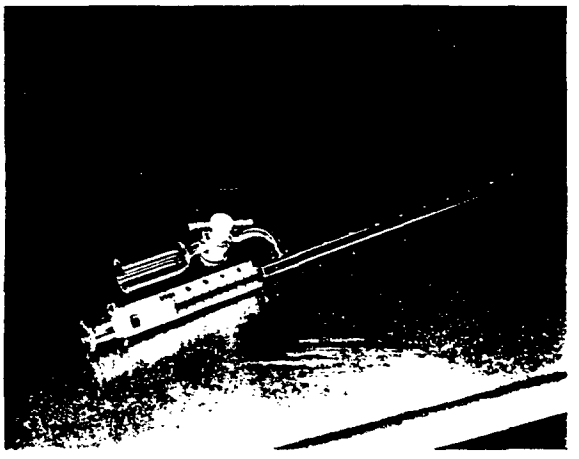

Fig. 3. Large bore syringe pipette with rinse reservoir attachment.