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WASH-170(Dcl.)

RADIOACTIVE WASTE

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UNITED STATES ATOMIC ENERGY COMMISSION

THIRD ATOMIC ENERGY COMMISSION AIR CLEANING CONFERENCE HELD AT LOS ALAMOS SCIENTIFIC LABORATORY, SEPTEMBER 21, 22, AND 23, 1953

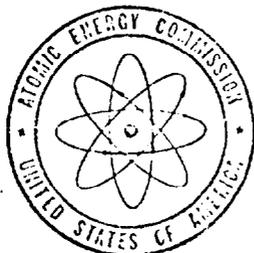
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PREFACE

Third AEC Air Cleaning Conference

Sponsored by
Division of Engineering AEC Washington

Held At
Los Alamos Scientific Laboratory

September 21, 22, 23, 1953

The following compilation of papers represents the proceedings of the third air cleaning seminar. The first was held in June 1951 at the Harvard University Air Cleaning Laboratory and the second at Ames Laboratory in September 1952. The proceedings of the latter conference were published as WASH-149.

These seminars are an important part of a continuing program to assist in the solution of air cleaning problems encountered in AEC operations, and to develop improved and more economical air cleaning systems to meet AEC requirements. The purposes of these conferences include the review of operating performance of existing facilities and the presentation of fundamental information obtained from basic studies of aerosol behavior. The list of titles gives a better indication of the scope of the program.

The Stack Gas Problem Working Group under the Chairmanship of Dr. Abel Wolman held its meeting simultaneously with the conference. Their contributions added materially to the success of the conference.

Much was also contributed to the success of this meeting by the Los Alamos Scientific Laboratory under Dr. Norris E. Bradbury, Director. Their hospitality and assistance is gratefully acknowledged.

TABLE OF CONTENTS

Page

Preface 6

Los Alamos Air Cleaning Activities, by J. B. Graham, IASL 7

The Los Alamos Incinerator, by H. F. Schulte, IASL 11

Ventilation and Air Cleaning Facilities for Normal Uranium Fabrication, by W. H. Baumann, C&CCC, Y-12 13

The Handling of Radioactive-Contaminated Air at ORNL, by W. G. Stockdale, C&CCC, ORNL 21

Hanford Air Cleaning Operations, by A. G. Blasewitz, GE, HAPO 40

Air Cleaning Activities at ANL, by D. P. O'Neil, ANL 48

Ventilation Activities and Programs at ANL, by R. W. Van Valzah, ANL 55

The Argonne Incinerator Program, by W. A. Rodger, and D. C. Hampson, ANL 58

Air Cleaning Problems at NRTS, by A. L. Biladeau, AEC, IOO 63

Operating Economics of Air Cleaning Equipment Utilizing the Reverse Jet Principle, by W. B. Harris, AEC, & M. G. Mason, Mallinckrodt Chem. Co. 68

Ventilation and Dust Control in Refining Uranium Ores and Concentrates, by H. I. Miller, Jr., Catalytic Construction Co. 79

Tests of the Aero-dyne Dust Collector, by W. H. Smith, GE, ANPP 87

Brief Summary of Air Cleaning Program at WAPD, by E. C. Barnes 99

Tower Observations of Atmospheric Dust at NRTS, by P. A. Humphrey, E. M. Wilkins and D. M. Morgan, USWB, IOO 102

KAPL Air Cleaning Program, by L. J. Cherubin and J. J. Fitzgerald, GE, KAPL 118

Brookhaven Air Cleaning Operations, by Leo Gemmoll, BNL 142

Mound Laboratory Air Cleaning Operations, J. E. Bradley and J. A. Rueth, Monsanto 146

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DECLASSIFIED

TABLE OF CONTENTS (Continued)

| | <u>Page</u> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| Air Cleaning Problems at the Savannah River Plant, by J. R. Clark, Du Pont | 155- |
| Ventilation and Air Filtration at the Rocky Flats AEC Plant, by R. J. Walker, Dow Chemical Co. | 161 — |
| Air Handling Facilities at the Ames Laboratory, by R. W. Fisher, Ames | 165 |
| Site and Contractor Activities and Programs U. C. Radiation Laboratory, by M. D. Thaxter, UCRL | 170 |
| Air Cleaning Program at the Livermore Research Laboratory, by G. T. Saunders, CR&D | 185 |
| Meteorological Aspects of Air Cleaning, by P. A. Humphrey and E. M. Wilkins, USWB, IOO | 191 |
| Fibrous Aerosol Filters, by C. E. Lapple, Chemical Engineering Department, The Ohio State University, Columbus, Ohio | 205 |
| Air Cleaning-New Developments at UCRL, by M. D. Thaxter, UCRL | 218 |
| A Constant Volume Radiochemical Hood, by G. T. Saunders, CR&D | 222 |
| Filtration of Microorganisms from Air by Glass Fiber Paper Filters, by H. M. Decker, J. B. Harstad, F. J. Piper, Chemical Corps, U. S. Army, Washington 25, D. C., and Myrl E. Wilson, 2nd Lt., USAF | 227 |
| Further Studies on Electrostatic Separation, by A. T. Rossano, USPHS, Harvard | 235 |
| Further Studies of Fabric Dust Collectors, by C. E. Billings, R. Dennis and L. Silverman, Harvard | 251 |
| Performance Characteristics of the Model K Electro-Polar Filter - Preliminary Report, by R. Dennis, C. E. Billings, and L. Silverman, Harvard | 262 |
| Preliminary Report on Cotton Aerosol Filter Studies, by R. D. Coleman, USPHS, Harvard | 272 |
| Incineration of Combustible Wastes Using Tangential Overfire Air, by L. A. Spano, R. C. Corey, U. S. Bureau of Mines | 281 |
| Properties of Various Filtering Media for Atmospheric Dust Sampling, by W. J. Smith, N. F. Surprenant, A. D. Little, Inc. | 305 |

TABLE OF CONTENTS (Continued)

| | <u>Page</u> |
|-----------------------------------------------------------------------------------------------------------------------|-------------|
| Survey of Air Sampling Media and Sampling Methods Used at AEC Areas and by Others, by W. J. Smith, A. D. Little, Inc. | 330 |
| Evaluation of KAPL Separations Process Stack Effluent, by J. J. Fitzgerald, GE, KAPL | 334 |
| Aerosol Investigations - University of Illinois, by H. F. Johnstone, Technical Director, Contract AT(30-3)-28 | 349 |
| a. Foreword | 349 |
| b. Turbulent Deposition and the Behavior of Deposits of Solid Particles, by S. K. Friedlander | 351 |
| c. Collection of Aerosols by Fiber Mats, by J. B. Wong | 356 |
| d. Filtration of Submicron Size Aerosols by Fibrous Media, by C. Y. Chen | 366 |
| e. Influences of Electrostatic Forces on the Deposition of Aerosols, by H. F. Kraemer | 374 |
| Author Index | 384 |
| Subject Index | 385 |

LOS ALAMOS AIR CLEANING ACTIVITIES

J. B. Graham
CMR Division
Los Alamos Scientific Laboratory

Because of the brief time allotted for these remarks, I feel that it would be unrealistic to go into detail on some one arbitrarily selected piece of work here at Los Alamos. Instead, I will give you a brief explanation of the organization here, the type of work being done by the various parts of the organization and the names of people involved in each type of work. In this way it is hoped that from this information, you will follow up your own special interests. Only the host installation finds itself in this fortunate position so we hope you take this opportunity to meet our people and inspect our facilities.

There are three major organizations at Los Alamos. The Atomic Energy Commission staff is, of course, responsible for overall operation of the Los Alamos project. The University of California is responsible for the operation of the Los Alamos Scientific Laboratory, and the Zia Company is the maintenance contractor for both townsite and laboratory.

Of interest to this seminar, the Atomic Energy Commission operates the Waste Disposal Laboratory at Los Alamos. This Industrial Waste Section of the Health and Safety Branch is under the direction of Mr. C. W. Christenson, who is inactive at present due to illness, and his work is being carried on by Everett Matthews. This section, with a staff of 16 people, operates three waste treatment laboratories on a combination routine and pilot plant basis. These plants handle all industrial and radioactive waste from the main technical areas at Los Alamos on a routine basis but at the same time are carrying out a research and development program on the coprecipitation of Pu by ferric hydroxide and aluminum hydroxide.

In addition to the above this Section carries out a research and development program which may be best explained by listing some of their recent work.

1. Radiation tolerance of activated sludge. This was done on a laboratory scale using cobalt sources on activated sludge. The work is complete and will be published.
2. Removal of P32 and ^{131}I by use of trickling filters. Work is complete.
3. Removal of mixed fission products by a trickling filter.
4. Removal of TNT, RDX and Ba salts by a precipitation of the Ba as BaSO_4 and adsorption of the TNT and RDX on activated carbon.
5. Movement of Pu thru soil and rock surrounding waste seepage pits. This work is in progress.
6. Treatment of radioactive laundry wastes by activated sludge process.
7. Concentration of Pu in industrial waste effluent by various algae.

Within the framework of the University of California organization at Los Alamos, there are several groups doing work of interest to this seminar.

In the Health Division, Group H-5, under the direction of Harry Schulte, is responsible for the Industrial Hygiene activities in the Laboratory. Mr. Schulte's group of 19 people concerns itself with all health problems involving non-radioactive materials but the work of this group is of interest here because of their experience in air sampling techniques and their experience in the evaluation of various hazards. This group is involved in one way or another with most stack gas problems at Los Alamos. This group acts in an advisory capacity on air sampling techniques to the Monitoring Group, H-1, which is under the direction of Mr. Dean Meyer.

Some recent work of Mr. Schulte's Group has been:

1. Development of certain phases of the Los Alamos incinerator. Mr. Schulte will have more to say about this in a few minutes.
2. Industrial hygiene in the Be shop. This included protection of the workers, adequate cleaning of the exhaust air and a particle size study from the particular machine operations involved.
3. Development and modification of air sampling equipment for special jobs.
4. Surveys for radioactive and non-radioactive hazards outside the Technical Areas to protect the community and the surrounding areas. As a result of this work, this Group has done a great deal of the air sampling and evaluation work in connection with the Nevada tests.

In the University of California Engineering Department, Mr. Charles Wherritt heads the Mechanical Design activities of Group ENG-2. As a part of their work, this group designs ventilation and filtration systems throughout the project. Since the main function of the Los Alamos Scientific Laboratory is research, the work of this Group must follow the research program and, as a result, is very wide in scope and is ever changing.

Recent work of Mr. Wherritt's Section includes:

1. Improvement of the air filtration system at the Graphite Shop. This was done by using a cyclone filter followed by a Hersey filter.
2. A 25 ton air conditioning system for the 701 calculator.
3. Equipment to maintain a flow of -70° F dew point air thru a process unit.

A Division of the Los Alamos Scientific Laboratory, the Chemistry and Metallurgy Research Division concerns itself almost exclusively to research and production work involving radioactive materials. Because of the special

problems in this work, the Chemistry and Metallurgy Division has people on its staff doing work of interest to this seminar.

In the CMR-10 Group of this Division, work done on the capillary air washer by Hammond and Leary is being carried on by Mr. Robert Clark of that Group. Mr. C. S. Leopold, a consulting engineer of Philadelphia, is also taking an active part in this work. This work which has extended over a period of several years has been centered around the research and development of the so-called "capillary air washer." This air cleaning device consists of a conventional capillary washer section followed by a dry pad section. The capillary washer sections are made up of 8" thick pads of 250 μ glass fibers. The first stage of the washer section is countercurrent flow while the second stage is concurrent flow. The dry pad following this washer section is made up of 1 $\frac{1}{2}$ " of 100 μ glass fibers followed by $\frac{1}{2}$ " of 10 μ glass fibers.

The above arrangement is followed by a second section consisting of one concurrent capillary cell stage followed by a dry pad.

Work has been done involving the variables, velocity, particle density and size, filter media density, water rates, etc. Also as a part of this work, a rather extensive program was carried out on sampling techniques and aerosol generation.

Work has been going on at other installations along similar lines and Mr. Clark will be happy to discuss the work and facilities here with any interested persons.

Also in the Chemistry and Metallurgy Division, CMR Engineering under my direction is responsible for the design of ventilation and filtration systems for this Division. Since CMR Engineering includes a mechanical equipment design section the work is usually a combination of equipment design, ventilation and filtration. This section develops special hoods and dry boxes for the Division as well as special ventilation and filtration systems. The ventilation systems worked on by this Group range from complete building systems of 600,000 cfm to single enclosures of 30 cfm.

I believe it is evident in work of this kind at a research laboratory that there is no one type of filter that answers all problems and it is the responsibility of this group to apply the proper filter for the particular job in CMR Division.

This section has developed an interchangeable dry box system that is now available commercially.

They have recently been concerned with the ventilation of laboratories handling very light gases.

In general, you will find that the approach to the filtration problem has been as follows:

1. Production areas. The supply air is filtered thru commercial filters and in addition, that portion of the supply air entering dry box trains is again filtered thru CWS type filters or the variable density type edge filters. The exhaust from these areas is filtered as close to the box as possible then passed thru back up filters before discharge to atmosphere.
2. Research areas. Due to changing conditions, it is usually not feasible to filter locally so all air from these areas is passed thru a main filter system. In two of our largest installations, capillary washer systems as described previously are used.

This is a brief explanation of the work at Los Alamos which may be of interest to you and an introduction to the people involved in that work. We hope you take advantage of your visit here to investigate matters of special interest to you.

THE LOS ALAMOS INCINERATOR

By H. F. Schulte, IASL

The Los Alamos incinerator has been discussed at Air Cleaning Seminars but the progress during the past year justifies its discussion again. Last Fall tests of combustion efficiency were made by Richard Corey and his associates of the Bureau of Mines and recommendations were made for changes to improve this efficiency. After making most of the changes, good combustion efficiency was obtained. Limited testing of the air cleaning system at the same time indicated that its performance was generally as designed.

After a winter shut down, the whole unit was overhauled in the Spring. After noting the bad condition of the fiberglass filters, it was decided not to replace them during the following test period. A series of test runs were made on the whole system during the summer using uncontaminated trash to which measured amounts of radio-barium-lanthanum had been added. Considerable difficulty had been experienced previously in sampling because of the high temperature and water content of the gases. Sampling of the hot gases was accomplished using two large impingers in series immersed in an ice bath. The water from the impingers was evaporated, plated and beta activity counted. For sampling at the outlet stack a water separator and reheater followed by a glass paper filter was used. The paper was counted directly. The water from the separator was evaporated, plated and counted but was found to contain very little activity. A water content of approximately 1 ml/cu.ft. of stack air was found. Efficiencies on a radioactive basis were as follows:

| | <u>Average</u> | <u>Maximum</u> |
|------------------------------|----------------|----------------|
| Cyclone (dry) | 70% | 94% |
| Cyclone (wet) | 82 | 89 |
| Venturi Scrubber | 94 | 97 |
| Overall (Cyclone & Scrubber) | 97 | 99.8 |

The average percentage of the radioactivity charged into the incinerator which reached the stack was approximately 0.3% or a decontamination factor of 300. The above figures for the wet cyclone were obtained using a spray system which had been installed for cleaning down the cyclone walls.

Temperatures during the runs were as follows:

| | |
|---------------------|---------|
| Incinerator outlet | 1200 °F |
| Spray Cooler outlet | 540 °F |
| Separator outlet | 125 °F |
| Stack | 90 °F |

These temperatures were unaffected by the addition of water in the cyclone.

As a result of experience with the incinerator it seemed likely that difficulty would be experienced in keeping down contamination during charging and ash removal. After a visit to Argonne National Laboratory, the following changes were recommended and are now being completed:

1. Continuous instead of batch charging
2. Collection of ashes in a sealed drum instead of pumping into a tank with water
3. Provision for by-passing the glass filters during normal runs and quickly changing to filtration if necessary
4. Installation of a medium pressure water spray system in the inlet of the cyclone

With these changes it should be possible to obtain a decontamination factor of 300 to 500 which is sufficient for the type of combustible now being buried.

Ventilation and Air Cleaning Facilities
For Normal Uranium Fabrication

By W. H. Baumann, C&CCC, Y-12

The fabrication of uranium necessitates rigid dust control procedures and effective air cleaning equipment to minimize the inhalation hazard both inside and outside the workroom areas. The effectiveness of control is evaluated through air analysis which in turn is correlated with urinalysis and integrated with a medical control program.

The level of air contamination reached high proportions in the early part of 1951 in the normal uranium processing areas which include the foundry and machining operations. The latter was moved into enlarged facilities and it was felt that hooding and exhaust ventilation were needed if widespread contamination was to be avoided.

After a preliminary study of diversified machining operations, it was decided that the polishing operation was the most dusty. Two hoods were installed and a substantial reduction in air contamination at the breathing zone of the machinist was noted.

In the design of the facilities, the contractor provided exhaust outlets, piping, and exhausters. Also air cleaning was apparent if operations were hooded since the uranium dust would concentrate in the effluent air and might constitute an air pollution problem. Fibrous filters were incorporated in the hoods in an effort to capture the dust as close to the source as possible. Both hand packed bronze fibrous filters and commercial glass fiber filters were tested and it was found that the former was inefficient as a particle collector whereas the latter deteriorated quickly under the high filtering velocity. Another objectionable feature of filters of this type is the buildup in resistance with loading with a diminution in the air flow rate thus reducing the performance of the hood. At this time, a central dust collecting system was considered, and a reversible jet bag type unit which handles dust from machining operations as well as foundry operations was chosen.

Since all machines were to be hooded, two standard hood designs were selected which were acceptable to production and were effective in abating dust.

SECRET

(3) Spreading operations over a larger area

large chips were found which could readily settle in the ducts thereby

(4) Minimizing and partial mechanization of polishing constituting a potential fire hazard. A chip trap or inertial type collector

(5) Reduction in time required to machine parts was installed as near as possible to the hood outlet, and two small lathes,

(6) Production

on which identical work was done, were selected for testing. Uranium

Several hoods were installed on large and small lathes, and dust loading was higher without the trap, and chip clusters, were found on the

samples were taken in the branch ducts to measure the dust. The probe tube of the sampler in the duct. The efficiency of the chip trap is

about 65% on a weight basis (amount collected was over 200 grams of

uranium over 400 hours of operation (not machine time), and the unit has

pressure drop of 2" Water Gage when handling 400 cfm. The unit collects

considerable coolant mist which is returned to the machine. Also the

device is readily demountable for cleaning at inventory time.

Air-borne contamination was not as great a problem in the foundry

area as the machining area. The trend is downward in the general level of

air contamination beginning with the latter part of 1951 to present. Factors

responsible for the reduction in air-borne uranium are:

- (1) Improvement in techniques (handling of material)

- (2) Better housekeeping
- (3) Renovation and improvement of existing source
ventilation
- (4) New equipment
- (5) Production

Exhaust air ventilation from the hoods in the foundry were cleaned by AAF Multiduty units. These units discharge at roof level and constitute a potential hazard since air intakes are near. On several occasions, the units were without oil, and considerable quantities of uranium were discharged on the roof. The units required considerable maintenance and the cleaning operation, once monthly for inventory purpose, was very messy. Dust loadings were light and averaged about 5 gr/1000 ft³.

The AAF units will be dismantled and all dust laden ventilation air will be passed through bag filters (self cleaning type). The outlet from each exhauster (27 units in all) which handles contaminated air from a given number of operations will discharge into a piping network proportioned to

handle air at a velocity of 3000 fpm. The air from the main will split into two streams (150,000 cfm) and each portion distributed through a filter house containing 64 wool felt bags (white virgin wool, 26 oz., by American Felt Co.) 18" in diameter and 19' high with a filtering velocity of 30 cfm/sq. ft. bag surface. A 150,000 cfm (300 HP) exhauster will handle air from each bag filter at a negative pressure of 7" WG, and both units will discharge into a 25-ft stack.

A bypass damper is installed in the system to insure a negative pressure of about 2" WG in the main duct work. In the event that the exhauster fails and a positive pressure is built up in the system, the bypass damper will open and an audible alarm activated.

The dust collectors cost \$58,000 and bags (non-treated with adjustable blow rings) about \$15,000. Total cost of the system is \$1.00 per cfm. (Interior of duct work has a prime coat and enameled). The system is still under construction and should be completed by November 1.

We hope to get some information on the performance of the system

when it is put into operation. This system should complete ventilation, air cleaning and hooding at normal uranium operations.

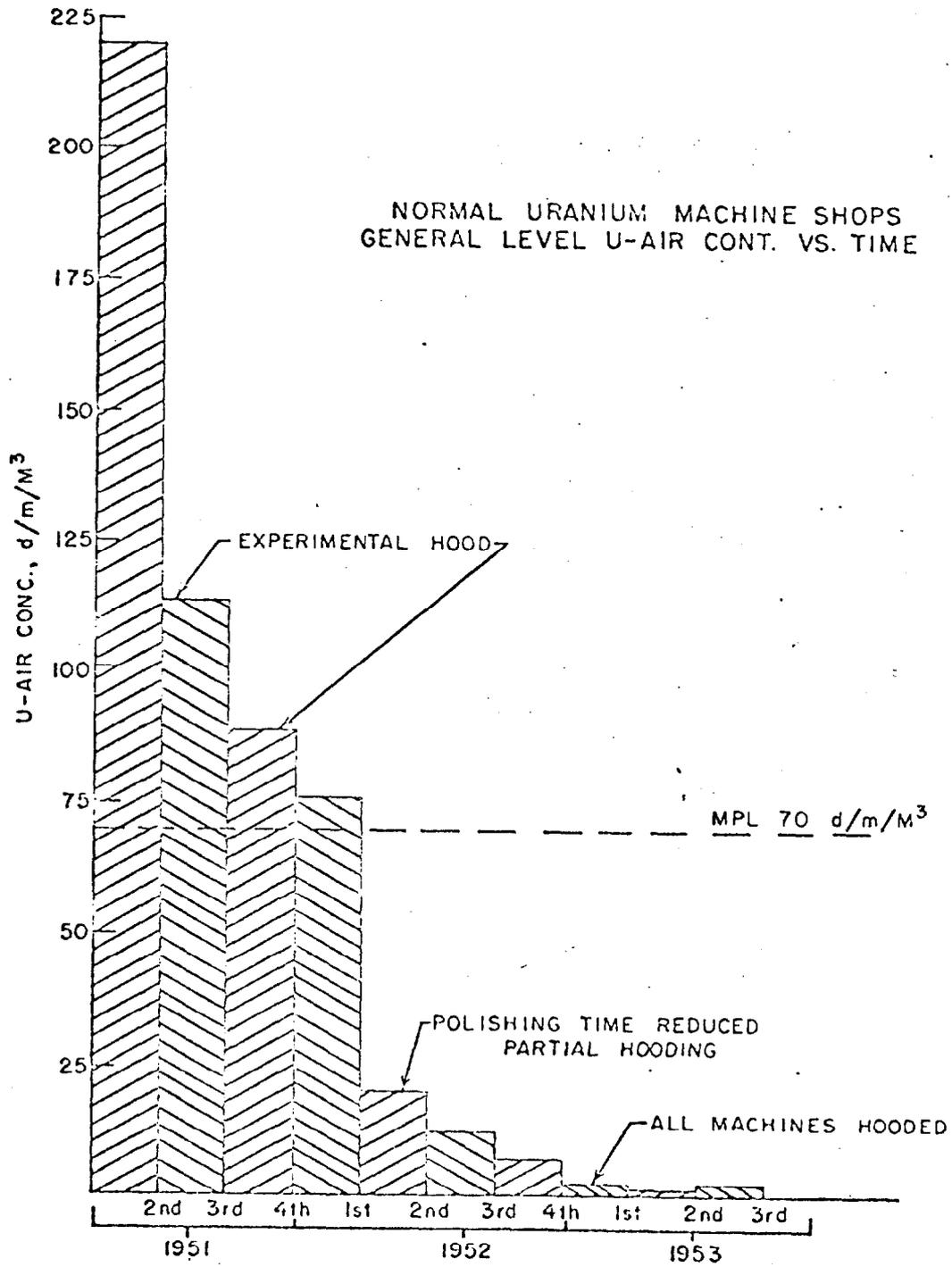


Fig. 1

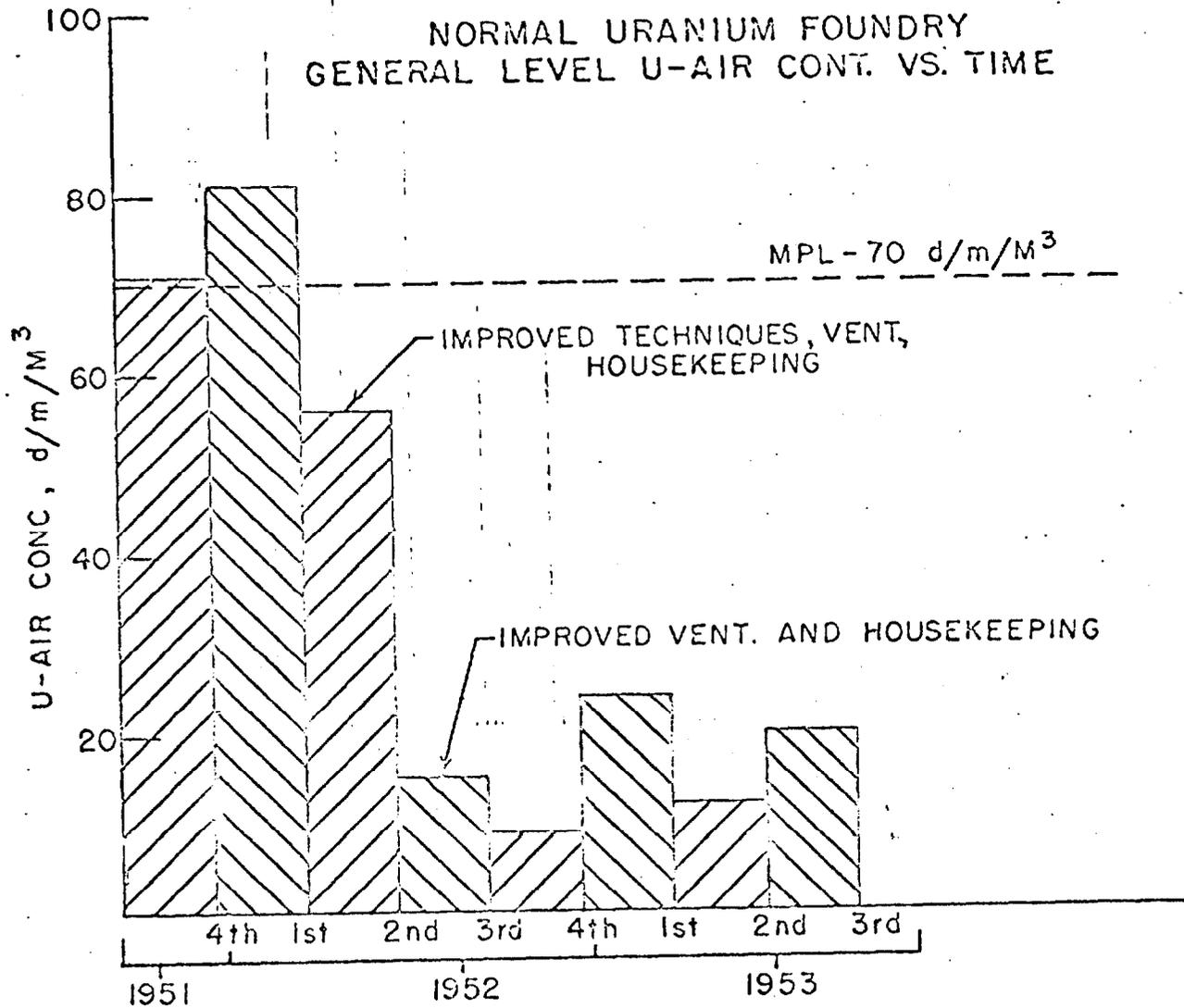


Fig. 2

THE HANDLING OF RADIOACTIVE-CONTAMINATED AIR
AT OAK RIDGE NATIONAL LABORATORY*

By W. G. Stockdale, C&CCC, ORNL

1. Introduction

Air contaminated with radioisotopes constitutes the greatest volume of radioactive waste created by the operation of nuclear reactors and associated chemical processes. It is part of the most costly single item in a modern radiochemical process - Waste Disposal.

Waste disposal accounted for 20 per cent of the total construction budget of a recently constructed radiochemical plant. This 20 per cent exceeds the total amount of estimated capital expenditure (E. P. Wigner and Associates) that can be allowed for a fuel recovery plant in connection with a power reactor if the reactor is to compare favorably with the present methods for producing power. This clearly indicates the importance of proper and economical disposal of radioactive waste and the importance that should be attached to it in design.

This presentation is to discuss the systems in use at Oak Ridge National Laboratory for decontamination of radioactive-contaminated air and its final disposal.

In 1948, at the start of the present air-cleaning program at Oak Ridge National Laboratory, the major source of the particulate contamination in the air was expected to be the air-cooled nuclear reactor, and work was immediately initiated on the design of a system for cleaning this air. At the same time, a survey was undertaken to evaluate the contribution of all the potential sources in the Laboratory to this problem of particulate contamination. The results

* Paper presented at Air Cleaning Conference and Stack Gas Working Group Meeting, September 21-23, 1953, Los Alamos, New Mexico.

of this study indicated that the large-scale chemical processing units at the Laboratory contributed more to the general area contamination than did the operation of the nuclear reactor. In addition, it was found that the amount of radioactivity contributed to the general atmospheric contamination from Laboratory hoods was relatively insignificant.

2. Air-Cleaning Facilities for ORNL Graphite Reactor

As a result of a literature search and consultation with companies concerned with problems of cleaning air, filtration was selected as the procedure to be used for cleaning the air from the nuclear reactor. Among the other techniques that were considered for this application were cyclone separators and electrostatic precipitators.

The ORNL graphite reactor filter house was designed to filter 120,000 cfm of air at a temperature of 215°F and a negative pressure of 50 inches water gage. The expected dust load was less than 900 grams per day of particles with a maximum diameter of 600 microns, a large number of them being in the submicron range. The designed efficiency of this house was 99.9 per cent or better for particles down to 0.1 micron in size.

To remove much of the estimated atmospheric dust load of 0.3 grain per 1000 cubic feet (280 grams per day), the cooling air is filtered before it enters the pile with American Air Filter Company Airmat Type PL-24 filter units loaded with 3/32-inch type G Airmat filter medium.

The filter house is a large reinforced concrete structure composed of four identical cells, each containing a roughing filter and a polishing filter. The capital investment was of the order of \$400,000. This is estimated to be approximately 25 per cent above normal costs owing to the crash program of two 10-hour shifts during construction, which was warranted because of the

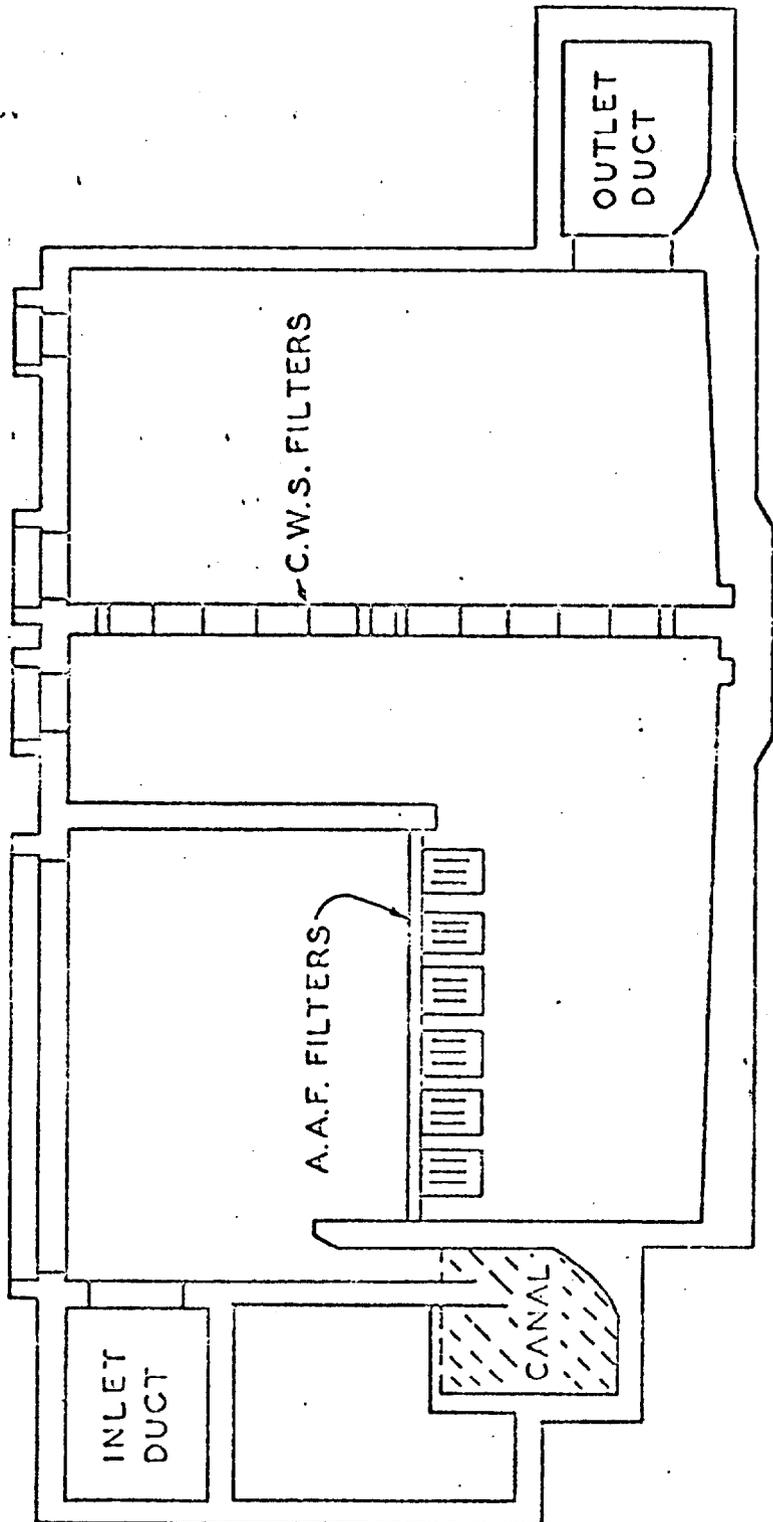


FIGURE 1

PILE FILTER HOUSE

serious atmospheric contamination at that time. A cross section of the filter house is shown in Fig. 1.

The air enters the top of the filter house, passes downward through the roughing filter, then horizontally through the polishing filter into the exit air duct. A canal located across the front of the filter house provides a water seal between the roughing filter area and the atmosphere and is a safe receptacle for the dust-laden filters when the filter medium is being renewed.

Precautions are taken to seal all filters in place in structural steel frames to ensure against leaks and bypassing of the filters. All access to the filters is through removable roof slabs which provide a method for remote maintenance.

The roughing filters are standard A.A.F. Co. deep-pocket filters, each pocket containing two layers of filter medium - first a 1/2-inch layer of FG-25 and then a 1/2-inch layer of FG-50. The polishing or finishing filters are CWS No. 6 or AEC No. 1 units 2 feet by 2 feet by 11-1/2 inches in plywood frames.

Maintenance of the filter house is practically nonexistent except for the periodic renewal of the filter medium. The average life of the roughing filters is two years and of the polishing filters two and one-half years.

The roughing filters are changed one cell at a time at approximately six-month intervals when the pressure drop across the filter house approaches or exceeds 8 inches water gage. The filters are washed down, removed, and stored in the canal. The medium is removed from the pockets and buried, and the pockets are reloaded for the next change.

The polishing filters are all changed at the same time when the pressure drop across them reaches or approaches 5 inches water gage. Both sides of these are sprayed with strip coating before they are removed from the building for burial. The manpower required for changing filters is as follows: (1)

Roughing Filters⁽¹⁾

| | <u>Man-days per Coll</u> |
|--------------------------------------|--------------------------|
| Loading and gasketing filter pockets | |
| Millwrights | 6 |
| Laborers | 2 |
| Changing filters | |
| Operation | 4 |
| Riggers | 2 |
| Utility mechanics | 1 |
| Health physics surveyors | 1 |
| Unloading and cleaning pockets | |
| Operators | 10 |
| | <hr/> |
| Total | 26 |

Polishing Filters

| | |
|-----------------------------------|-------|
| Manufacture and loading of frames | |
| Carpenters | 10 |
| Changing filters | |
| Riggers | 10 |
| Painters | 3 |
| Truck drivers | 2 |
| Health physics surveyors | 2 |
| | <hr/> |
| Total | 27 |

The cost of operation of the filter house is low except during filter changes. Normal operation of the house requires less than 1 manhour per day. The following is a breakdown of the cost of a complete filter change:⁽¹⁾

Roughing filters

Material \$ 3,800

Labor and Equipment 3,400

Subtotal \$ 7,200 \$ 7,200

Polishing filters

Material \$10,000

Labor and Equipment 4,500

Subtotal \$14,500 \$14,500

Total \$21,700

With one roughing filter change every two years and one polishing filter change every two and one-half years, the annual maintenance cost would be \$9,400.

(1) Data taken from letter to W. R. Page, BNL, May 21, 1952 by J. A. Cox, CRNL.

3. Air Cleaning Facilities for Laboratories and Chemical Plants

During the recent construction program at Oak Ridge National Laboratory to replace temporary facilities, it was necessary to develop new basic procedures for the ventilation of the working areas and the control of radioactive contamination in air. It was proposed to reduce to a minimum the amount of air that is certain to or has a possibility of becoming contaminated, and to classify radioactive contaminated air according to the degree of contamination and to prevent its dilution by less radioactive streams before treatment. The areas considered in this program were offices, laboratories, hoods, cells, and radiochemical processing equipment. These procedures are briefly summarized as follows:

Office Air: six changes of air per hour, without treatment.

Laboratory Air: minimum of ten changes of air per hour, without treatment.

Laboratory Hood Air: minimum of 50 feet per minute face velocity with provisions for the installation of the filter when demonstrated necessary.

In addition, each hood will have two vacuum systems: the first system with 10 inches of water vacuum to draw the gases off vessels containing high levels of radioactivity and the second system with 20 inches of mercury vacuum to be used for solution transfers and other applications where high vacuum is required. The air from both these vacuum systems will be cleaned before being discharged to the atmosphere.

Cell Air: held at reduced pressure (1 inch of water) when contamination is anticipated; air flow limited to about 250 cubic feet per minute, which will require the air to be cleaned. When cell air contamination is not probable, 20 changes of air per hour without treatment is permitted.

Radiochemical Process Vessel Off-Gas: a system with a vacuum of 40 inches of water to be used for the dissolver and process vessel off-gas line and one with a vacuum of 28 inches of mercury to be used for solution transfers and high-vacuum applications. The air from both vacuum systems will be treated.

A central facility has been established at Oak Ridge National Laboratory to clean the radioactive contaminated air from the chemical processing areas and to dispose of it to the atmosphere. The air from the off-gas systems is cleaned by passing it through a Cottrell electrostatic precipitator followed by an A. A. F. Co. FG-25-50 combination filter identical in performance with those described in Sect. 2. This system has a capacity of 2000 cubic feet of air per minute and collects gas from all radioisotope production vessels, off-gas from hoods, and ventilation air from dry boxes.

The second air-cleaning facility in this area is on the ventilation systems from radiochemical processing areas. This facility consists of a bank of FG-25-50 combination A. A. F. Co. backed by CWS No. 6 paper filters, and is essentially a miniature of the graphite reactor filter house described earlier.

The third system consists of central collection ducts from laboratory hoods in the area and experimental cells when, by the nature of the work, the possibility of contamination is slight. This volume of air is discharged to the atmosphere via a 250-foot-high stack without preliminary cleanup. The discharge from the two previously mentioned systems also empties into this stack.

Figure 2 is a schematic drawing of the central air-cleaning facility. Figure 3 is a photograph of the area as constructed. To the left behind the concrete barricade is the filter bank on the ventilation systems. To the right foreground are the main exhaust fans. Figure 4 is a photograph of the same area showing the top of the Cottrell precipitator and the stainless steel discharge line to the stack. Figure 5 is a photograph of the precipitator during construction.

The Cottrell precipitator is of the exposed-tube type, containing twenty-three 8-inch-diameter tubes 12 feet in length, fabricated of No. 14 gage stainless steel. Those parts of the precipitator that come in contact with the gases to be cleaned which may be corrosive are constructed of type 347 stainless steel. Figure 6 is a cross-section drawing of the precipitator.

The discharge electrode system is stainless steel wire longitudinally centered through each collecting electrode, suspended from porcelain insulators, and held taut by porcelain weights at the bottom.

The precipitator is equipped with a continuous water-flush system. Nozzles are provided at the top of each tube in such a manner that a continuous film of water is maintained on the inner surface of the tube. In addition, a water-spray system is located in the extreme top to facilitate washdowns. The water which is collected in a catch tank is recirculated to the precipitator. When the activity level or the acid content (NO and NO_2 are present in the off-gas) becomes high, the water is discharged to its proper location in the liquid-waste-disposal system of the plant.

The precipitator is designed to operate at a maximum temperature of 200°F and a negative pressure of 60 inches water at a flow of 2000 cubic feet per minute. The water flush system operates at 3 to 6 gallons per minute per tube.

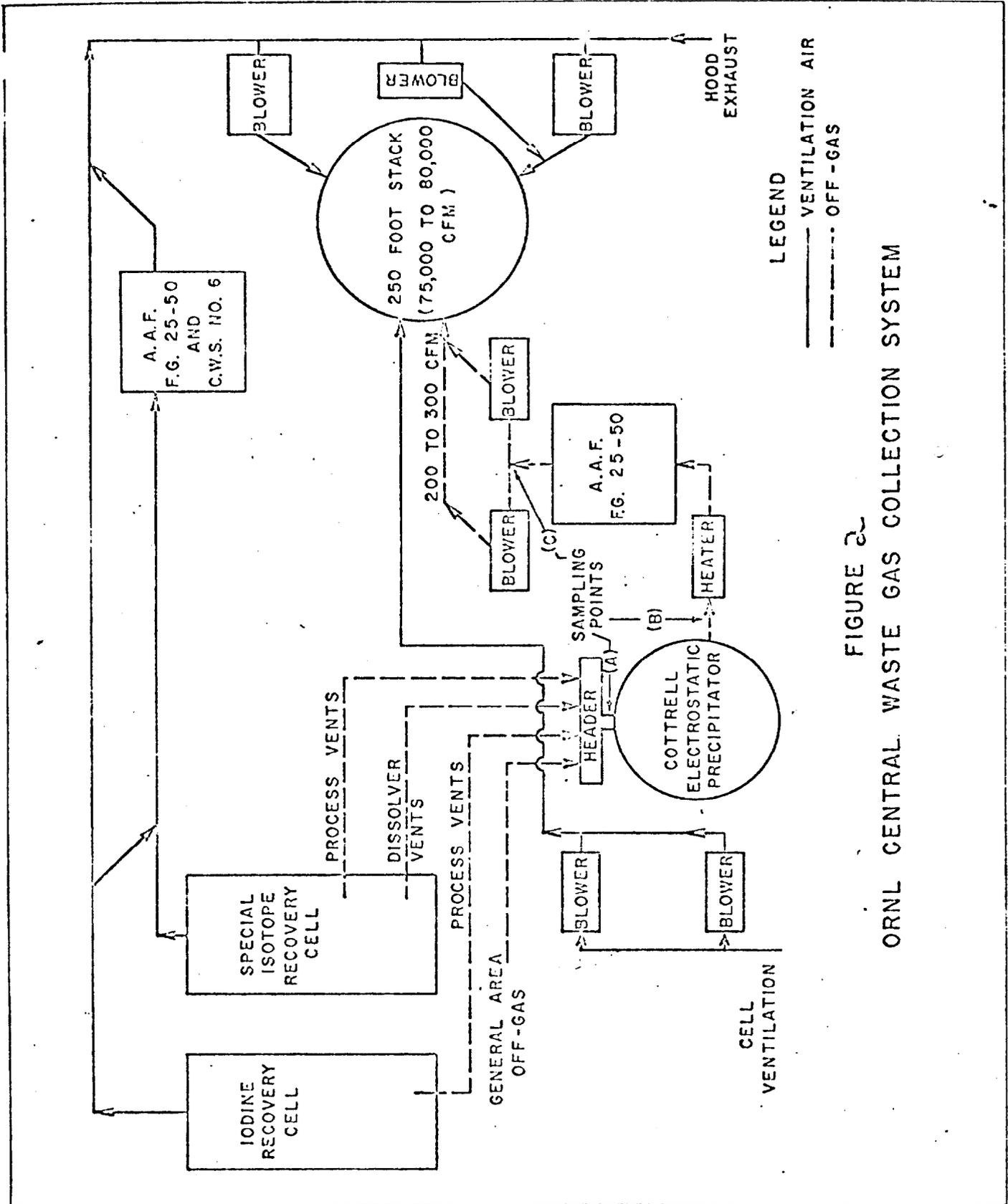


FIGURE 2
ORNL CENTRAL WASTE GAS COLLECTION SYSTEM

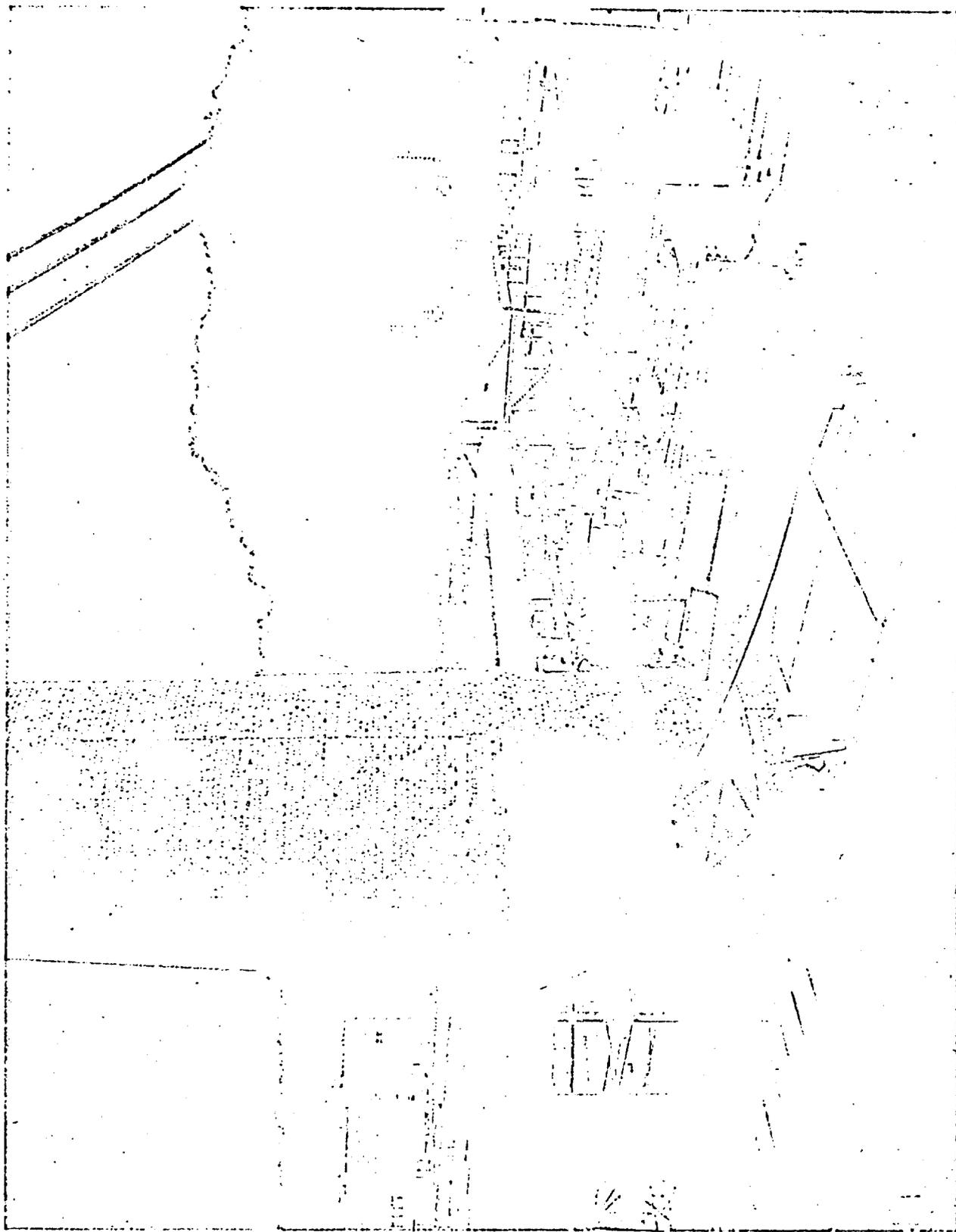


Figure 3

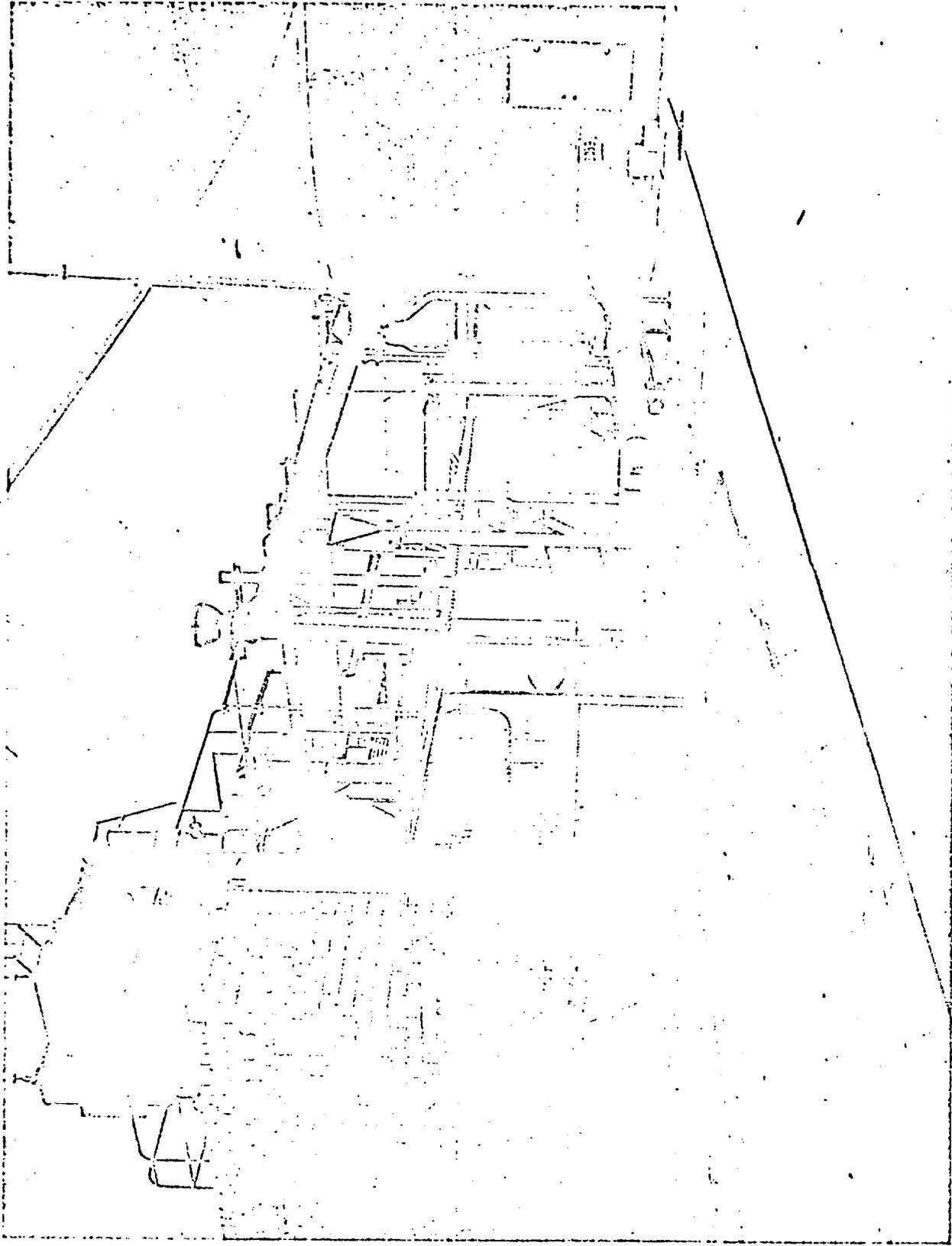


Figure 4

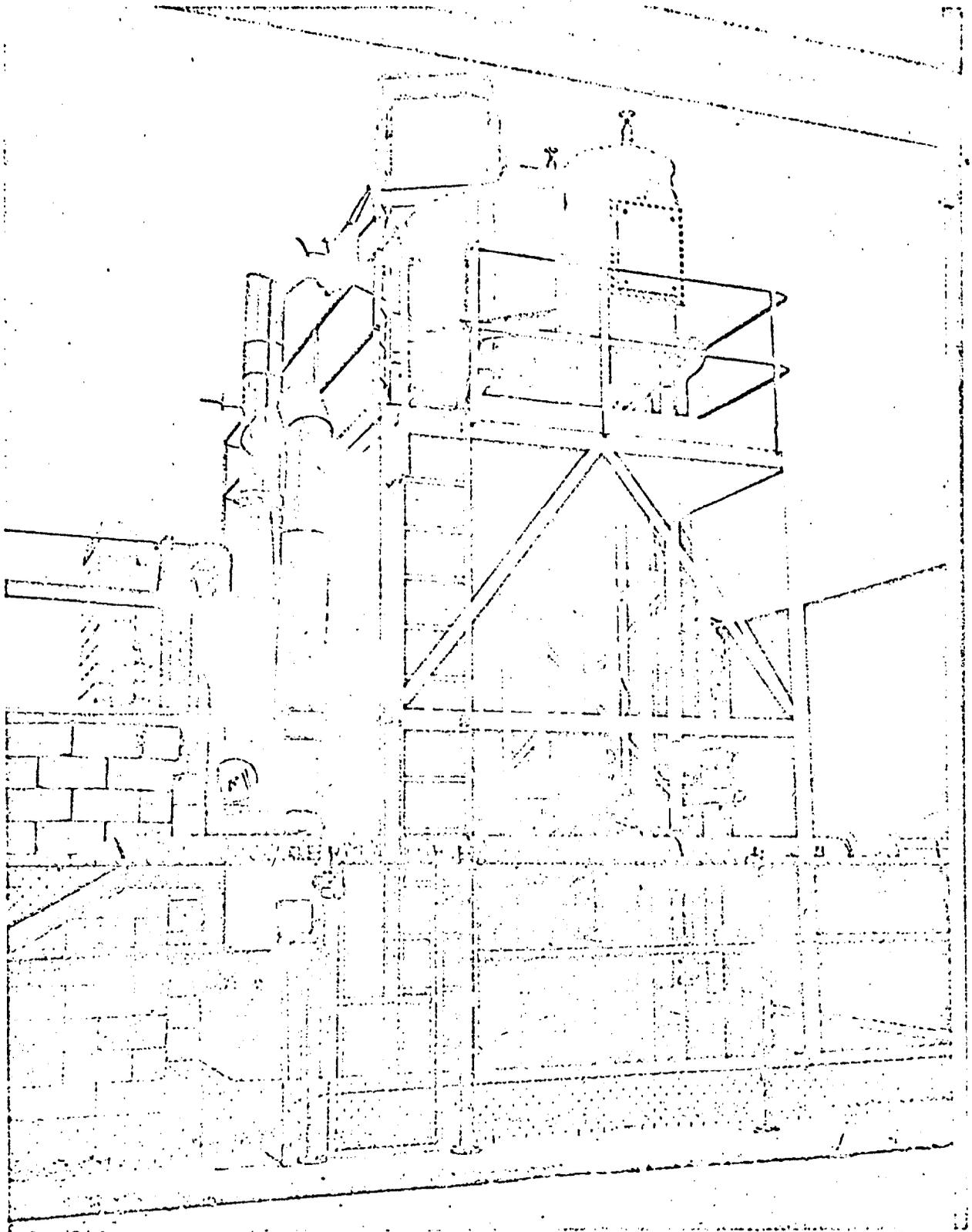


Figure 5

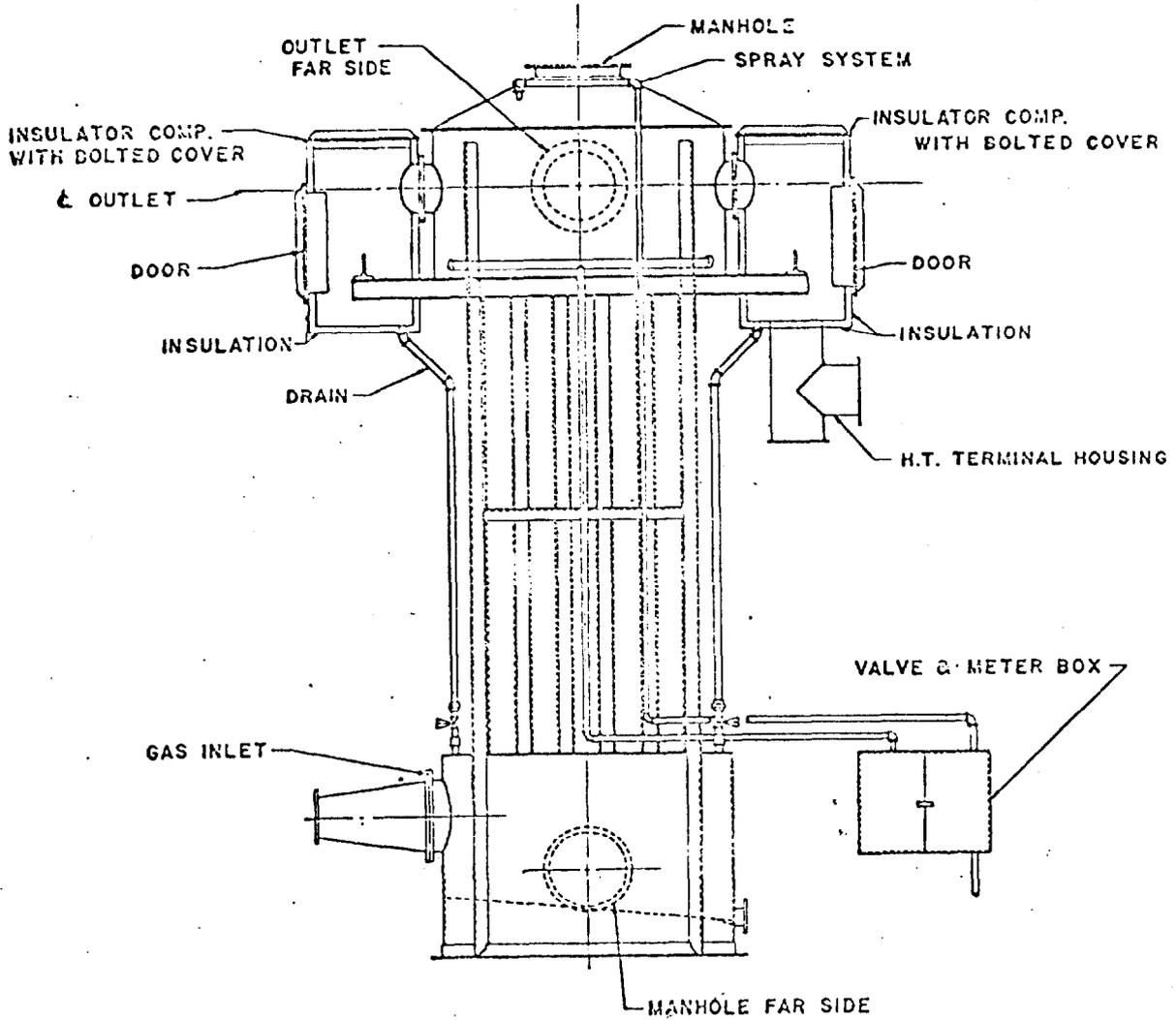


Figure 6

COTTRELL PRECIPITATOR TYPE "A"

The electrical design voltage is 75,000 volts, 25 kilovolt-amperes and operates on 440-volts 3-phase 60-cycle current to the power pack. In actual practice the precipitator is operating with 52,000 volts and a current of 130 milliamperes.

The capital investment of the entire system is \$100,000.

In addition to the main central facility, several small air-cleaning filters are located at isolated experimental radiochemical installations. These are miniature replicas of the graphite reactor filter installation except for one unit in which a graded filter-fibre unit developed at Hanford is used.

5. Homogenous Reactor Experiment Air-Cleaning System

A charcoal system was constructed for the Homogenous Reactor Experiment. Its purpose is to absorb the fission gases present in the effluent gas stream, and thereby hold up the active gases until they have had time to decay to a safe level before being discharged to the atmosphere. This system consisted of a pipe coil 328 feet in length and containing 13.94 cubic feet of Columbia activated coconut charcoal (gage 9, 8 to 14 mesh granular) and was designed to operate at atmospheric temperature and pressure with a flow rate of 24 standard cubic feet per day. Here, the air cleaning facilities were to be used only for the relatively short time during which the experiments are to be carried out.

HANFORD AIR CLEANING OPERATIONS
A. G. Blasowitz, G. E.

I. INTRODUCTION

At a previous Air Cleaning Seminar, a presentation was made of the program which led to the development and adoption at Hanford of the silver reactor and the Fiberglas filter as methods for the intensive removal of radioiodine and particulate contamination from process gas streams. The initial evaluation data of the plant-scale equipment, which established that the iodine removal efficiency of the silver reactor was greater than 99.99 per cent and the filtration efficiency of the deep bed Fiberglas filter was in the order of 99.99 per cent, were also presented at that meeting. At the completion of the evaluation of this equipment, approximately 2-1/2 years ago, the Hanford Stack Gas Group was disbanded and the personnel assigned to other activities.

Although there has been no formal program conducted by personnel of the Technical Section since that time, there are two items associated with this period which appear appropriate to today's discussions. The first is a brief summary of the operating experience which has been obtained at Hanford with the deep bed fibrous glass filters and silver reactors, and the second is an alternative filter equipment which is presently under consideration for the filtration of the ventilation air of Separations Plants.

II. OPERATING EXPERIENCE WITH PLANT DECONTAMINATION EQUIPMENT

A. Glass Fiber Filters

There are at the present time eleven fibrous glass filters in operation at Hanford which could be described as major plant installations; in addition, there

is a large number of secondary or auxiliary applications. All of the major units are in applications involving continuous operation. The service lives of these filters presently range from one to three years. All of the original units are still operating and there have been no significant variations in the operating characteristics. Likewise, there have been no maintenance requirements for any of the filters.

B. Silver Reactors

A total of seven silver reactors have been installed at Hanford. The basis of operation is the use of a silver bearing, reacting bed at an elevated temperature. For the purpose of economy of silver, Berl saddles which have been coated with silver nitrate are used for the reactor packing. The iodine reacts chemically to form silver iodide and is retained within the bed. The rapidity of the reaction and the low vapor pressure of iodine above silver iodide at the operating temperature are primary factors in the success of the process.

At last year's meeting, the monitoring data which established that the filtration efficiency of the plant scale Fiberglas filter was in the order of 99.99% were presented. The time then available did not permit the presentation of the actual monitoring data of the plant silver reactors and the results were only mentioned. It would, therefore, be desirable to take this opportunity to present this information. The data are contained on the first slide.

SLIDE IPERFORMANCE OF A PLANT SILVER REACTOR

| <u>Sample Period</u> | <u>Sample Flow Rate (scfm)</u> | <u>Radioiodine in Scrubber Sol. (uc).</u> | <u>Total Off Gas Flow (scfm)</u> | <u>Total Radioiodine to Stack (curies)</u> |
|----------------------|--------------------------------|-------------------------------------------|----------------------------------|--------------------------------------------|
| 1 | 1.0 | 0.48 | 100* | 0.00005 |
| 2 | 1.0 | 0.35 | 90 | 0.00003 |
| 3 | 1.0 | 1.72 | 90 | 0.00015 |
| 4 | 1.0 | 4.73 | 87 | 0.00041 |
| 5 | 1.0 | 2.68 | 85 | <u>0.00023</u> |
| | | | Total | <u>0.00087</u> |

* Flow was not recorded for this period....100 scfm assumed for purposes of the calculation.

Note: A value of 100 curies has been substituted for the actual radioiodine content of the metal and the monitoring values adjusted accordingly.

Reactor Efficiency > 99.99%.

One difficulty was experienced in the operation of the silver reactors. Appreciable quantities of radioiodine were detected passing through three of the first reactor installations after approximately two months' operation. The situation was investigated and it was determined that the difficulty had been caused by an overheating of the reactor assemblies which resulted in the silver nitrate film melting and running off the Berl saddle packing. A lowering and closer control of the temperature of the gas streams passing to the reactors has essentially eliminated this difficulty.

During this operating period, it has also been determined that a high removal efficiency can be quite easily restored to a reactor which is beginning to permit the passage of a significant amount of radioiodine. When an appreciable quantity of radioactive iodine is detected downstream from a reactor assembly, the unit is cooled and a 5 molal silver nitrate solution is sprayed over the top of the reactor packing. The treatment requires only a few hours and is sufficient to restore the efficiency to the 99.99 per cent range. The various reactor installations have operated for periods ranging from three months to two years between such treatments. The variation in the operating periods is due to the different quantities of material which have been passed through the units and individual operating circumstances, such as an accidental overheating of an assembly.

In summary, the Hanford operating experience with the deep bed Fiberglas filters and silver reactors has been highly satisfactory, both from the viewpoints of the intensive contamination removal which they have provided and the low maintenance requirements.

III. ALTERNATIVE FILTER EQUIPMENT

The second item is concerned with alternative filter equipment arrangements which are currently being considered for the treating of ventilation air streams. In the first Separations Plants constructed at Hanford, the vent gases from the process vessels were discharged to the cells and then to the main ventilation air stream. When the presence of radioactive particles in the plant environs was demonstrated, the problem was met by the filtration of the ventilation air through deep bed sand filters.

A corollary study performed during the subsequent Fiberglas filter development program established that the process vessel vent gases constituted the

primary source of the radioactive aerosol present in the effluent ventilation air. This information was incorporated into the design of a plant which was constructed approximately two years ago to the extent that a separate vessel vent system was provided to permit the removal of the contaminated aerosol at its source. This was accomplished by manifolding the vessel vent lines and passing the composite off-gases through a deep bed, high-efficiency, Fiberglas filter. A sand filter was also provided for the filtration of the main ventilation air stream.

The inclusion in this plant of both high-efficiency Fiberglas units for the separate filtration of the vessel vent gases and a sand filter for the decontamination of the main ventilation air stream, together with appropriate monitoring facilities, made it possible to assess the relative contributions of the two systems to the particulate decontamination of the effluent stack gases. When the design for a new Separations Plant was initiated approximately a year ago, this information was consulted to determine whether any possible improvements in the ventilation system were indicated. At that time, the plant having individual filtration facilities for the vessel vent system had been in operation for one year. The data showed that the average radioactivity content of the ventilation air prior to its passage through the sand filter at this installation was less than the activity present in the air streams downstream from the original plant sand filters.

In view of this information, an alternative equipment for filtering the ventilation air was proposed. This arrangement is shown on the following slide.

The primary advantage to be gained through the use of such a standby filter unit is that it is no longer necessary to incorporate a large life expectancy factor into the equipment and an appreciable savings in fabrication and installation costs can therefore be realized. A comparative cost estimate has been made for a sand filter and an emergency unit, each having a capacity of 100,000 cfm and has shown a cost differential of approximately \$500,000 in favor of the standby unit.

The decision was made a year ago by the people responsible for the design of the new Separations Plant that a detailed study would be made of the ventilation system of the plant presently providing separate filtration facilities for the vessel vent gases and the main ventilation air stream and that the results of this study would guide future construction. During the past year, process changes have necessitated an almost continual alteration and replacement of equipment in this reference plant. This has resulted in a more frequent occurrence of significant activity levels in the ventilation air than was experienced during the first year's operation. The detailed study of the long term radioactivity level of the ventilation air and the characteristics of the contaminated aerosol, as they are related to the feasibility of this standby filter arrangement, has been made the responsibility of the group under the direction of Frank Adley and it is presently planned to conduct this investigation before the end of the year.

The consideration of Technical Section personnel of alternative filter equipment is based upon two primary factors. These factors are that a ventilation air stream be treated in accord with both the decontamination required and the present state of equipment development, rather than through the use of equipment which will undeniably do the job but which may represent an unwarranted overdesign or antedated design.

In this regard, it should be noted that the particular alternate, the standby filter which has just been discussed, represents only the most economical,

and therefore the most attractive, means of providing an additional decontamination of the air stream. There are, however, several steps in the economic range of possible facilities and these, together with approximate cost estimates for a capacity of 100,000 cfm are indicated in the next slide.

SLIDE III

VENTILATION AIR DISPOSAL SYSTEMS

| <u>Ventilation Air Treatment</u> | <u>Direct Installation Costs*</u> <u>(100,000 cfm)</u> |
|----------------------------------------------------------------------|-----------------------------------------------------------|
| 1. Direct discharge to stack. | |
| 2. Standby filter....occasional 99% decontamination. | \$100,000 |
| 3. Main line, deep bed, fibrous filter....99% decontamination. | \$250,000 |
| 4. Main line, deep bed, fibrous filter....99.99% decontamination. | \$375,000 |
| 5. Main line sand filter. | \$750,000 |
| * Exclusive of overhead. | |

- Note: (1) The premise is made that vessel vent gases will be filtered at their source.
 (2) The estimates for items 2, 4, and 5 were prepared by personnel of the Estimating Unit at Hanford Atomic Products Operation and the estimate for item 3 is based upon an interpretation of the data contained in these estimates.

In view of the large cost differentials involved in the use of these various systems, it has been the consensus of opinion that the proposed detailed study of the most recently installed ventilation system, which will be conducted to provide guidance for future plant construction, represents an investigation which was both indicated and required; and results of this study will be awaited with interest.

Air Cleaning Activities at Argonne National Laboratory

Presented at the Los Alamos Meeting of the
Air Cleaning Seminar

September 21-23, 1953

By D. P. O'Neil, ANL

The majority of the air cleaning studies made at Argonne vary little from those that would be made in any large diversified research laboratory. This morning I would like to discuss two of the investigations we've made within the past year, one of which has already been completed, the other is still in progress.

The first concerned the investigation of the absorption of some halogen gases from an air stream. Before any work was started on this project a search of the literature revealed that essentially two methods used in the past should be investigated to determine their applicability to our setup. These were first, a method by T. P. Hignett and M. R. Siegel in Industrial Engineering Chemistry, 41,2493 (1949) wherein they used a four foot deep bed of $\frac{1}{4}$ " - $\frac{1}{2}$ " oölitic limestone particles to extract HF from the exhaust gases of a phosphate roasting process where the temperature of the gases ranged from 200 to 900°F. Efficiencies of 71 to 96% were obtained with the aid of a recycle process used to remove the calcium fluoride fines and thereby provide fresh reaction surface. The oölitic type, i.e., the large open grained type limestone, was found to be superior to non-oölitic (fine grain structure) such as crushed marble, because the calcium fluoride reaction product held to the parent calcium carbonate less tenaciously.

The other method for removal of halogens was that of absorption by scrubbing. This had been investigated by W. B. Burford and J. M. Hamilton in National

maintain the spray cone had little effect on the efficiency. With contact time as short as 1.7 seconds, it was found that 98% efficiencies were obtained for fluorine absorption, while hydrogen halides showed comparable absorption efficiencies.

At concentrations ranging from 900 to 70,000 PPM and under various operating conditions, the lowest efficiency obtained for any halogen or interhalogen in the scrubber was greater than 90%.

From these results, and many others which time will not permit us to discuss, it was concluded that the dolitic-limestone is adequate for the removal of HF from air streams at room temperature until about 50% of the bed is consumed, providing particles $\frac{1}{4}$ - $\frac{1}{2}$ " in diameter are used. An increase in the depth of bed will give an increase in efficiency while a decrease in particle size will increase capacity. The limestone, however, is not adequate for halogens other than HF particularly bromides if a high efficiency and capacity are desired.

The concurrent spray tower with 1 stage will effectively remove halides and interhalogens with efficiencies greater than 90% when a 5% KOH scrubber solution is used. In addition, there is the advantage of working under a negligible pressure drop through the system because of the aspiratory effect of the spray nozzle, making an increase in blower capacity or strengthening of ductwork in the existing system unnecessary. It is estimated that using the conservative distance of 1 foot between each of three stages and using 3000 to 6000 pounds per hour of scrubber liquid per sq. ft. of tower with a gas contact time of 1.7 seconds, a halogen concentration of 2000 ppm would be reduced to an effluent concentration of 10 ppm.

This work was done by Messrs. R. C. Liimatainen and M. Levenson of the ANL Chemical Engineering Division and is written up more thoroughly in ANL Report 5015.

Another study brought on by economic considerations revolves around the prefilters being used in the laboratory hoods. These filters used in the rear of all hoods as shown previously by Mr. VanValzah serve two useful purposes; first, they act as diffusers making for an even flow across the face of the hood, and secondly, they prefilter the air before it passes through the final filter and thereby it is hoped they increase the life of the final AEC filter. However, this second point has never definitely been established and the exact effect on the life of the final filter is not known. The pre-filters in use (PF 314) have an average life of from 3 to 6 months. While the final filters vary from 12 to 18 months, the relative cost of the final to the prefilter is approximately 10-1.

Theoretically, the prefilter could shorten the life of the final filter by only intercepting the large particles and thereby permit the smaller ones to pass through to the final filter where they could plug it more rapidly than if the large particles had been allowed to pass. This possibility is, of course, remote, but has not been resolved, so a test was undertaken to determine the true situation.

A typical hood was selected in a new building in which the supply air is prefiltered and air samples were taken simultaneously on the clean and dirty side of a new hood prefilter using AA millipore filters.

These samples were taken periodically over a two months period, counted, and sized. The counts ranged from 32,000 to 900,000 particles per cubic foot, and had an estimated geometric mean diameter of $.17\mu$ and a standard deviation

of 3.28 on the dirty side and $.12 \mu$ with a standard deviation of 3.0 on the clean side. These values for the geometric mean diameter were obtained by extrapolating the curves obtained by plotting the cumulative percent less than a certain size vs. that size on logarithmic probability paper. For example, on the dirty side it was found that 80% of the dust was $.52 \mu$ or less in diameter and that 98.5% of the dust was 3.0μ or less in diameter. There were other intermediate points that fell along this line, but the smallest sized group plotted was that in the range from $.52 \mu$ down to the limit of resolution of the microscope which was plotted at the $.52 \mu$ size. Since this group contained 80% of the dust it was then necessary to extrapolate back to the 50% size to determine the geometric mean size of the dust.

The standard deviations were obtained by dividing the 84.13% size by the 50% size as selected from the logarithmic probability plot.

Efficiencies of the prefilter, by count, ranged from 17.2% to 69% with an average of 42.2%. These efficiencies were for particles $.33 \mu$ in diameter or larger, $.33 \mu$ being the limit of resolution for the lens combination used for counting. However, only 30% of the dust sized was greater than $.33 \mu$ in diameter as determined by the logarithmic probability curve and so it is expected that the true efficiency will be somewhat less.

From these preliminary studies, we now know the approximate size distribution of the dust we're dealing with, and the efficiency by count of the PF314 prefilter. However, the really important work lies ahead, that is the effect of the prefilter on the life of the final filter. We plan to get information on this by installing three or four different types of prefilters in different modules with similar dust exposure. By pre-weighing these filters

and the final AEC filter, and determining the original pressure drop across both, the life and weight gain of each type including the final filter can be determined. A single sample with each type will not be significant statistically and so it is expected that this work will continue over a period of time.

It is hoped that more conclusive results will be available next year.

VENTILATION ACTIVITIES AND PROGRAMS AT ARGONNE NATIONAL LABORATORY

By R. W. Van Valzah, ANL

The ventilation program at Argonne may be considered as having progressed through three periods, the first being the design and construction period, the second being an operating period of several years, and the third being a transition period in which modifications to the present systems are necessary in order to meet the new requirements and demands of the scientific staff. Changes and additions have been made during the operating period but the capacity limit of the present supply systems has been reached. More supply and exhaust air is particularly needed throughout the Chemistry Building 200 while the Physics Building 203 and the Chemical Engineering Building 205 have only a limited number of laboratories which require additional ventilation. With this increased ventilation problem there also is the attendant provision for increased air conditioning facilities. A preliminary proposal has recently been submitted to the AEC for making the required changes to the present ventilation systems.

The ventilation systems in all three of the above mentioned buildings are not identical. However, the Chemistry Building 200 may be considered representative of all three and a brief resume of the ventilation facilities in this building will be given. The systems were originally designed on the basis that all toxic and radioactive experiments would be performed in hoods. Blickman hoods with or without glove panels, and vacuum hoods, were generally adapted for the research activities which cover a wide range of chemistry applications. Special ventilation problems which the standard design would not accommodate were to be dealt with individually. Some of these special problems will be described later.

The Chemistry Building is divided up into six wings tied together at both ends by transverse corridors connecting with the wing corridors. The wings are separated by courtyards so that the plan resembles a ladder. Each wing is divided up into laboratories and offices with a corridor between them. The unit of width for a module is 10 feet so that a laboratory or office may be any multiple of this number. The normal laboratory unit consists of two 10 foot modules and two 10 foot offices. Hausorman steel panel partitions are used for dividing each wing into the required number of laboratories and offices, the maximum being 24 of each.

All six wings of the building are of similar design and construction and contain practically identical heating and ventilating equipment. Perhaps the starting point for an understanding of the ventilating and air conditioning systems is a description of the supply system. Slide 501-219 is a schematic diagram of the supply ventilation system in each wing. All fresh air is taken from the outside and passed through the primary and secondary filters. These are AAF Company Type PL-24 filters with standard 5 ply fire resistant airmat in the primary filters and standard 10 ply fire resistant airmat in the secondary filters. The life of the primary and secondary media ranges from 1 to 2 months and 2 to 4 months respectively based on a maximum pressure drop of approximately .5" WG for each. These filters are removing a high percentage of the dust particles as indicated by the particle size efficiency tests conducted by Mr. O'Neil on the hood prefilters.

The supply air is next drawn through the preheat coil by two fans and discharged into a plenum from which there are three separate branches. The first main branch supplies a constant volume of air to the offices and corridor, the second main branch supplies a constant volume of air to the laboratories and the third main branch supplies a variable amount of air to the corridor. Cooling and reheat coils in the three mains temper the air to the required conditions for maintaining the specified temperature and humidity. Special rooms are provided with booster heating and cooling coils in the supply risers where lower than general conditions are required.

The air flow pattern is as follows: air from the offices is vitiated to the corridor; the corridor air and the vitiated office air is vitiated into the laboratories; and this air together with the laboratory supply air is removed by the laboratory exhaust systems.

Whenever the laboratory exhaust air demand is greater than the minimum air supply, the extra supply air is provided through the variable air branch which discharges into the corridor from which it is vitiated to the laboratories. A static pressure regulator controls the opening of the variable air damper. The other temperature and humidity controls are also indicated but time does not permit further explanation of them.

The removal of the minimum supply air for air conditioning purposes and the maximum exhaust requirements will be discussed next. In view of the varying exhaust demands per laboratory and the necessity for flexibility, the exhaust systems were set up on a modular basis. Each ten foot module may have a maximum of two fans and two runouts exhausting approximately 1000 cfm each. The number of hoods in the laboratory determines the number of fans. A maximum of three Blickman hoods per runout has been established. One hood fully open requires 1000 cfm at a 150 fpm face velocity but this available quantity of exhaust air may be divided up between the other hoods on the runout. An alarm bell on the system notifies the occupant when the exhaust limit has been reached.

The runouts from the laboratory go up to the fan loft where they discharge into the dirty plenum. Slide 420-315 shows the risers connecting into the dirty plenum. Between the dirty plenum and the clean plenum are located the high efficiency filters. Slide 420-313 shows the mounting of the filters with inspection doors above and below the filters. The damper operating sectors which allow for the isolation of the filter from the system when filter changes are made are also shown. Slide 420-312 shows the exhaust fans connected to the clean plenum and discharging the air above the fan loft roof to the atmosphere.

Wherever radioactive hoods are installed, a laboratory bypass duct from the dirty plenum in the fan loft to a register in the laboratory is used so that a minimum amount of air is exhausted at all times from the laboratory. The hoods are provided with air velocity regulators which maintain nearly a constant air flow velocity for any position of the hood door. Air may either be exhausted from the hoods or from the laboratory bypass. A plenum static pressure regulator controls the laboratory bypass damper and also a clean plenum damper. All the exhaust fans on the system run continuously so that the above dampers regulate the amount of air removed from the laboratory up to the capacity of the fans. Slide 501-218 shows a control diagram for the hood, lab bypass and plenum bypass dampers. Where the minimum air is removed by a constant exhaust from another piece of equipment such as a vacuum hood or canopy no lab bypass is required.

No doubt you all are familiar with Blickman hoods. Slide 420-314 shows one of these hoods installed in a laboratory. At the back of the hood are four pre-filters. These maintain uniformity of air distribution across the face of the hood, remove a certain portion of the particulate matter thereby increasing the

life of the special filters and condense some of the vapors that would otherwise be carried into the system. Two types of media have been used in these filters namely 25 FG and PF 314 fiberglas. These filters have to be changed at anywhere from 3 to 6 month intervals depending upon the pressure drop. The maximum allowable resistance for these filters in order to maintain the required air flow is .7" WG. It is therefore economically advisable to start with as low an initial resistance as possible consistent with the required efficiency for obtaining the maximum life from the filters. With the above requirements in mind, AAF Co. has recently developed a new media for this filter with an initial resistance of .2" WG or less at an air flow of 250 cfm. The discoloration efficiency tests with atmospheric dust for these filters ran 47 to 56%. It is understood that AAF Co. is going to standardize on this media for this type of filter and discontinue the two other types.

One of the special air cleaning problems which has been under development at Argonne is that of removing perchloric acid fumes. This matter was referred to Dr. Silverman who developed a scrubber for this purpose. The constructed model which may be placed inside of a hood has been in operation at Argonne for approximately 6 months. Recently the filter which was made especially for this unit by Arthur D. Little, Inc. became clogged. The following slides show the unit as well as the condition of the filter after failure: Slide Nos. 235-108, 109, 124 and 125. Apparently the aluminum separators disintegrated either from the Na_2CO_3 or the acid fumes. Arthur D. Little, Inc. kindly made a replacement filter, the separators of which are made of sheet steel instead of aluminum. The Air Cleaning Studies Progress Report for February 1, 1951 to June 30, 1952 covers a description of the scrubber along with test data on the performance of the scrubber with sulphuric acid. Further tests by Mr. O'Neil on this unit with perchloric acid showed efficiencies ranging from 96 to 99.9%. Drawings are now in progress for the construction of several of these units.

There are other ventilation problems at Argonne still in the process of resolution. The one causing the most concern at present is the ventilation treatment required for metallic fluorides. It is hoped that some information in this connection may be obtained during this visit.

Nuclear Energy series, Div. VII, Vol. I, McGraw-Hill, N.Y. 1951 Page 198; R. Landau and R. Rosen, Ind. Eng. Chem., 40,1389 (1948) and National Nuclear Energy Series, Div. VII, Vol. 1, McGraw-Hill, New York, 1951, Page 133 and E. M. Berly, M. W. First and L. Silverman in N.Y.O.-1585 1952. The former two using NaOH as the scrubber liquid with low gas velocities and a relatively long contact time of approximately one minute reported high absorption of F_2 and HF. The latter, i.e., Silverman et al. using successive stages of saran fibre wetted by a spray of water and followed by a dry cell effected efficiencies of 99% with velocities of 200 L FM but with a pressure drop of $4'' H_2O$.

With these two methods available then, it was the objective to evaluate each, i.e., for the limestone bed process to determine the efficiencies for fluorides, chlorides, and bromides at room temperature and to determine the minimum bed depth and gas velocities for minimum pressure drop and for adequate efficiency with no recycling. And for the scrubber method to determine the efficiency for elemental fluorine and interhalogens using a contact time on the order of seconds rather than minutes in order to keep the size of the tower reasonable.

The investigation of these two processes involved the use of two 5 inch diameter pipes, one 4 feet long used as a spray tower in which a Shutte-Zoerting hollow cone 60° spray nozzle was centered and one 6 feet long in which the various depths of limestone bed were packed. After the mixing of the halogen and the air stream, the air-halogen stream entered a gas distribution section, flowing either up through the bed in the limestone absorption tower or down through the spray tower flowing concurrently with the aqueous potassium hydroxide solution which was sprayed from the nozzle and which was used as the absorbing solution.

THE ARGONNE INCINERATOR PROGRAM

Presented at the Los Alamos Meeting of the

Air Cleaning Seminar

September 21-23, 1953

By W. A. Rodger and D. C. Hampson, ANL

The basic program for the investigation of the operation of the Argonne Active Waste Incinerator has been completed, and the two primary objectives of this program have been successfully accomplished. They are:

First, to design and construct an incinerator which would safely and economically reduce the volume of combustible radioactive waste that is produced at Argonne National Laboratory. The incinerator's capacity of 100 cubic feet of normal wastes per 8-hour day is more than ample to handle the daily accumulation of wastes. The radioactivity of the exhaust gas from the incinerator has, under normal combustion conditions, been consistently below the exhaust gas tolerance specified by Health Physics and has in most cases contained less immediately measured activity than that found in normal surrounding atmosphere.

Second, to determine and make the modifications in the equipment and flowsheet that were necessary to obtain maximum efficiency throughout the system. These modifications were the result of the data obtained in the experimental phase of this program and have resulted in a 50 per cent increase in combustion rate and in an increase of A.E.C. filter life from 6 hours per filter to more than 60 hours per filter. The maximum over-all decontamination factor from feed to exhaust gas for the present operating conditions is 2 to 3×10^7 .

As shown by the over-all decontamination factors and by the fact that the effluent exhaust gas contains less than the natural activity of the surrounding atmosphere, the incinerator system is able to handle higher levels of activity than used in those runs to which activity was added (maximum of about 10^{11} disint./ (min.)(cu.ft.) since the effluent gas from these high level runs was a factor of 20 lower than tolerance. However, on the basis of the high background activity readings encountered during these runs, it is apparent that remote charging, ash removal, and additional shielding of the furnace cone and ash barrel would have to be provided to enable such levels of activity to be handled routinely.

The incinerator equipment consists of a type 330 stainless steel incinerator body in which the material is burned in the presence of excess air; a Schraier-Bartolucci vane plate washer, in which large particles of fly ash are removed; and a secondary scrubbing unit consisting of a Pease-Anthony Venturi and a Peabody scrubber in which the gas-borne radioactivity is normally reduced to within tolerance. Final clean-up is accomplished by an A.E.C. filter which is capable of removing radioactive particles to well within the minimum tolerance levels specified by this Laboratory's

Radiological Physics Division (2×10^3 beta disint./min.)(cu.m.) and 70 alpha disint./min.)(cu.m.)). When replacement is necessary, the loaded filter is burned in the furnace. From the filter, the gases are drawn through a positive displacement blower which moves the gas stream on to the discharge stack on the roof. The ash resulting from combustion falls through a grate system and settles through water located in the cone in the base of the furnace into a canvas bag filter inside of a stainless steel drum. The bag and its contents are removed from the system, dewatered, and then stored.

Sampling of the gas stream to determine the efficiency of each piece of equipment was carried out in two ways. The first method was based on the total amount of activity entering and leaving each unit. The second method was based on the total amount of particles (based on weight) entering and leaving a unit. Experimental results have shown that these two methods produce nearly equal results, at least in the less-than- 2μ particle size range.

The gas stream was also monitored after it passed through the final unit of the cleaning train (A.E.C. filter). This monitoring, based on radioactive counting of particulate matter, helps to insure safe operation of the incinerator with respect to the total amount of radioactivity discharged to the atmosphere.

In cases where the gas temperature was too high (above 200°F) to allow use of cellulose filter paper (Watman #44), a special fiber glass filter was used. The only sample point where this media is necessary is prior to the Schreiber-Bartolucci scrubber. Here, in addition to high temperatures, a heavy particle loading is encountered. In order to be on a comparable basis, both influent and effluent gas samples around the Schreiber-Bartolucci scrubber were taken with the same media.

Isokinetic samples were taken with a sample probe or head which was inserted directly into the gas duct through a 2-inch opening. Stairmand discs were used prior to each sample point.

After the sample has been taken, the filter media was removed and the radioactive count determined by use of Bradley Proportional Counters. The low level samples (less than 1×10^4 beta ct./min. per paper) were counted by means of PC-2 counters and the high level samples (greater than 1×10^4 beta ct./min. per paper) were counted in PC-1 counters. The counting time varied from 1 to 10 minutes depending on activity level. Both counters have 62 per cent yield.

For weight determinations, the sample media was dried and weighed prior to and following the sampling. Both weight efficiencies and activity efficiencies can be determined on each sample. Efficiencies are based on the influent and effluent particulate concentration in the gas at each unit of the scrubbing train. The experimental program that was carried out investigated the major operating variables of the gas cleaning train. The salient results obtained from this investigation are as follows:

The decontamination factors produced by the furnace itself varied from 150 to 300. It should be noted that this decontamination factor is significantly different from that previously reported by KAPL (about 2000). Private communications indicate that the originally reported figure of 2000 was in error by a factor of 10, and the two sites are in agreement that 200 is a realistic value for the furnace decontamination factor.

As it was not feasible to sample the gas stream between the Pease-Anthony Venturi scrubber and the Peabody scrubber, the radioactivity removal efficiency was determined around the Pease-Anthony Venturi-Peabody scrubber couple at a constant water temperature and flow rate to the Peabody scrubber.

The scrub solution to gas ratio in the Venturi was varied between 4.7 and 45.6 gal./min. per 1000 cu.ft./min. The most effective flow ratio was about 20 gallons of scrub solution per 1000 cubic feet of gas.

The efficiency of the Venturi is indirectly proportional to temperature of the scrub solution over the range of 64°F. to 148°F.

The use of steam injection to enlarge the particles by means of the condensation nuclei principle was also investigated. Steam was introduced into the duct leading to the Pease-Anthony scrubber about 12 inches upstream from the Venturi throat.

In general, it was found that for a given Venturi scrub solution temperature, particle removal efficiency was about 50 per cent greater with steam injection than without steam up to temperatures at which efficiency fell off rapidly with no steam (about 140 to 110°F., respectively, with and without scrub solution in the Peabody scrubber). Above these temperatures, removal efficiency with steam injection decreased only slowly as the scrub temperature was further increased compared to a rapid decrease in efficiency in the absence of steam.

As long as the plates in the Peabody scrubber are kept covered with scrub solution, neither the scrub solution temperature or rate affects the efficiency of this unit between 100°F to 145°F and 2.5 to 7.0 gal./min.

The efficiency of the Peabody scrubber is proportional to the number of wet plates between zero and three plates; the addition of a fourth wetted plate does not appear to increase the efficiency of this unit appreciably.

It appears that the efficiency of the Schreiber-Partolucci scrubber is dependent upon the nature or size of the particulate being fed to it. The efficiencies varied from 25 per cent to 75 per cent depending upon the type of material being burned.

Very little experimental work has been done to determine the overall efficiency of the A.E.C. filter since A. D. Little Company, who designed the filter, has determined that it is 99.9% per cent efficient on 0.3 to 1 micron sized particulate. This corresponds to minimum decontamination factor of 1×10^3 .

The efficiency of the filter was checked during one of the high activity level runs, and an average decontamination value of 2.6×10^3 was obtained. This value corresponds to an efficiency of 99.96 per cent.

The over-all decontamination factor for the entire system is proportional to the level of activity in the feed and reaches a maximum value of 2 to 3×10^7 where it remains constant.

A summary of decontamination achieved by the incinerator components is:

| <u>Component</u> | <u>Decontamination Factor</u> |
|--------------------------------|-------------------------------|
| Furnace | 2.2×10^2 |
| Schroier-Bartolucci Scrubber | 1.2 |
| Pease-Anthony Venturi Scrubber | 50 |
| A.E.C. Filter | 2.6×10^3 |
| Over-all | 3.4×10^7 |

In order to test the efficiency of the gas scrubbing train on atmospheric dust, two experiments were conducted in which air from outside of the building was drawn through the gas train. The conditions were the same as during a normal combustion period except that no material was burned. The results are as follows:

| | <u>Air Intake, disint./ (min.)(cu.m.)</u> | <u>Air Exhaust disint./ (min.)(cu.m.)</u> |
|-------|---------------------------------------------------|---------------------------------------------------|
| Run 1 | $\alpha = 73$ $\beta = 219$ | Background of Counter 40 |
| Run 2 | $\alpha = 393$ $\beta = 863$ | 2.8 14 |

It is apparent, since the exhaust stack gas normally contains less activity than the natural radioactivity present in the surrounding atmosphere, that considerably lower efficiency could be tolerated through-out the system. The main value of increasing the over-all efficiency is in decreasing the "dust" load to the A.E.C. filter, thereby increasing its operating life. The experimental work on the Venturi-Peabody couple produced data which enabled the filter life to be extended from one 8-hour day to ten 8-hour days. This over-all increase has reduced the cost of the filter from \$40.00/day to \$4.00/day.

The cost of incineration of active wastes based on 8-hour operation, and 24-hour operation are as follows:

| | <u>8-Hour</u> | <u>24-Hour</u> |
|----------------------------------------|----------------------|----------------------|
| Direct Operating Costs | \$1.78/cu.ft. | \$1.38/cu.ft. |
| Depreciation of Building and Equipment | <u>\$0.90/cu.ft.</u> | <u>\$0.22/cu.ft.</u> |
| TOTAL | \$2.68/cu.ft. | \$1.60/cu.ft. |

These values are direct out of pocket costs based on actual operating figures.

At the time the incinerator program was originally set up there were two primary motivations to the program. One was to provide a means of safely reducing the bulk of the dry active waste for temporary storage at this site; since at that time no site had been established as either an interim or long term National Burial Ground. The other was to pilot plant the process of incineration to obtain cost and operating data, since there was at the time widespread and general interest in incineration as a unit operation.

The pilot program has been successfully completed and reported in detail in ANL-5067. Oak Ridge National Laboratory has recently been willing to accept shipment of all the solid waste from this Laboratory and indications are that the arrangement can be continued for some time.

A cost analysis of the first shipment of waste to ORNL indicated that the savings to be realized by incineration of the combustible portion of the waste were only about ten cents/cubic foot over shipping all of the waste as collected.

In view of the current man-power shortage and in light of the above facts, the incinerator program has been concluded and the equipment placed in standby condition.

AIR CLEANING PROBLEMS AT NRTS

By A. L. Biladeau, AEC, IOO

The National Reactor Testing Station's air cleaning problem is similar in most respects to that encountered elsewhere. However, we do have conditions that are somewhat different from that normally encountered.

The terrain on which our reactors are constructed is in a fairly flat desert area with sagebrush being the principal vegetation. Once the sagebrush is removed and the ground disturbed, the dust problem becomes intense. Soil stabilization is required at all our plants as a means of dust control. Fortunately the natural ground, if undisturbed, is fairly stable. Winds are rather common and at times of fairly high velocity. Prefiltering of all air is, therefore, required in all our plants.

The Chemical Processing Plant is the NRTS's only plant to date requiring air cleaning facilities above that normally required. All air entering the plant is cleaned by the use of capillary air washer filters. The Hood system uses C W S filters and exhaust direct to the atmosphere through vents located on the plant roof.

Positive pressure ventilation is supplied to the cold areas in the plant by 2-60 HP fans. This air is distributed to the cold area and flows to the roof vents or to the hot areas. After passing through the cells, the hot area ventilation emerges in two vent tunnels on each side of the building. These vents go to the fan building via an above ground metal duct.

The fan building contains 2-75 HP fans which draw air from the above ducts and discharge it directly to the stack without filtering. The stack has a minimum diameter of 10 feet and is 250 feet in height. A stack heater is provided to increase the stack draft during periods of adverse weather conditions.

The sampler off-gas ventilation system takes its air from the cold areas, draws it over the sample bottles and through fiberglass filters. Two fans discharge the filtered air directly to the metal duct leading to the fan house.

All vessel off-gas is vented separately and operates under reduced pressures with respect to the cells. This air is discharged through a six inch stainless steel pipe to fan house where the air is filtered through special fiberglass filters before being exhausted to the stack by 2 - 2400 cfm fans.

These gases are filtered through fiberglass filters and discharged to the stack by a steam jet.

The Materials Testing Reactor air is prefiltered on entering the reactor. That air used to cool the graphite core, and at present the only contaminated air of any volume, is filtered and monitored before being discharged to a 5 foot diameter 250 foot stack for dispersion to the atmosphere.

The Experimental Breeder Reactor air is prefiltered by use of electrostatic air cleaners (precipitron) and that air used to cool the outer core is again filtered and monitored before being discharged to the atmosphere through a 50 ft. metal stack on top of the reactor.

The Ship Thermal Reactor air cleaning problem can be considered as routine. They have provided special filtered force air discharge to the atmosphere through metal stacks located on top of the reactor in event of trouble involved in the dismantling or repair of the reactor.

A new gas treating problem and one involving greater volumes than any of our other plants, including the Chemical Processing Plant, is the new ANP Project. The testing and operations of a nuclear aircraft engine will involve a very complex air treatment problem.

Some of the problems to overcome are: (1) Treatment of high air temperatures. (2) Limited restriction on the amount of back pressure permitted through the filtering process. The efficiency of these engines drops off rapidly with any degree of back pressure. (3) A stack 150 feet in height and 20 feet in diameter will have an effective stack height of around 600 feet under the above conditions and a 15 mph ambient air velocity.

Dust will be one of three likely sources of radioactive contaminants to remove. That dust in the air, on being drawn through the nuclear engine, will be highly contaminated on discharge. Fuel element erosion particles will be another contaminant that will have to be removed. Possible fuel element rupture also must be considered in the air cleaning design. Radioactive argon may be a contaminant that will have to be removed. The degree or percentage of each contaminant to remove can only be estimated. The dust problem can be partially corrected by selecting the day in which to run the engine tests. The U. S. Weather Bureau will be the chief consultant in this matter. Fuel element, erosion and rupture have yet to be firmed up, but they hope to have it by test time.

The extreme temperatures at which the gases are discharged will create a filtering problem but will help by reducing the required stack height for adequate dispersion.

Doctors Silverman and Lapple have both been retained as consultants on these problems and can probably give you a much more detailed account of the problem encountered should you be interested.

OPERATING ECONOMICS OF AIR CLEANING EQUIPMENT
UTILIZING THE REVERSE JET PRINCIPLE

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ABSTRACT

Plant experiences with the operations of 18 dust collectors is described. This equipment, supplied by two different manufacturers, is in continuous operation in one plant. The units are operated at housing pressures from 2" of water to 10" of mercury with capacities from 700 cubic feet per minute on pneumatic conveying to 12,000 cfm on dust control. The total designed capacity is 110,000 cfm.

Dust loading varies from 0.002 grains per cubic foot to 32 grains per cubic foot, with an average of 5 grains per cubic foot. Discharge air measures 0.0001 grains per thousand to 0.41 grains per thousand with an average of 0.16. Average cleaning efficiencies range from 99.946 to 99.9996 with an average under all conditions of 99.986. Overall annual cost, including five-year amortization, is 0.32 dollars per year per cfm for all equipment and 0.23 dollars per year per cfm for suitably designed equipment. This compares with three large wet collectors which have been described. They operate at 93.5% collection with an annual cost of 0.197 dollars per cfm. Maintenance costs of the wool felt collectors alone amount to 0.12 dollars per year per cfm for all units and 0.042 dollars per year per cfm for 14 adequately designed collectors.

OPERATING ECONOMICS OF AIR CLEANING EQUIPMENT
UTILIZING THE REVERSE JET PRINCIPLE

With the obsolescence of the war-built equipment for the refining and processing of uranium, it has been necessary to design replacement facilities. While the heavy stress of production was being carried by existing plants, it was possible to give adequate study to the many problems before settling on new plant designs.

Among the areas requiring special attention, the control of inplant and outplant pollution received intensive engineering consideration. This included:

1. The design of process controls and equipment to reduce exposures to potential toxic materials to within specified limits.
2. The design of adequate replacement air facilities to make up for that which would be removed by ventilation.
3. The design of air cleaning equipment to provide for minimum process losses and a clean external environment.

Experiences which had been gained in the many plants which cooperated in the production of uranium materials were carefully examined in every design area. On the basis of these experiences, it became obvious that the major problem in the choice of air cleaning equipment for operations of this type was to find equipment which would efficiently remove airborne dust from exhaust system effluents. The process and the material were such as to dictate dry collection as the preferable means of dust separation. Particle size and dust concentrations in all cases were comparable to usual industrial loadings.

CHOICE OF EQUIPMENT

On the basis of our experience with the collection of this type of dust, the following criteria were applied to the choice of equipment:

1. To attain the high efficiencies required both by health standards and process accountability, electrostatic precipitation was considered uneconomical.
2. Inertial and scrubber type air cleaners were found to be inherently of too low efficiency for most of the materials to be removed.
3. Deep-bed filters were discarded as not having sufficient holding capacity nor would they permit satisfactory recovery of the material for reprocessing.

4. Any kind of well designed and constructed cloth filter arrestor was believed to be adequate for this job.

After a careful investigation of commercially available cloth collectors, it appeared that conventional equipment had several basic disadvantages for our type of operation. Briefly, these were:

1. Under our conditions of use, this equipment required a degree of maintenance in man hours per year which resulted in unacceptably high radiation dosage to maintenance personnel. The only protection possible against exposures of this type is uneconomical shifting of personnel to reduce the duration of exposure.
2. The same thing is true of dust exposures to these toxic materials. Although in most cases, this type of exposure could be reasonably well controlled through the use of personal respiratory protection; this type of protection is, in our opinion, undesirable.
3. Our experience showed relatively high out-of-service time resulting either in process or sometimes plant shutdown with the alternative of large unnecessary loss of valuable product.
4. The fluctuating collector pressure drop of the conventional dust collector required either exhaust system overdesign, or the operation of the system at low efficiency during a portion of the cycle. In either case, this resulted in a diminished economy and generally in some loss of product either through increased carry-off or increased dispersion into the working environment.
5. A study of plant effluents revealed that large bursts of dust found their way outside of the plant immediately after filter cleaning.

In our attempt to reduce these deficiencies, we investigated the use of reverse jet air cleaning equipment. Installations were made on small extremely difficult units and considerable experience was gained. As a result of experiences with the operation of these few early dust collectors, the decision was made to standardize on the use of wool felt, reverse jet type, air cleaning equipment in all cases where high efficiency of collection was required and where the material being handled was dry dust. Other types of collectors have been used under other conditions. However, the purpose of this report is to describe the experience of one plant in the use of this type of air cleaning equipment.

The information presented in this report covers the operation of 18 dust collectors built by two different manufacturers, all under the Hersey patent. These dust collectors are in continuous operation at the Mallinckrodt Chemical Works, Atomic Energy Commission plants.

SUMMARY

The following data summarize the conditions of operation:

1. They are operated at housing pressures varying from 2" center to 10" of mercury, vacuum.
2. The individual capacity range is from 700 cubic feet per minute on a pneumatic conveying system to 12,000 cubic feet per minute on a simple dust control application.
3. The total design capacity of all of these machines is about 110,000 cubic feet per minute.
4. The average operating dust load for the individual collectors covers the range of from a minimum of 0.002 grains per cubic foot to a maximum of 32.0 grains per cubic foot. A peak dust load in excess of 100 grains per cubic foot occurs in the one pneumatic conveying system. The overall operating average dust load is about 5 grains per cubic foot.
5. The discharge air from the individual collectors under full dust load conditions contains dust concentrations ranging from a minimum of 0.0001 grains per 1000 cubic feet to a maximum of 0.41 grains per 1000 cubic feet. The overall average being about 0.16 grains per 1000 cubic feet. The data include the filter for the pneumatic conveying system as well as all process dust control filters. It should be noted, however, that they represent normal operating conditions (including cleaning cycles) but do not take into account unusual losses through the collector from abnormal operations such as excessive seepage or bag failure.
6. The average cleaning efficiency found during the two-year study period on individual collectors in the group has ranged from a minimum of 99.946% to a maximum of 99.9996% with an average efficiency for all machines under all conditions of test of 99.986% for the same period.
7. The overall costs for operating this equipment including a five-year write-off on initial installed cost and all labor and material maintenance comes to 0.32 dollars per year per cubic foot per minute. This, however, is not an accurate presentation of the facts as this number includes a cost of over \$3 per year per cubic foot per minute for a single grossly undersized dust collector to an average of \$0.23 per cubic foot per minute per year for equipment of adequate design.
8. Maintenance costs alone amount to \$0.12 per year per cubic foot per minute when all units are included, and 0.042 dollars per year per cubic foot per minute for equipment of adequate design.

PILOT INSTALLATIONS

The first Hershey type filter installed at the plant was designed for an air/bag ratio of 20 cfm per square foot of filter surface. A number of small mechanical problems required correction before this machine gave satisfactory service, but once these corrections were made, it did do a very good job of air cleaning. Measurements made under operating conditions showed an average grain loading of 2.02 grains per cubic foot with an average cleaning efficiency of 99.977%. Within twelve months after the beginning of successful operations with this machine, two more machines were installed.

The second installation was also designed for 20 cfm per square foot, but before it could be completed, the process equipment was revised so that it became necessary to operate this machine at about 28 cfm per square foot in order to obtain satisfactory dust control. After start-up this machine was found to have dust loadings as high as 32 grains per cubic foot.

The third machine was installed as a final filter on a pneumatic conveying operation; it operates at an air/bag ratio of 17 cfm per square foot and an average grain loading of 1 1/2 grains per cubic foot with peaks exceeding 100 grains per cubic foot. This machine has given good cleaning efficiency, but maintenance problems have been excessive, indicating some deficiency in design. Certainly, for a collector of this design the dust and pressure loads are too high for the available filter.

In both of these latter filters the differential pressure across the filter was found to range from four to ten inches water gauge, even with continual operation of the reverse jet blow ring. Under the conditions as stated, bag life on both of these machines averaged about three weeks of operating time. There was found to be excessive stretching of the bags from the high differential pressure. This, combined with continuous blow ring operation, caused both the bags and the blow rings to wear excessively.

The experience gained with these three machines indicated that satisfactory cleaning could be done at an air/bag ratio of 20 cfm per square foot; however, it was apparent that when dust loadings were high enough to cause excessive pressure drops across the bag; the life of the filter would be shortened and maintenance would be high.

FIRST PRODUCTION GROUP

The next seven machines installed were designed to operate at a dust loading of approximately 1 grain per cubic foot of air, with air/bag ratios not to exceed 20 to 1. Many additional features were incorporated in this group of seven machines to eliminate some of the shortcomings which had developed with the first three installations.

Performance tests on these seven machines under operating conditions showed that six of them were doing a very satisfactory job of cleaning; the lowest efficiency found being 99.990%. The seventh machine, however, did not give completely satisfactory service, despite the fact that the air/bag ratio was only 17.5 to 1; with a dust loading of 4.2 grains per cubic foot. Extensive experimental work with this last machine established that the dust being handled is a "seeper" which migrates through the filter medium resulting in excessive losses. After several changes, a special resin treated felt which resulted in satisfactory operation was finally obtained from the supplier of the collector. However, this machine still gives as much trouble from a maintenance standpoint as any two other collectors of this group of seven.

SECOND PRODUCTION GROUP

Experience gained with this first group of machines resulted in the selection of a lower air/bag ratio for subsequent installations. Most of the collectors installed since that time have been designed to have an air/bag ratio not to exceed 15 cfm per square foot. The eight collectors installed since then have given very satisfactory long term operation.

MAINTENANCE PROGRAM

A preventive maintenance schedule provides for a daily inspection of all collectors and charts by production personnel. The Maintenance Department inspects each machine bi-weekly for mechanical conditions of bags, blow rings, suspension chains, drive sprockets, blow ring air supply tubes, etc., paying special attention to the following:

1. Blow rings must remain smooth and level to avoid excessive bag wear.
2. Bags must be maintained taut to avoid sagging or bulging.
3. Contact between blow ring and bag must be correct.
4. The blow ring air supply hose must be good to assure that bags are properly cleaned.
5. Canvas wear strips over sewed seams in the bags must remain in place to avoid splitting the bag from blow ring wear.

The Maintenance Department has assigned to one man the sole responsibility for all dust collectors; he has learned the problems of each individual machine and usually anticipates trouble before it happens. This policy has proved most advantageous.

Maintenance requirements for the eighteen collectors averaged 2 1/2 man days per week over a two-year period. If only 14 machines are included, this is a 1 man day/week. This covers both repairs and preventive maintenance.

With the exception of the three troublesome units previously discussed, maintenance problems have been minimal; however, none of these collectors can be expected to give continual good operation over long periods if allowed to go completely untended. It has been found desirable to provide safeguards in the form of instrumentation, a thorough inspection program and a preventive maintenance program in order to assure good continuous operations.

INSTRUMENTATION

All reverse jet collectors at the plant are now provided with pressure control instruments to provide intermittent blow ring operations; this instrumentation is of the recording type so that inspection of the charts immediately reveals abnormalities in operation. Optimum pressure setting maintains a pressure differential across the filters of between three and four inches water gauge. Electric eye dust detectors have been installed in the discharge stack of all collectors to detect bag failure. Thermocouples are installed in the housing of all collectors handling heated gases to provide an alarm and to safeguard against rises above permissible filter temperatures (175°F).

MAINTENANCE

The average downtime for sixteen of the collectors including preventive maintenance, has been less than two hours per month per machine. For the two remaining collectors downtime has averaged about two hours per week per machine; these machines are the pneumatic conveying system collector and the one other heavily loaded machine.

Average bag life for all machines included in these data was eight months per bag. However, this number does not correctly illustrate the true usage picture because it includes the high usage of the underdesigned pneumatic system and ore crushing system collectors, as well as the high usage on the seeper before the special resin treated felt was installed. The following breakdown shows actual usage by groups of machines.

| Machine | # Machines | No. of Bags | # Bags Replaced/ 2 Years | Bag Life Months/Bag |
|------------------|------------|-------------|-----------------------------|------------------------|
| Pneumatic System | 1 | 1 | 70 | 0.33-1.5 wks |
| Ore | 1 | 2 | 49 | 1 |
| "Black" | 1 | 4 | 16 | 6 |
| "Orange" | 1 | 4 | 16 | 6 |
| Others | 14 | 52 | 29 | 43 |
| TOTAL | 18 | 63 | 180 | 8 |

Since these data were collected, a new collector has been installed on the pneumatic conveying system. Although there are still some bugs in this system, bag life is now approximately two months. Further improvements to the system, now underway, are expected to extend this number to six months.

Plans to increase the size of the ore room collector were cancelled because recent process changes reduced both dust load and usage of this machine so that bag life now exceeds six months.

The special resin treated felt has produced satisfactory operations on the seeper and it is not planned to make further changes to this system.

ROUTINE MAINTENANCE PROBLEMS

1. Wear of supporting chains and drive sprockets results from excessive blow ring operation, from misalignment, and from faulty equipment design. Chain or sprocket slippage will cause cocking of the blow ring which in turn may tear up the filter medium and may cause breakage of the blow ring.
2. Failure of blow ring air supply hose due to excessive operation of the blow ring and/or poor alignment of air outlets on the side of the collector housing --- will result in failure to clean the filter medium which in turn causes excessive pressure drop across the bag with resultant bursting of the bag.
3. Excessive blow ring operation due to underdesign of equipment or to changes in ductwork - continuous blow ring operation causes unnecessary bag wear and low collection efficiency. This in turn causes frequent bag changes and high effluent dust loadings.
4. Faulty blow rings, i.e.: warping of the blow ring; improper manufacture, and poor selection of blow ring material; erosion of the blow ring surface, or buildup of residue on the face of the ring causing localized wear of the bag which eventually results in splitting. The material of choice for blow rings is stainless steel with overlapping staggered slots. It has been found that very few dusty materials will adhere to stainless steel and the hardness of stainless steel minimizes surface flaws.
5. High temperature will result in rapid degeneration of the wool fibers, which in turn cause frequent bag failure. Exhaust systems should be designed so that collector housing temperatures do not exceed 175°F.
6. Some chemical fumes may result in splitting of the bags at the seam due to acid or alkaline action on the material used to sew the seam. Wool felt is moderately resistant to both mild acids

and mild alkalines. However, the material used for stitching the seam should be selected to resist the particular chemical fume present. Nylon stitching has been found satisfactory for alkaline fumes and orlon stitching is satisfactory for acid fumes.

7. Poor clamping of the bag to the bag collar resulting in the bag tearing loose at high pressure differentials, with a resultant high loss of material in the effluent air stream.
8. Stretching of bags usually due to excessive temperature or excessive pressure drop across the bag --- the bag should be pulled tight at frequent intervals to avoid lapping of the filter media beneath the blow ring. This eventually results in creasing and splitting of the bag.

COSTS

Total maintenance cost for all machines during the two year period is summarized as follows:

| | |
|-----------------------------|------------------------|
| Total bag cost for 180 bags | \$16,500.00 |
| Blow ring hose | 1,800.00 |
| Miscellaneous parts | 2,000.00 |
| Maintenance labor | <u>6,300.00</u> |
| | \$26,600.00/2 years or |
| | \$13,300.00/year |

110,000 cfm @ \$13,300/year = \$0.12/year/cfm.

Operating costs may be computed on the basis of \$13.90/1000 cfm or \$1400 for 110,000 cfm. Assuming a five year write-off and using \$1.00/cfm as installed collector cost, the total annual cost for all machines is:

$$22,000 + 1,400 + 13,300 = \$36,700$$

or \$0.335/year/cfm.

Cost for maintaining new design equipment is obtained as follows:
Operating costs for 14 machines:

| | |
|----------------------------|-----------------------|
| Total bag cost for 29 bags | \$3,900.00 |
| Miscellaneous parts | 1,500.00 |
| Maintenance labor | <u>2,400.00</u> |
| | \$7,800.00/2 years or |
| | \$3,900/year |

93,000 cfm @ \$3,900/year = \$0.042/year/cfm.

A calculation similar to that made previously shows, for the 14 well designed machines:

| | |
|-------------------|------------------|
| Operating Costs | \$ 1,300.00 |
| Maintenance Costs | 3,900.00 |
| Amortization | <u>18,600.00</u> |
| | \$23,800.00 |

or \$0.256/year/cfm.

The following conclusions may be drawn from the above data:

| | <u>All Collectors</u> | <u>Well Designed Units</u> |
|----------------------------------------|-----------------------|----------------------------|
| Man hour/week for maintenance | 2 1/2 | 1 |
| Downtime - hours/month/machine | 3 | 2 |
| Bag life - months/bag | 8 | 43 |
| Total cost - \$/year/cfm | 0.335 | 0.256 |
| Maintenance cost - \$/year/cfm | 0.120 | 0.042 |
| Total cost - \$/ton material handled | 6.50 | 5.00 |
| Maintenance & operating costs - \$/ton | 2.50 | 1.00 |

An interesting comparison can be drawn between the operation of these dust collectors and that of three large wet collectors recently reported by Bloomfield*. These three units were high efficiency wet collectors with a cumulative capacity of approximately 52,000 cfm. Installed cost of these collectors is \$38,600 or 0.74 dollars per cfm. On the basis of the data given, the annual cost of these collectors, neglecting maintenance is:

| | |
|---------------------------------------------------------------|------------------------------------------------------|
| Operating Cost (assuming power at an average cost of 5 mills) | \$ 2250.00 |
| Maintenance | -- |
| Amortization | <u>8000.00</u> |
| TOTAL | \$10250.00 or 0.197 dollars per year per cfm. |

The overall average efficiency of these collectors operating on an average dust load of 1.70 grains per cubic foot is 93.5%.

* "Efficiency Studies on Three Wet Type Dust Collectors", Heating and Ventilating, Volume 51, No. 4, Page 89, Bernard D. Bloomfield.

It can be seen from the above data that any cost advantage is lost when the material being collected can be valued at \$16.00 a ton or more.

It is also interesting to note that the installed cost of collector A operating at 89% was .64 dollars per cfm, while collector C which had an average efficiency of 97% cost 1.20 dollars per cfm.

VENTILATION AND DUST CONTROL IN REFINING
URANIUM ORES AND CONCENTRATES

H. I. Miller, Jr.
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The metallurgical processing of most ores and concentrates is attended by the presence of noxious or nuisance dusts and gases that must be controlled to varying degrees depending on the toxicity of materials encountered. The refining of uranium ores and concentrates into the metal is typical in a general way, involving heavy metal dust, hydrogen fluoride, and oxides of nitrogen. To these are added the unusual categories of radioactivity of radium during the early stages of the refining process, and radioactivity of the uranium and its daughter products throughout. Operations involving these elements call for control of air pollution, both within and outside of the operations area, to an unusually high degree. Fortunately standard ventilation and dust control equipment can be adapted to the purpose.

This paper presents some of the problems and their solutions in the design of control facilities for health protection in a large uranium producing plant operated for the Atomic Energy Commission.

Design criteria called for maintaining an operations atmospheric pollution level for radioactive dust not to exceed 70 disintegrations per minute per cubic meter of air (which for uranium is equivalent to 50 micrograms per cubic meter). This figure served for dust control of uranium and any dusts associated with it, including pitchblende dust with its radium content. Uranium is an alpha-ray emitter. Direct radiation from it is unimportant, being stopped by almost any barrier, including the normal skin. However, inhaled or ingested into the body where it attains close proximity to tissue it can do serious harm. Uranium slowly breaks down into daughter products, UX_1 and UX_2 which are beta-ray emitters. The beta rays encountered in this process are readily stopped by thin glass or metal so that hood or hopper may provide ample protection from radiation.

The radium in the pitchblende ore and in the process rejects is a gamma ray source and constitutes the most serious direct radiation hazard in the process. Design criteria called for a maximum weekly exposure of 300 mr. of gamma radiation. Actual design was predicated on a tolerance of half this amount to allow for inevitable short periods of high level exposure by operators subject to unusual duties. Radium is always accompanied by its daughter product, radon gas, for which the design criteria limit was 10^{-8} curies per cubic meter of air (or approximately 7×10^{12} parts per million).

Other contaminants were to be limited in accordance with currently accepted standards for maximum allowable concentrations.

INTEGRATION OF DESIGN

The project group handling the industrial hygiene phases also bore the responsibility for radiation protection and for the general heating and ventilating of buildings, in order to coordinate effectively all these interrelated functions. This group of specialist engineers produced completely integrated design to satisfy the requirements for process, health, and comfort in the working environment. It is not especially pertinent to this paper, but of general interest as to coordination of effort, that this project group also designed (1) a medical dispensary completely equipped to do X-ray work and minor surgery; (2) a "health-physics" laboratory, with instrument repair and calibration facilities, machine shop, dark room, and chemical laboratory, with associated equipment; and (3) a decontamination room, furnished with fixed and portable equipment suitable for treatment of surfaces contaminated with radioactive materials; even a repair shop for contaminated shoes was set up in this room. These features, along with specifications covering issue clothing and shoes, were done in consultation with medical and health specialists of the Atomic Energy Commission and Operating Contractors, who made available their wealth of experience.

The design approach for ventilation and dust control did not differ, except in degree, from usual industrial hygiene methods. They had to be adapted, as necessity dictated, to the interposing of radiation barriers and remote control.

The methods may be briefly listed as (1) isolation of process, (2) application of local and/or general exhaust ventilation, (3) highly efficient filtration of solids from collected air, and neutralization of acid vapors where appropriate, (4) dispersion of effluent gases by discharge through high stacks, (5) provision of adequate tempered make-up air to replace that exhausted, and (6) wet handling. Although it is impossible to separate out each entity for discussion in its own right because of the general interrelationship, an attempt is made in the remainder of this discussion to indicate briefly examples or considerations for the methods listed.

ISOLATION OF PROCESS

The value of the materials, as well as their toxicity, required that special effort be made to utilize tightly inclosed equipment, such as elevators, conveyors, blenders, batch dumping equipment. Theoretically these can be maintained dust-tight, but actually poor maintenance must always be presumed. Where there is any possibility of dusting out, local exhaust ventilation must be applied to the inclosure. In fairly tight systems there arise the problems of air quantities and the maintaining of conveying velocities for dust laden air under varying circumstances. A discussion of these matters is given under EXHAUST VENTILATION below.

The major point to be emphasized in this connection is the importance of keeping process materials within the process stream and thereby minimizing the health and economic problems of rehandling that portion collected as dust.

An example of a process not amenable to control by closely applied cover or exhaust ventilation was the weighing and deheading of drums of pitchblende. These operations had to be walled off because of gamma radioactivity, and incidence of radon and dust. For protection of plant employees these operations were established in a closed ventilated room utilizing remotely operated equipment. It was expedient further to isolate the operator in a concrete walled room that projected into the processing area. The concrete walls and a lead

glass window provided for his complete protection.

The handling of hydrogen fluoride is obviously a dangerous operation, and where it was necessary to do so indoors, the bulk of the equipment was isolated in a walled off area of the building, provided with continuous supply and exhaust ventilation at about fifteen air changes per hour. Emergency ventilation fans were furnished that would move up to about sixty air changes per hour and these were linked electrically with automatic dampers in the exterior walls which would open when the fans operated, insuring adequate inflow of air to the space.

EXHAUST VENTILATION

Both local and general exhaust ventilation were employed wherever needed throughout the project.

Dust control claimed the major portion of all the design work done on the industrial health aspects, embracing a variety of processes in several buildings. Self-balancing systems were designed such that at the desired rates of flow the total pressures at main and branch junction points were calculated to be identical.

It is not infrequently the case on construction contracts, and this was no exception, that dust collecting and other air handling equipment must be ordered very early in the design period to insure delivery on time. This meant estimating collecting requirements before the process equipment was fully known. Then, after process design was firm, however changed, it meant recalculating the local exhaust systems to (1) give the desired control, (2) be self-cleaning, (3) be self-balancing, and (4) be adaptable to the collectors bought. Heat losses in some buildings were only a fraction of the heat required for replacing ventilating air, so that the procurement and adequacy of supplied air heaters and blowers were directly affected by the early estimates. Successful accomplishment of this type of work necessitates specialists of considerable experience and judgment.

The handling of hot corrosive dust laden gases, sometimes accompanied by water vapor, required alloy ductwork and collectors as well as judicious cooling by water jacketing of ductwork in some instances or introduction of dilution air.

Air quantities for local exhaust ventilation were determined by the needed inflow through actual and anticipated openings to prevent contaminant from getting out. Volumes and entrance losses for the unusual types of hooding were readily determined, but, for tightly closed vessels receiving dry materials, venting for egress or ingress of air had to be provided, and for reasonably tight systems some provisions had to be made for inspection ports which might be left open or panels not tight. Three measures were employed.

1. Where a vessel was perfectly tight and was to fill or empty at a steady rate, a breather bag of large size was suspended vertically, the top end closed and the lower end tied over a short vent pipe on the vessel. Usually a dust collector bag was used. A weather cover was furnished on outdoor installations. No exhaust ventilation was applied.

2. For tight weigh vessels, not tolerating a breather bag, a conical or bell-shaped exhaust system inlet was located over and around the top of the vent, but not touching it. This is an adaptation of the familiar draft diverter stack connection used on domestic gas furnaces. The required velocity of air for dust carrying is maintained in the exhaust branch without physical connection or undue draft on the vessel, yet any escaping dust is captured. Volume and velocity of the exhaust air must be adequate for any expected surges when filling the vessel.

3. For fixed vessels or reasonably tightly enclosed systems a rigid duct connection was made. A port was cut into the side of the duct close to the connection and a sliding sleeve installed to permit covering as much of the port as necessary for control. This device permits application of draft to the vessel or system exactly as needed and allows sufficient by-pass air through the port to maintain carrying velocity.

Powered roof ventilators were widely employed for general ventilation for the removal of heated air generated by process or summer sun. A five degree F temperature rise over ambient was usually taken as permissible for calculating volumes to be removed. (Make-up air was not provided for heat removal exhaust).

An exhaust system of some interest was that provided in a pitchblende thawhouse for removal of radon. A thawhouse is a necessity in winter for treatment of frozen drums of ore prior to processing. Enormous quantities of heated air would be needed for the combined requirements of radon removal and thawing under ordinary circumstances. Using the isolation principal, the thawhouse was made up as a tight box, the drums of pitchblende traversing it on powered conveyors between steam heated plate coils. Inlet and outlet doors were self-closing, counter balanced, open only for introducing or releasing drums. An exhauster, discharging to a high stack, was made to operate continuously. It could draw little air except when a thawhouse inlet or outlet door was opened, and even then it was dampered to about half capacity. Should access by personnel be necessary either or both of two large purge doors in the sides of the thawhouse could be opened, whereupon the exhauster damper would automatically open wide and the chamber would be purged of the heated, highly radon-contaminated gases. Blocking open the end doors would hasten the purging. Following the emergency, shutting the purge doors cause the fan to be dampered as before. (Of course the radiation hazard is serious in this building so that operators having to enter can stay only a very limited time.)

For completeness, it is well to mention that a piercing device was placed at each inlet door for perforating heads of drums prior to their introduction. By this means any dangerous steam pressure buildup in the drums during thawing was averted.

FILTRATION OF SOLIDS

The choice of air filtration equipment for uranium dust and associated materials was the reverse jet suspended bag-type collector. Cost, adequacy of filtration, commercial availability, practicability for maintenance, and successful experience in similar operations were all important considerations. Although not subjected to the heavy loadings for which this type collector was designed it had been found to give better than 99 per cent recovery at fractional grain loadings of comparable dust. An optimum filtration rate of 10 to 11 cfm per square foot of filter cloth was determined on an efficiency - horse-power - maintenance basis; 15 cfm per square foot was the design maximum. The bags employed were a special resin treated wool felt, and ranged from 9 to 18 inches in diameter, depending on the vendor. Their top operating temperature was limited to 180°F. Recently, calendared orlon bags have become available and some were furnished to the project on an experimental basis. These show much promise in regard to acid and alkali resistance, high temperature (275°F.) and wear.

Fixed vacuum cleaner systems were established for cleanup work, and in some instances to provide or supplement local exhaust ventilation. The effluent air from these, having been filtered in cotton bags, is directed to reverse jet bag-

type collectors for cleanup. The vacuum cleaner systems in many instances also provide dust collector unloading facilities. These collectors so served are fitted at bottoms of hoppers with a unique wind-swept valve connected to the vacuum system. All dust caught in several collectors can be transported to one locality where the material can be placed in drums and returned to process. Dust collectors were thoroughly instrumented. Each stack is monitored by a photoelectric haze detector with alarm to warn of leaking or broken bags. To reduce wear on bags and to maintain a high filtration efficiency, blowing operation is controlled by differential pressure across the bags, usually being placed in operation at four inches water gage and cutting off at two inches water gage. Each collector has a low differential pressure alarm, normally set at one inch water gage. This device also detects broken bags.

Wet collectors were specified for handling steamy dusty air, utilizing the principle of passing air around an underwater baffle. Provision was made for fiberglass after-filters, should they be required. Electrostatic mist collectors were provided for handling uranium bearing oil mist from machining operations, the cleaned air being returned to the room.

MAKE-UP AIR

In buildings having exhaust ventilation the provision of make-up air is an important factor in the control of toxic dusts or gases. It is often overlooked. Where small volumes are withdrawn infiltration may be adequate, but it is always well to investigate. To prevent rooms or buildings becoming airbound and to insure the unimpaired functioning of hoods and inclosures connected to exhaust systems, make-up air was carefully distributed, tempered as needed, in amount equal to or slightly greater than that withdrawn. In most instances it was further heated to take care of the winter heating requirements of the building. To conserve steam the large make-up air units were automatically dampered to recirculate room air when exhaust ventilation systems were shut down. Each such supplied air unit consists of a standard steam coil and blower set supplemented by a moving frame automatic oil-type air filter and by a damper set and controls that permit outdoor air for make-up and recirculated air for the remainder. The filter protects the heating coils and keeps dirt out of the distribution system. The oil in the filter is itself cleaned by pumping it through a replaceable cartridge filter similar to that in an automobile oil system.

Supplied air distribution systems followed the usual ASHVE practice. Stainless steel and protective-coated steel had to be provided in corrosive areas. Certain recirculating air heating coils were protected by a baked-on protective coating.

WET METHODS

The handling of the reject gangue materials with which the radium leaves the process stream offered a potential hazard as (1) radioactive dust, (2) a source of direct gamma radiation, and (3) a source of radon gas. Catalytic's process engineering group worked out a system such that the material is never handled in dry form. Following digestion of the ore, the insolubles are filtered and washed and the wet filter cake is repulped immediately. The resultant slurry, carrying the radium, is pumped to large covered concrete storage tanks located well away from the operations area. The solids settle out in these tanks and the

clear decant liquor is recycled for use again as the repulping medium. The filtration is done in ventilated rooms behind barrier walls.

Reference was made earlier to the use of fixed vacuum cleaning systems for cleanup of dry materials. For wet spills sump systems were provided into which the floor and platform washings can be directed. Sump contents are subsequently introduced into the process stream in wet form.

SPECIAL PROBLEMS

There were many unusual problems. One wherein processing and health were equally demanding involved the ventilation of a rotary pitchblende dryer. As much as five per cent of the charge could be carried over in the off-gases, which were to be in the vicinity of 400°F., undoubtedly 100°, or more, higher at times. Bag filtration was the method of choice, but bag allowable temperature was limited at the time to 180°F. To cool the gases a heat exchanger was procured, having a water tube bundle suspended in an insulated shell through which the gases should pass. To prevent condensation on the tubes (gases could have as high as 130°F. dew point) and to minimize dust adherence to cold surfaces a recycling system for the cooling water was designed to maintain its entrance temperature at about 100°F. (A higher temperature gave too little spread for cooling.) To relieve the cooler of the great burden of dust a multi-cyclone was provided ahead of the cooler. Both cyclone and cooler were equipped with rotary feeders continually discharging the accumulated dust to a process conveyor. Finally, the riser from dryer to multi-cyclone was made as large as practicable to reduce the velocity and the carryover (about 1400 fpm was the lowest attainable). Such a system is more complex than desirable, but with attention will pay for itself in values saved many times over.

TESTING

All heating and ventilating and vacuum cleaning systems were subject to rigid performance testing by the construction contractor prior to turnover to the operating contractor. Catalytic specifications covered air quantities, balancing, permissible instruments for testing and methods of conducting tests, as well as workmanship and furnishing of specified materials and equipment. Very generally +15 to -5 per cent of design rating was allowable for dust collector systems, with a + 10 per cent for balancing. Supplied air systems, being less complex and being balanced by dampering, were required to be balanced to + 5 per cent.

In conclusion it is worth noting that the work done on this project on heating and ventilating and dust control occupied the efforts of six engineers for 1-1/2 to 2 years and resulted in installations in these categories approximating some \$2 million, installed cost, or about 2-1/2% of total project cost.

In the six major plants - Ore Refining, Green Salt, Metals, Metals Fabrication, Sampling, and Scrap - there are 34 dust collectors and 34 fixed vacuum cleaners, plus certain auxiliary continuous exhausters, emergency exhausters, and requisite make-up air heaters. Based on procured equipment only (not including piping, ductwork, conduit or any installation costs) all such heating and ventilating equipment represented about 4 per cent of the total process equipment cost for these plants. The variation was 2-1/2% to 10%. Hersey-type

collectors ranged in size from 600 cfm (at equipment cost of \$3 to \$6 per cubic foot depending on design and use of stainless steel) to 15,000 cfm (at \$0.95 to \$1.35 per cubic foot).

Acknowledgment is made of the considerable assistance afforded by Mr. W. B. Harris and his staff of the Health and Safety Laboratory, New York Operations Office, AEC; also that received from Messrs. K. J. Caplan and Mont G. Mason of Mallinckrodt Chemical Works, St. Louis, and from Mr. R. C. Heatherton and Joseph Quigley, M. D., of National Lead Co. of Ohio, Cincinnati.

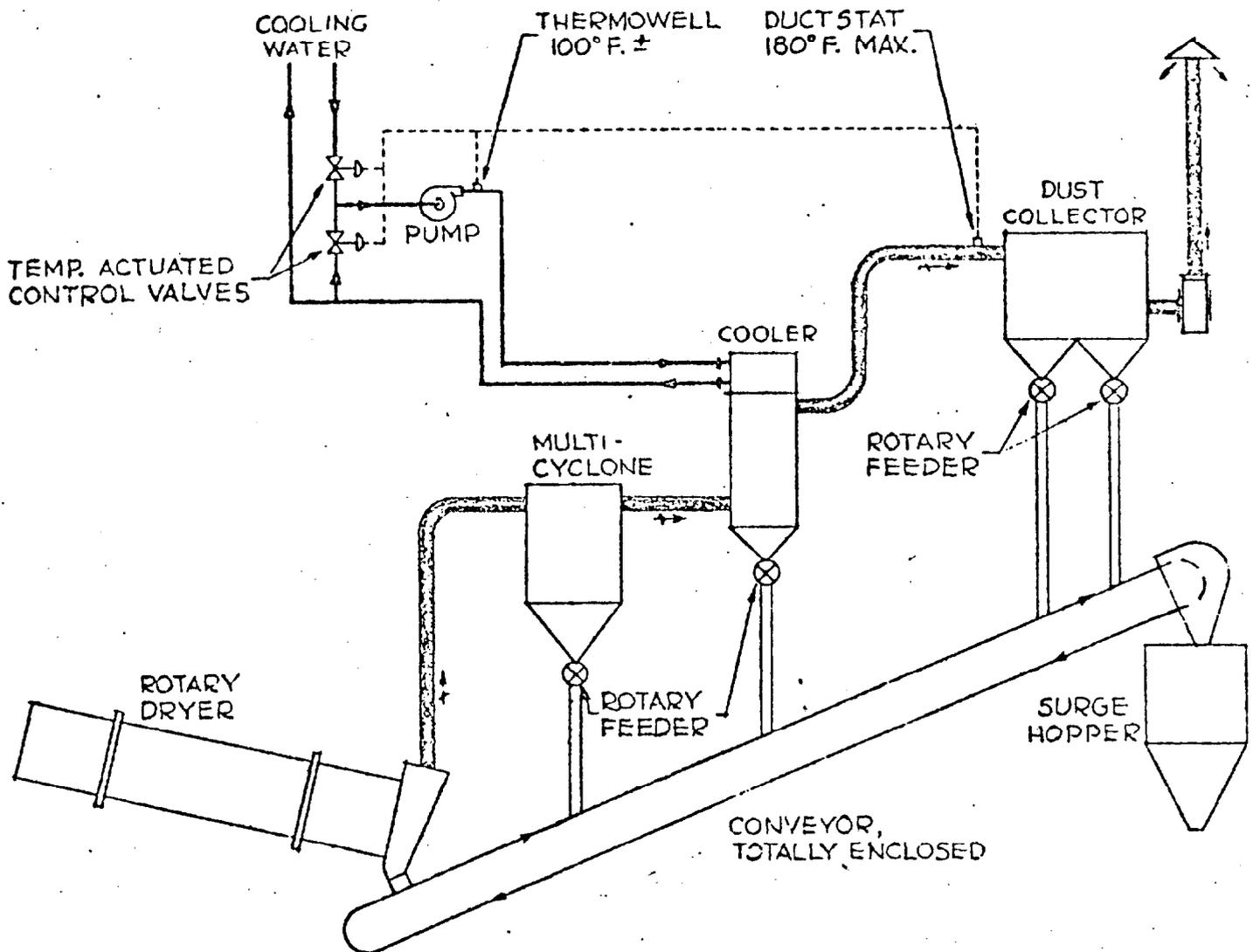
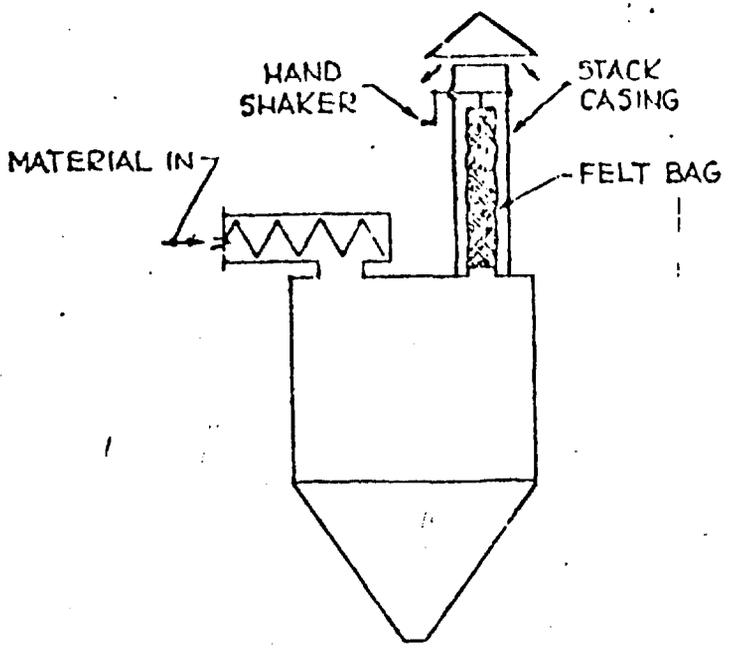
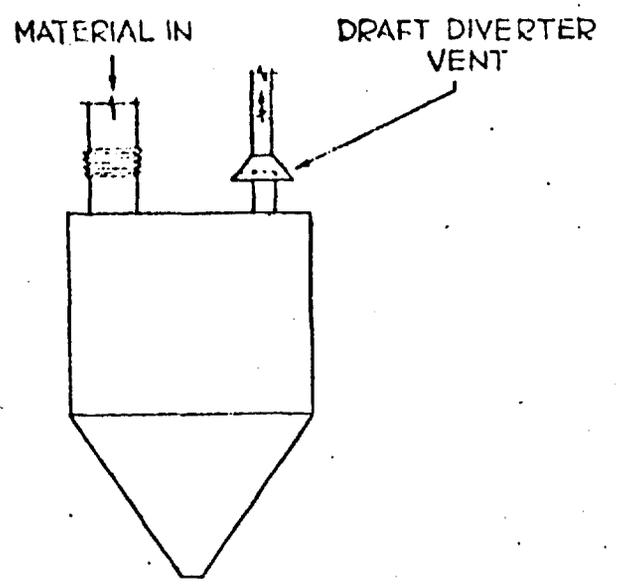


Figure 1

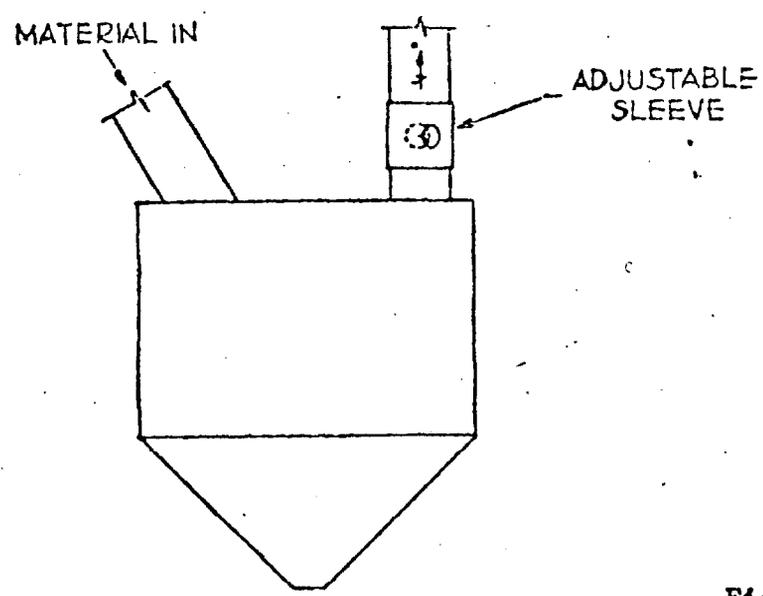
FLOW DIAGRAM
DUST COLLECTION - DRYER SYSTEM



HOPPER VENT
DUST FILTER



FLOATING OR
WEIGH HOPPER



STATIONARY
SURGE HOPPER

Figure 2

REPRODUCED FROM

TESTS OF THE AERODYNE DUST COLLECTOR
Warren H. Smith, G.E., ANP

This presentation of the air cleaning program of the Aircraft Nuclear Propulsion Department of General Electric will be limited to recent tests of the Aerodyne dust collector.

Mechanical dust separators usually do not involve as great expense due to accumulated dust as do filters. The Aerodyne was a mechanical dust separator which was available for test and which appeared possible to operate at required efficiency in the 2 to 5 micron range of dust particle size. Previous tests on the Aerodyne had been made at dust concentrations of 0.5 grain per cubic foot and higher, as are encountered in usual dusty industrial processes. This information indicated an increase in efficiency with a decrease in dust concentration. No information was available at concentrations below 0.5 grain per cubic foot or with relatively high specific gravity of the dust material. This test was made to cover the range of dust concentration below 1/2 grain/CF. The efficiency of dust separation is dependent upon the size distribution of the test dust. To test the efficiency at small particle sizes, it is necessary to separate, from the test dust, the large agglomerates, which may contribute a large fraction of the mass. To permit comparison of results, the size distribution of the airborne dust must be determined.

The essential feature of the Aerodyne dust collector is a cone, shown in Slide 1; this cone is the primary separator, in which dust is concentrated toward the apex; the separation occurs when the air makes a sharp turn out through the louvres and the dust, having greater inertia keeps a straighter path, toward the apex. (Slide 2). About five percent of the total air flow, along with the separated dust passes out from the narrow section of the cone and is drawn through a two stage cyclone separator of conventional design. The cyclone effects final concentration of dust to solid material. The air from the cyclone goes through a blower necessary to maintain circulation in the secondary loop, and from the blower is returned to the duct above the inlet to the cone.

Most of the total air flow entered the test system through efficient paper filters; a small fraction was supplied by the jet.

The test dust was cupric oxide powder, of Merck or Baker & Adamson manufacture, technical or CP grade.

The dust was dispersed from the jet shown in Slide 3. The copper oxide agglomerates were transported to the jet where much of the agglomerated material was sheared into smaller particles. The dust feed system is shown in Slide 4.

The copper oxide was fed to the pneumatic transport tube at an adjustable rate by raising a hydraulic elevator. The elevator and copper oxide tube were in a pressurized container, built up from pipe, tubing, and fittings: the standard fittings are not detailed in the schematic drawings. Compressed air at about 90 psig

was put through 2 parallel, porous, liquid entrainment separators and then through a depth of about 6 feet of 6-12 mesh silica gel to make the air unsaturated. This dried air was fed to the jet and to the pressurizing container for the feed tube. The flow through the pneumatic transport line was stabilized by a diaphragm pressure control and adjusted to maintain the copper oxide powder level in the supply tube about one inch below the inlet of the transport tube to the jet. Use of a plastic viewing window, glass supply tube and a small light permitted observation of the copper oxide level in the supply tube and indicated the uniformity of delivery to the transport tube. Feed rates yielding from .5 grain/cubic foot down to .0087 grain/cubic foot were used, at 2320 standard CFM total flow.

Some control of the particle size distribution for the larger particles was obtained by variation of the average residence time for air in the dust chamber, dependent upon the location of the partition, as shown in Slide 5.

Flow through the sampling filters was either limited by a critical pressure orifice or measured by a Fisher-Porter flowmeter with indicated rates reduced to standard pressure.

Total air flow was measured by the differential pressure across the standard flow nozzle. Readings were corrected for barometric pressure and temperature. The average of 20 values is given; the maximum deviation from the average was 2%. Manometers were also used to check pressure differentials across the large filters, across the blowers, and at several other points of the flow system.

The efficiency of dust separation was obtained by weighing the dust collected in the Aerodyne dust chamber and taking the ratio of this to the amount delivered to the Aerodyne; the amount delivered is the difference between the total amount fed to the jet and the amount that settles out in the large dust chamber. The amount settling out was determined by careful cleaning of the large dust chamber with a "Filter Queen" brand vacuum cleaner. With this cleaner it is possible to weigh the filter and collected dust separately from the rest of the cleaner so that accuracy to one thirtieth ($1/30$) of one ounce is possible. The same method was used to get the weight of CuO in the dust collection chamber of the Aerodyne Unit.

The Aerodyne Unit as supplied by the manufacturer gave separation efficiencies around 41%, due to partial flow through a pipe from the dust concentrate line to the main blower, (Slide 2). When this opening was plugged and reasonable flow established in the secondary flow circuit by increasing the secondary blower speed by 33% to give .3 inch water lower pressure in the cone exit than in the cone chamber, the dust removal efficiency was increased to the values given in the abstract, 62 to 79%, depending upon dust concentration.

The airborne dust particle size distribution was obtained by examination of a typical area of a "Millipore" analytical filter, upon which a sample of the dust was deposited.

The dust particles were compared in size with circular areas on an eyepiece reticle, made by Kodak, Ltd. The comparison areas increased geometrically, each being twice the next smaller one. The parameter M, Slide 6, is the index number of the areas, and corresponds with the micron scale when the oil immersion, 95X objective was used, with 15X eyepiece. Other magnifications were used to increase the statistical accuracy for larger particles, but the data at high magnification is required to provide the distribution at small sizes. Use of the 3 magnifications and reduction of data to equivalent 95X conditions leads to some non integral values of M. All data are normalized to the same total area, corresponding to 30,300 reticle fields with the 95X objective; the data plotted indicate the overlapping ranges of size observed at the 3 magnifications used. The particle distribution by number, $\frac{\Delta N}{\Delta M}$, as graphically averaged, was multiplied by the particle volume and normalized to give the mass distribution:

$$51.5 D^3 \left(\frac{\Delta N}{\Delta M} \right)$$

The mass median was obtained by numerical integration of the mass distribution, giving the value 4.3 microns; the mass median size is indicated.

The overall efficiency* of the Aerodyne, E, is in terms of the separate average efficiencies of the cone, E₁, and of the cyclone, E₂:

$$E = \frac{E_1 E_2}{1 - E_1 (1 - E_2)}$$

This relation follows from the steady state condition for the mass of dust recycled per second, K, in terms of the efficiencies E₁ and E₂ and the dust mass fed to the system per second, M:

$$K = (K + M) E_1 (1 - E_2)$$

Here K + M is the dust load per second entering the Aerodyne cone, E₁ the average efficiency of the cone, not for the primary dust, but for the combined distribution of primary feed M and recycled dust K; this combined dust tends to smaller average particle size than the primary dust because the cyclone separation efficiency is higher for larger particles; however, a competing effect, the higher efficiency of the cone for larger particles, tends to increase the size of the recycle dust compared to primary. The cyclone efficiency, E₂, similarly applies to K + M, the combined

* Derived by C. C. Gamertsfelder, private communication.

distribution, but multiplied by the separation efficiency, a function of partial size, for the cone.

To investigate the influence of the cyclones upon the efficiency of the Aerodyne, the cyclone unit was replaced for one run by 4 two inch thick American Air Filter "Amerglass" filter units in series, as indicated by the dotted squares in Slide 2.

With other conditions the same as when the overall efficiency of 69% was obtained with the cyclones as dust collectors, with the filters an overall efficiency of 73% was obtained. The amounts recovered on the successive filters were 271, 53.3, 10.7 and 4.0 grams, indicating that the first filter removed 78%. The amounts collected on each filter are plotted (Slide 7) and if the curve is extrapolated to estimate the efficiency of the four filters by comparison with an infinitely thick filter, then the efficiency of the four filter units used was 98%. This indicated that the Aerodyne cone efficiency was about 73% at this dust concentration; recycling in the secondary flow circuit is here unimportant since the small sizes passed by the four filters are passed with high probability by the Aerodyne cone.

If the cone efficiency of 73% is used with the overall Aerodyne efficiency of 69% (all at .1 grain/cubic foot), and if the efficiency for the combined recycle and primary dust is assumed the same as for the primary dust, the calculated cyclone efficiency for the combined dust is 82%.

The efficiency relation gives useful and possibly unexpected results:

| E_1 (primary) | E_2 (secondary) | E (overall) |
|--------------------|----------------------|------------------|
| 50 | 100 | 50 |
| 100 | 50 | 100 |

These values indicate that the primary efficiency E_1 is (if both E_1 and E_2 are tolerably good) much more important.

The Aerodyne Test Results are tabulated:

Weights of CuO, grams:

| To Jet | Settled in Dust Chamber | Delivered to Aerodyne | Collected by Aerodyne | Collection Efficiency % | Dust Concen- tration grains/ cubic foot |
|--------|-------------------------------|-----------------------------|-----------------------------|-------------------------------|-----------------------------------------------|
| 820.0 | 461.6 | 358.4 | 222.3 | 62 | .49 |
| 614 | 248 | 366 | 252 | 69 | .112 |
| 710 | 231 | 479 | 349* | 73* | .112* |
| 621 | 281 | 340 | 269 | 79 | .0087 |

* Filters replaced cyclones.

ACCURACY:

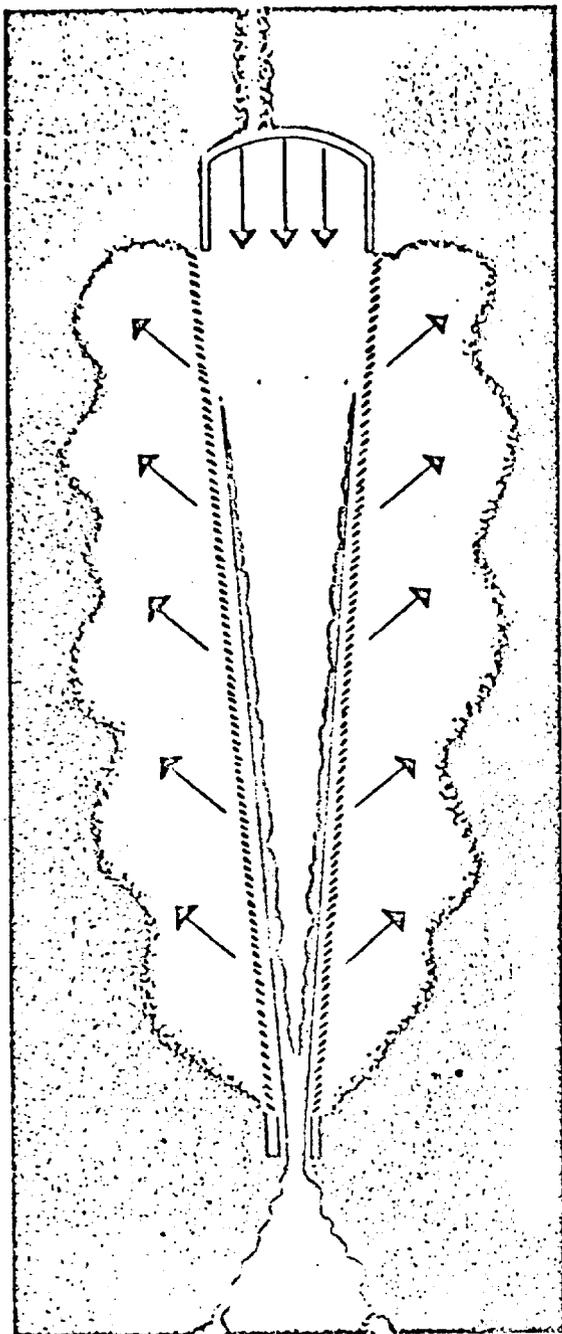
Weights were accurate to 1% or to one gram, the larger being applicable. The collection efficiency accuracy is 1%. The particle size distribution by number has statistical accuracies of 10% from .3 micron to 5 microns, 17% at 6 microns and 30% at 8.5 microns; no particles larger than 9 microns were found.

Systematic variation from one magnification used in counting particles, to another magnification displaced the corresponding points of the distribution by slightly more than $\Delta M = 1/2$.

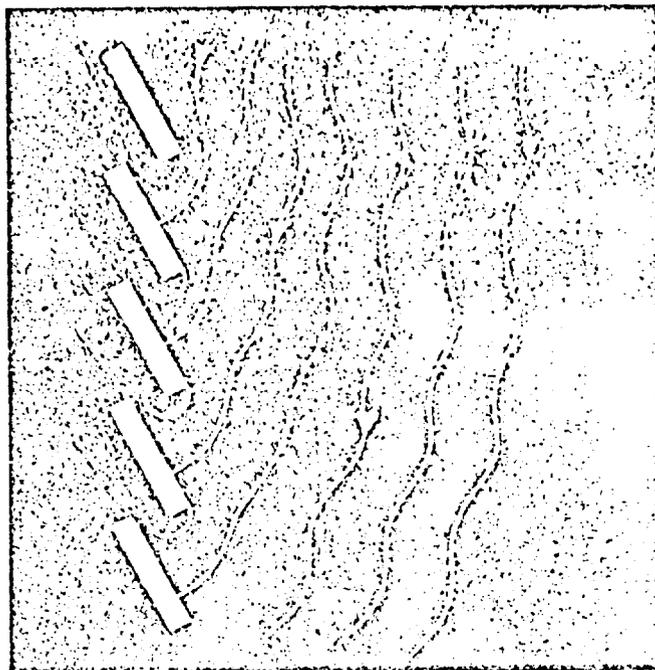
Each particle was assigned to a group within $\Delta M = 1/2$. The perceptible dispersion of the experimental points of Slide 6 is due primarily to the difficulty in classification by group index M, even though eleven groups were used. This source of error is larger for smaller numbers of groups. The mass median, 4.3, microns, is accurate to one micron, limited by experimental uncertainty in the distribution.

To summarize, the efficiency of an Aerodyne Dust Collector was determined as a function of dust concentration, for values below 1 grain/cubic foot. Copper oxide powder was the test dust, with an experimentally determined mass median of 4.3 microns and with no particles observed above 9 microns. The efficiencies obtained were:

| <u>Approximate Dust Concentration</u> | <u>Weight Efficiency</u> |
|-------------------------------------------|--------------------------|
| .5 grain/cubic foot | 62% |
| .1 grain/cubic foot | 69% |
| .01 grain/cubic foot | 79% |

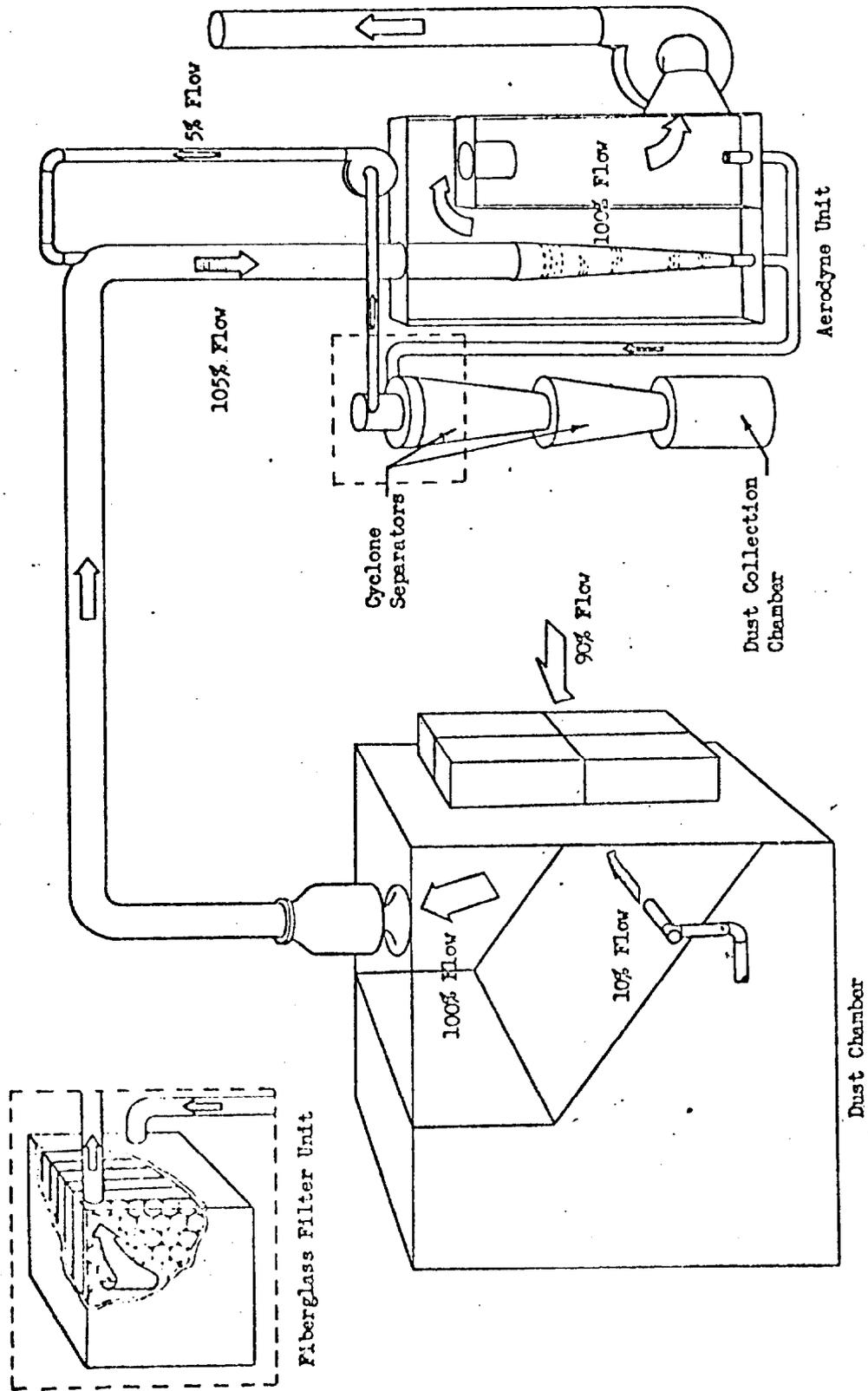


AERODYNE CONE FLOW AND
DUST SEPARATION

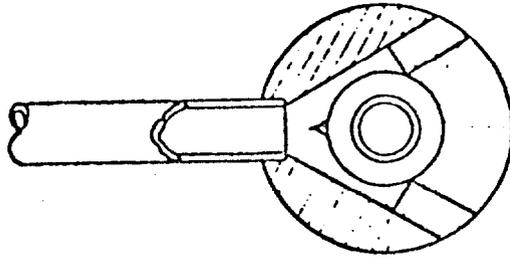


LOUVRE FLOW DETAIL

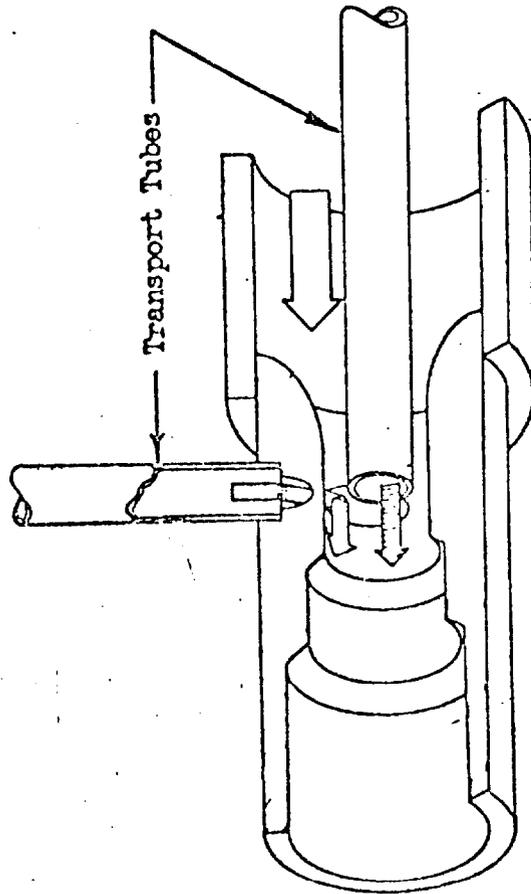
SLIDE 1



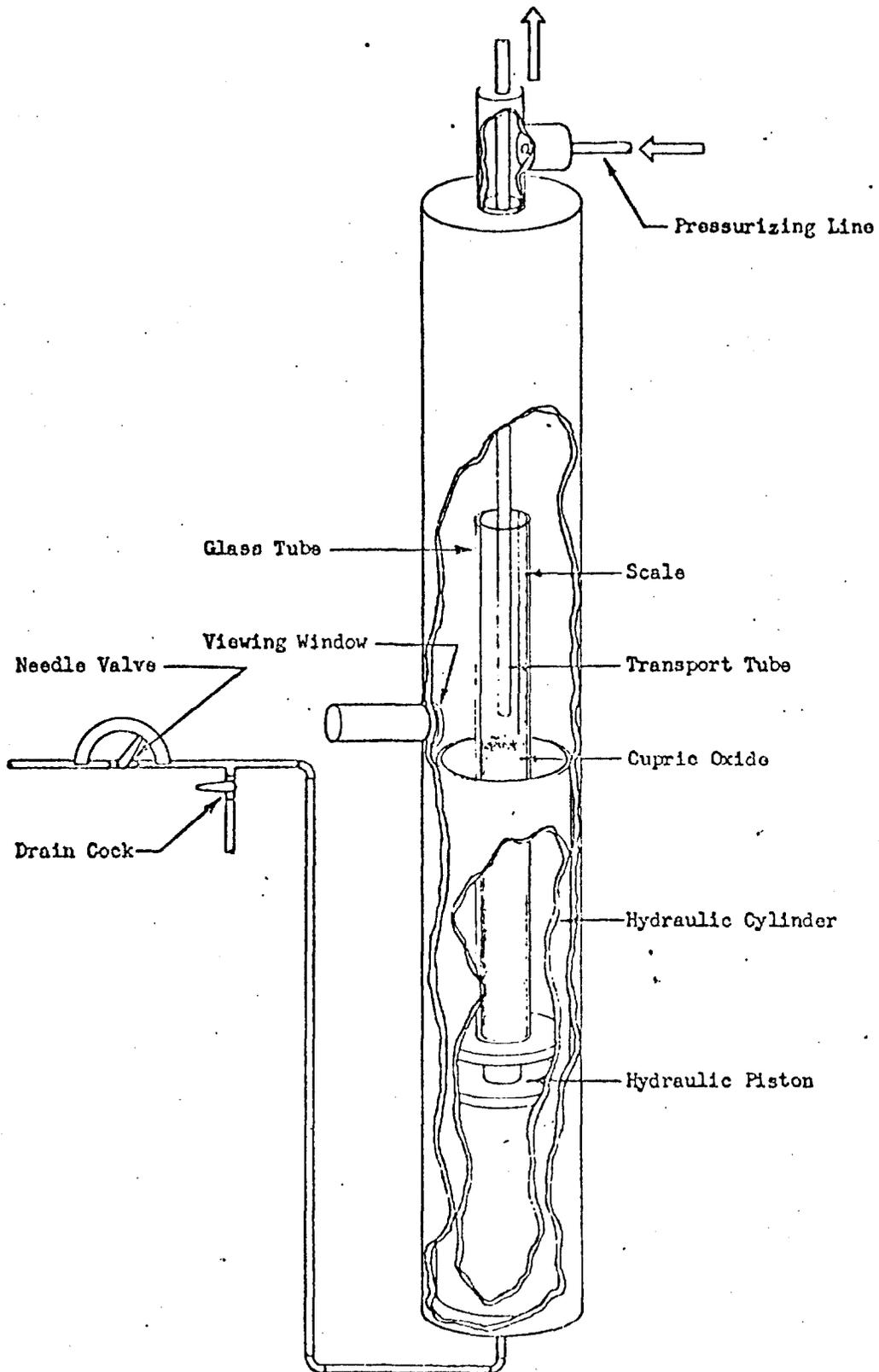
Slide 2. MAIN FLOW SHEET



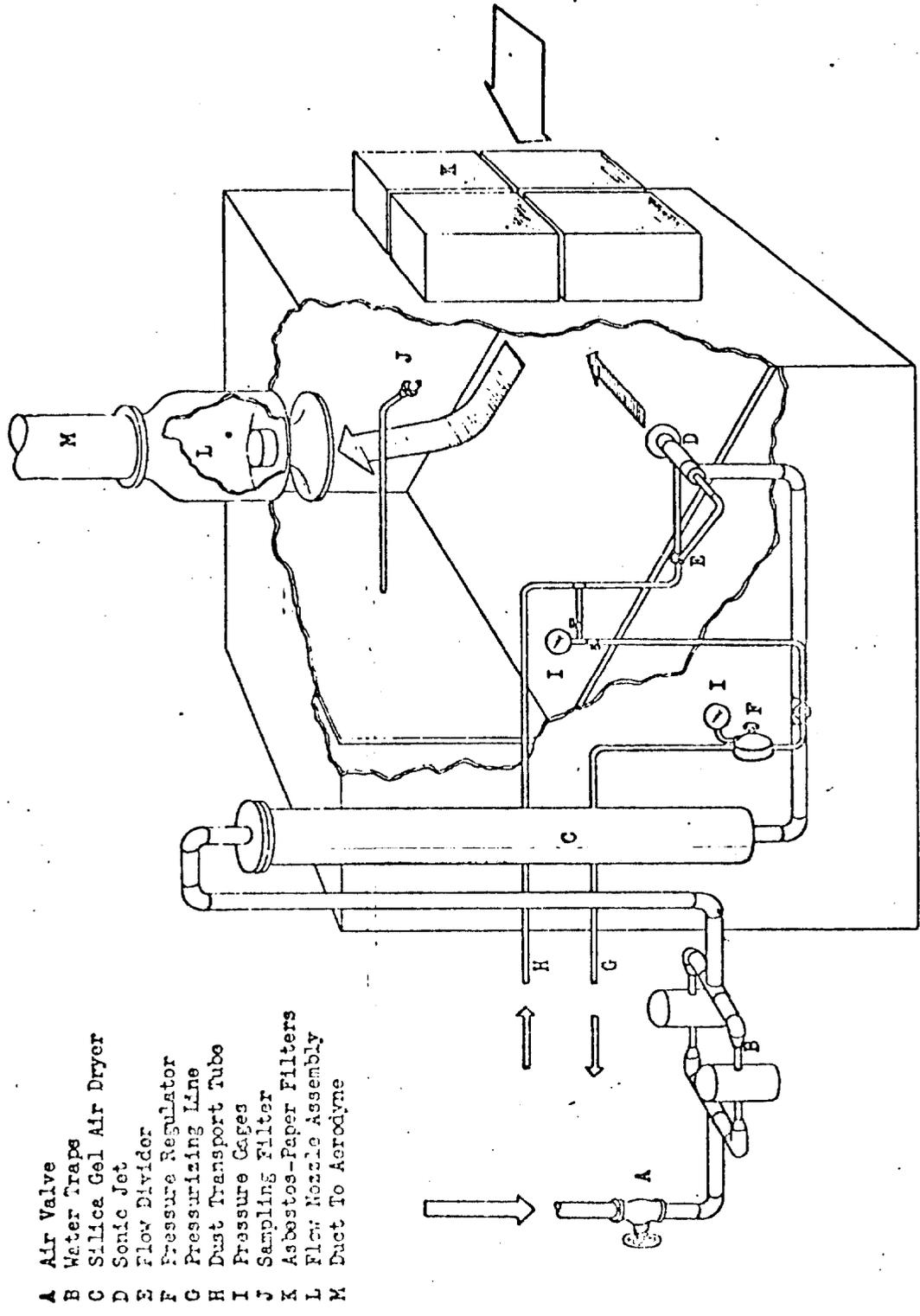
Throat Section



Slide 3. DUST GENERATOR SONIC JET

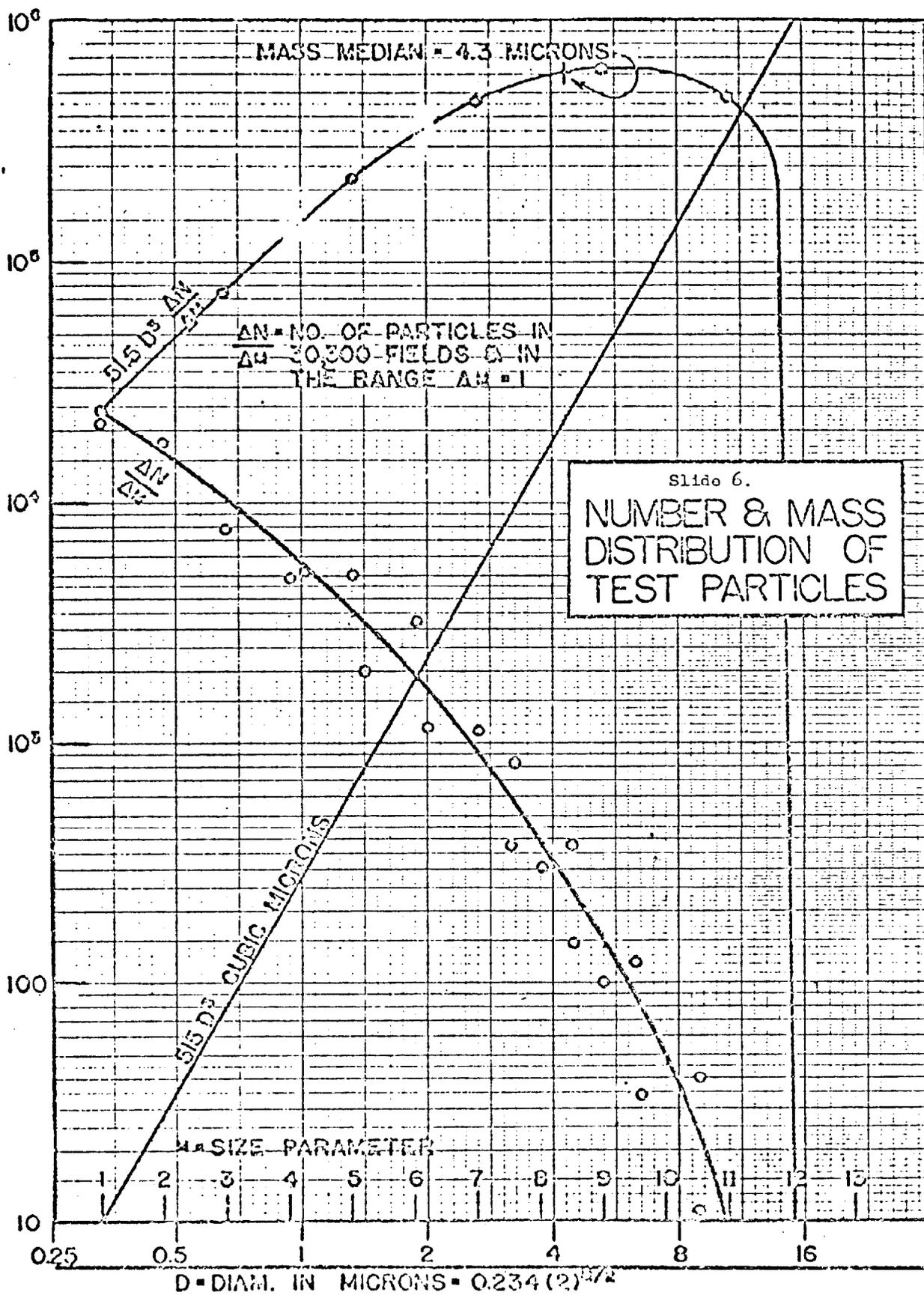


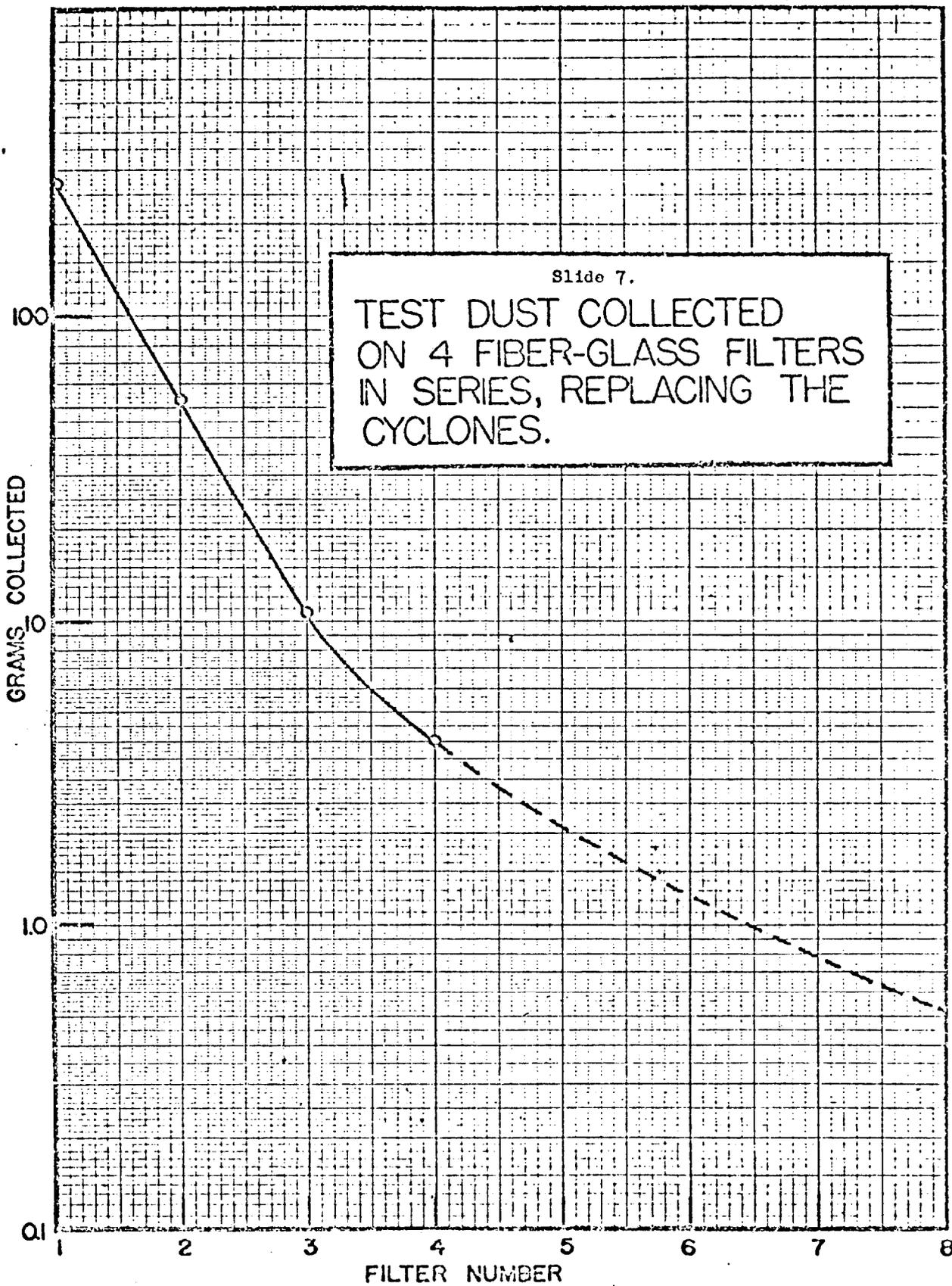
Slide 4. DUST GENERATOR VARIABLE FEED UNIT



- A Air Valve
- B Water Traps
- C Silica Gel Air Dryer
- D Sonic Jet
- E Flow Divider
- F Pressure Regulator
- G Pressurizing Line
- H Dust Transport Tube
- I Pressure Gages
- J Sampling Filter
- K Asbestos-Paper Filters
- L Flow Nozzle Assembly
- M Duct To Aerodyne

Slide 5. DUST CHAMBER AND AUXILIARIES





BRIEF SUMMARY OF AIR CLEANING PROGRAM AT
WESTINGHOUSE ATOMIC POWER DIVISION,
PITTSBURGH, PA.

E. C. Barnes

Until recently the Westinghouse Atomic Power Division experimental facilities were largely devoted to the development and manufacture of the submarine thermal reactor (STR) power plant. During the first phase of our program, which involved constructing new facilities and doing research, development and design work; considerable effort was expended not only in controlling the hazards during this work, but also in developing processes which would minimize the production or dispersion of dust or fumes.

Currently a wide variety of research and development work is being done involving such activities as chemistry, chemical engineering, physics, metallurgy, engineering and electronics. Also, manufacturing operations are being done which involve a variety of processes and machines. Radiation or radioactive materials are used in many phases of these operations.

A considerable variety of dusts and fumes are evolved which require the use of some form of dust or fume collecting equipment; but, with a few exceptions, high dust loadings or high levels of

radioactivity are not encountered. Some of the facilities which require exhaust ventilation and dust collecting equipment are metallurgical and machining operations, analytical chemistry laboratories, physics activities and a five-cell Hot Laboratory.

At the present time there are 17 Type "N" Rotoclones in use ranging in size from No. 1½ to No. 6 with a total capacity of approximately 70,000 cfm. Precipitrons having a capacity of 7,500 cfm are in use for dust control. A specially designed filter is used on certain metallurgical and machining operations. We refer to this as an "accountability filter", and it was designed primarily for the collection of dusts which might need to be recovered.

These units consist of a rectangular case with air entering at the top and passing downward through two layers of FG-50 fiberglass filter media supported horizontally on a screen. The filter media is operated at 100 cfm per square foot. Immediately beneath the filter is a plenum chamber containing an exhaust fan. The flat top of the case is removable to permit access directly to the filter media so that it can be rolled up and retain all the dust in it. This arrangement permits cleaning of duct work and opening the top of the filter to clean down the vertical surfaces on the dirty side of the filter media while the exhaust blower is operating. This prevents any dispersion of the dust, as well as depositing it all directly on the filter media. The dust loadings on these operations are low. Thirteen of these units are in use: 10 - 500 cfm units, 1 - 2500 cfm unit and 2 - 5000 cfm units.

In addition to this dust collecting equipment, there has been need for a number of "clean rooms", and these are furnished with air which has been cleaned by Precipitrons.

Stacks from some dust collectors are sampled continuously during their operating period using filter paper samplers which have been permanently installed. Such monitoring is done on only those stacks where it has been demonstrated that radioactive materials may pass through filters in significant concentrations. Other dust collectors are periodically inspected to insure satisfactory operation.

In general it can be said that the dust collecting equipment which we are using at the present time is taking care of a wide variety of dust, fumes and vapors; and serious difficulties are not being experienced.

TOWER OBSERVATIONS OF ATMOSPHERIC DUST
AT THE NATIONAL REACTOR TESTING STATION

By P. A. Humphrey, E. M. Wilkins, and D. M. Morgan, USWB, 100

Consideration that the placing of air intakes for reactors at various elevations above the ground may be important to air cleaning design has resulted in tower observations of dustiness at the National Reactor Testing Station. The purpose of these observations is to determine for various meteorological conditions the variations of dustiness in the vertical.

It was assumed beforehand that the vertical gradient of dustiness would show characteristic differences for various wind velocities, and for temperature lapse (daytime) and temperature inversion (nighttime) conditions.

The 250-foot radio tower in the Central Facilities area was used to elevate high volume air samplers to various heights above the ground (Figure 1). The tower also accommodates continuous recording resistance thermometers at the 5, 100 and 250-foot levels, which are used to determine temperature lapse and temperature inversion conditions. Continuous wind speed records from an instrument exposed 20 feet above ground were used rather than records from the wind equipment on top of the tower. The high-volume samplers were attached to the tower at 5, 15, 30, 100, and 250 feet (Figure 2). Rate of flow through the samplers was checked at the beginning and ending of each sampling period.

Dust Concentrations

As might be expected, it is extremely difficult to separate the effect of winds from that of air stability, because the stronger winds and

temperature lapse conditions tend to occur simultaneously. Plots of dust concentration versus height for several conditions are shown in Figure 3.

The following points are made:

- 1) Concentrations near the ground are much higher during periods of strong winds, but at 250 feet they are no higher than during periods of light or moderate winds.
- 2) There is little practical difference between concentrations during lapse conditions and inversion conditions as long as wind speeds are about the same.
- 3) The decrease of dustiness with height shows a distinct advantage in having air intakes located at the highest feasible elevations. This is especially true for the dustiest conditions.

Table I gives percentages of the 5-foot level dust concentrations found at levels above five feet. Note that there is only 42% as much dust at the 30-foot level during dustiest conditions and from 50%-69% as much during average conditions.

Particle Sizes

For particle sizing, dust was vacuumed off of the fluted filters on to molecular filters, and counting was accomplished by conventional methods using a Porton graticule in the ocular of the microscope. Median sizes ranged between three tenths and six tenths of a micron for all sampling periods, and all levels. As might be expected, the median size decreases with height, and increases with wind speed. There was a noticeably smaller

percentage of particles greater than 10 microns at higher levels. In the dustiest sample, the percentage of particles larger than 10 microns was five times less at 250 feet than at five feet.

Also of interest is the variation of the standard geometric deviation of particle sizes with height during various conditions. The same samplings shown in Figure 3 are plotted in Figure 4. The exact shape of the curves cannot be verified for so few samples; however, the following items are worthy of mention:

- 1) The two curves for lapse conditions show characteristic increases in standard geometric deviations (which means decreasing homogeneity of particle sizes) with height. Near the ground, however, the deviations are smaller for the cleaner sample.
- 2) The curves for "inversion" and for "lapse and inversion" show characteristic decreases of standard geometric deviations with height in the lower levels. These curves show larger standard geometric deviations near the ground than the two curves for lapse conditions.
- 3) The standard geometric deviations tend to be about the same at the 30-foot level during all meteorological conditions, ranging from five to six.

Larger Particles

Since the characteristics of the larger particles were not easily observed at the magnification of 1800X used for particle sizing, material

Table 1. Percent of 5-Foot Level Dust Concentrations Found at Various Levels

National Reactor Testing Station

| Wind Condition | Total Exposure Hours | 5-Ft. Level Concentration | 15-Ft. Level % | 30-Ft. Level % | 100-Ft. Level % |
|--------------------------------------------|----------------------|---------------------------|----------------|----------------|-----------------|
| LAPSE | | | | | |
| Mostly Strong | 10 | 0.416 mg/m ³ | —% | 42% | 11% |
| Mostly Light | 33 | 0.088 | 89 | 62 | 38 |
| Mostly Light | 41 | 0.085 | 89 | 63 | 39 |
| LAPSE AND INVERSION | | | | | |
| Moderate, Day - Light, Night | 24 | 0.091 | 90 | 64 | — |
| Moderate, Day - Light, Night | 24 | 0.075 | 85 | 69 | 49 |
| Moderate, Day - Light, Night | 24 | 0.072 | 76 | 50 | 21 |
| Moderate, Day - Light, Night | 72 | 0.069 | — | 55 | 35 |
| Mostly Light, Day - Light, Night | 24 | 0.068 | 83 | 57 | 11 |
| Mostly Moderate, Day - Mostly Light, Night | 72 | 0.053 | — | — | 38 |
| INVERSION* | | | | | |
| Light | 53 | 0.065 | 99 | 79 | 65 |
| Light | 55 | 0.051 | 84 | 79 | 56 |

WASH-170

Light Wind 0 - 11 mph, Moderate 12 - 23 mph, and Strong > 23 mph

* In the first inversion test, 19% of the preceding lapse periods had moderate winds; but only 6% had moderate winds in the second test. Strong winds did not affect either test.

U. S. W. B.

was shaken from the fluted filters by rapping and examined at 100X. The following remarks apply to the examinations of the samples at low power and do not compare particles smaller than 45μ .

For all conditions, at the elevations sampled, particles in the size range from 45μ to 90μ predominated the microscopic field. At lower levels, inorganic material was predominant over organic material when smaller sizes are considered except during the windy, lapse period and during the typical inversion period. During these periods inorganic and organic material were more uniformly mixed.

At higher elevations there were fewer large inorganic particles ($> 100\mu$), and in the typical inversion case there were practically none even at the lowest elevation.

Largest inorganic particles varied as follows:

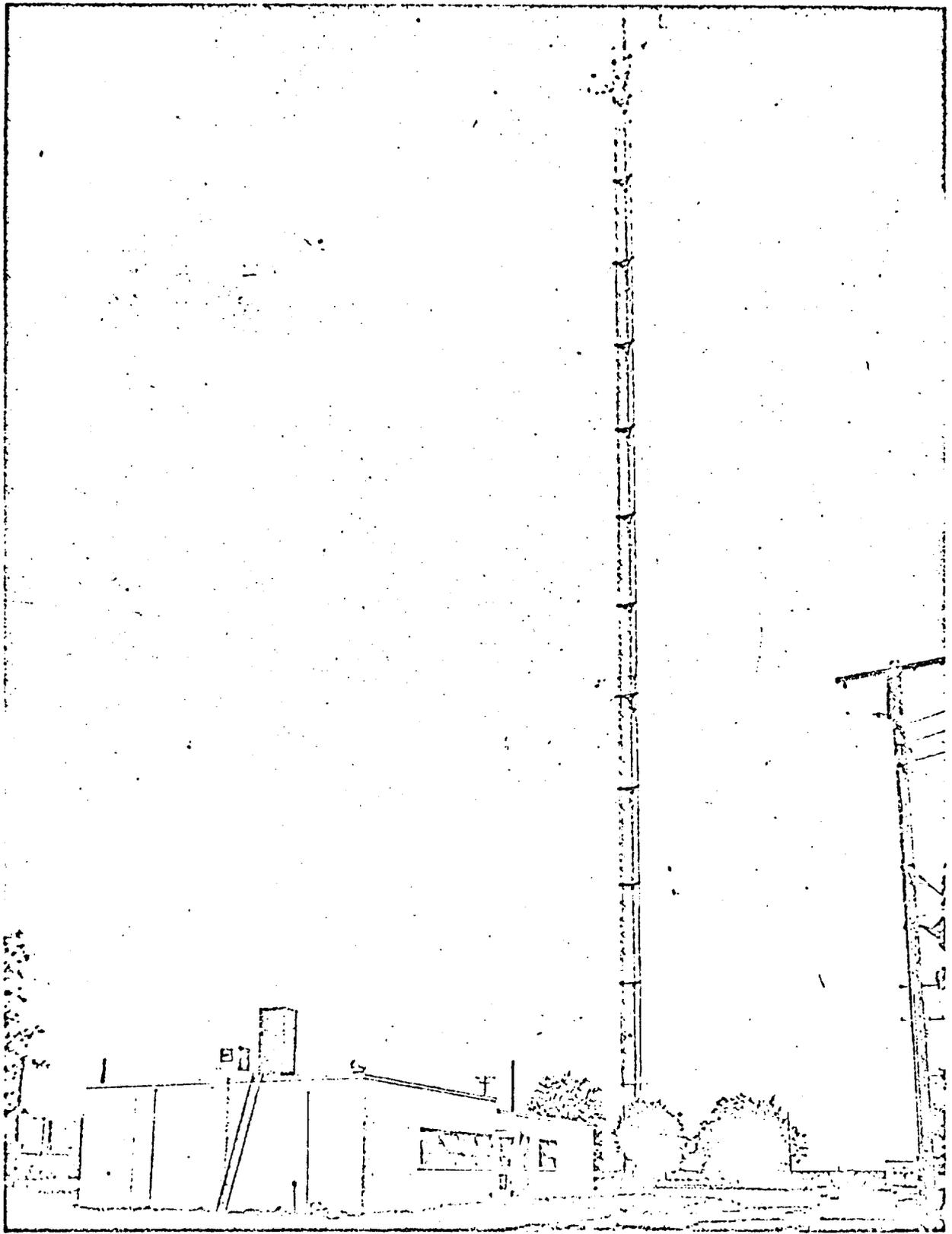
TABLE II

| | <u>5'</u> | <u>100'</u> | <u>250'</u> |
|----------------------------------|-----------------|-------------|----------------|
| Continuous (Lapse and Inversion) | $300\mu-550\mu$ | 260μ | $75\mu-175\mu$ |
| Typical Lapse | 640μ | 225μ | -- |
| Windy Lapse | 890μ | 360μ | 100μ |
| Typical Inversion | 200μ | 75μ | -- |

Shape was perhaps a factor in determining the heights at which largest inorganic particles were found since some were flake-like..

Organic material appears to have less density and does not show significant size variations with height. The ratio of small to large particles remains nearly constant. Pollen varieties from 60μ to 450μ were evident at all levels.

Several houseflies were always present in each filter for 5 and 15 feet, but never at 30 feet and above. Smaller insects (300μ - 2800μ) were present at all levels.



Figuro 1

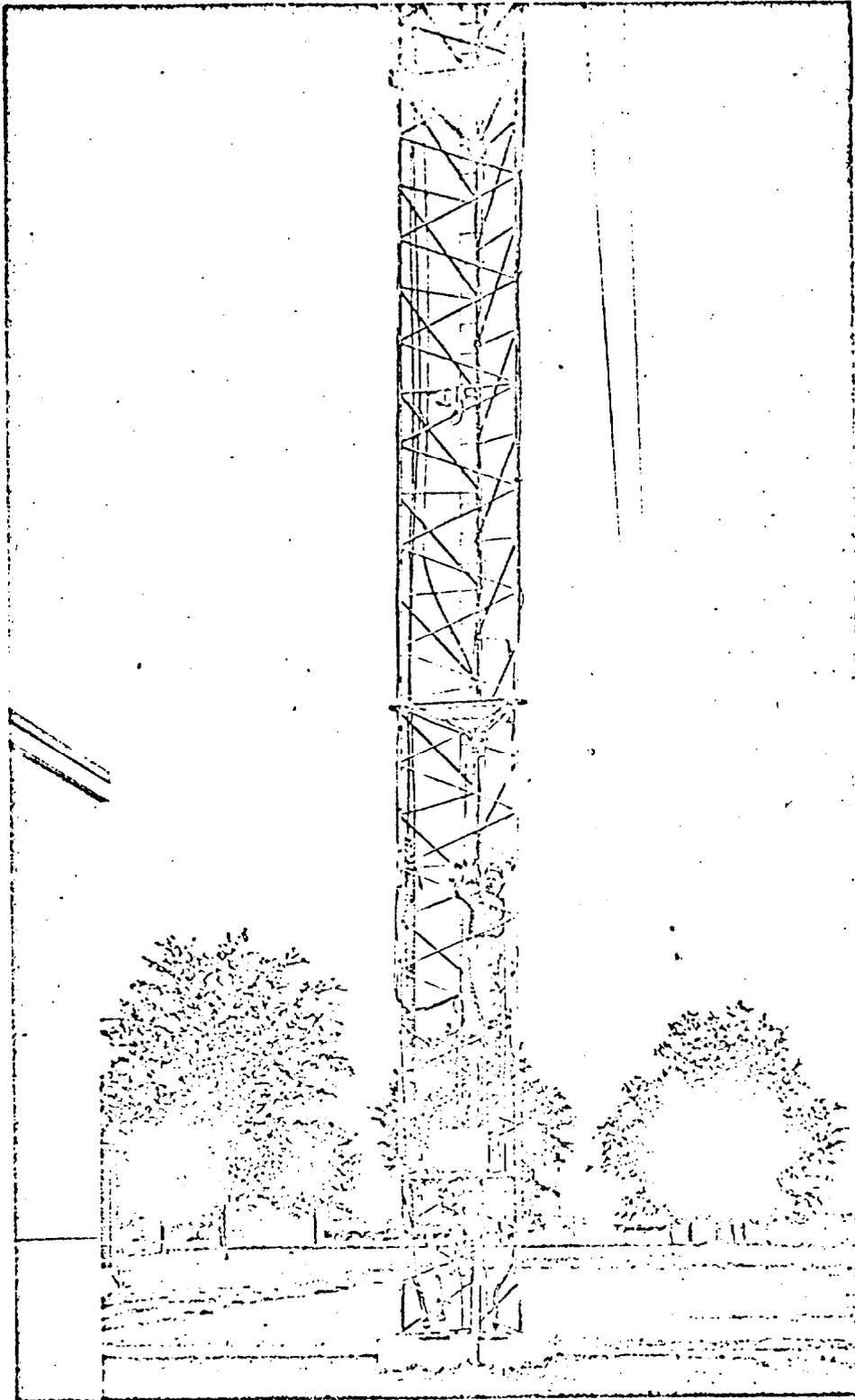


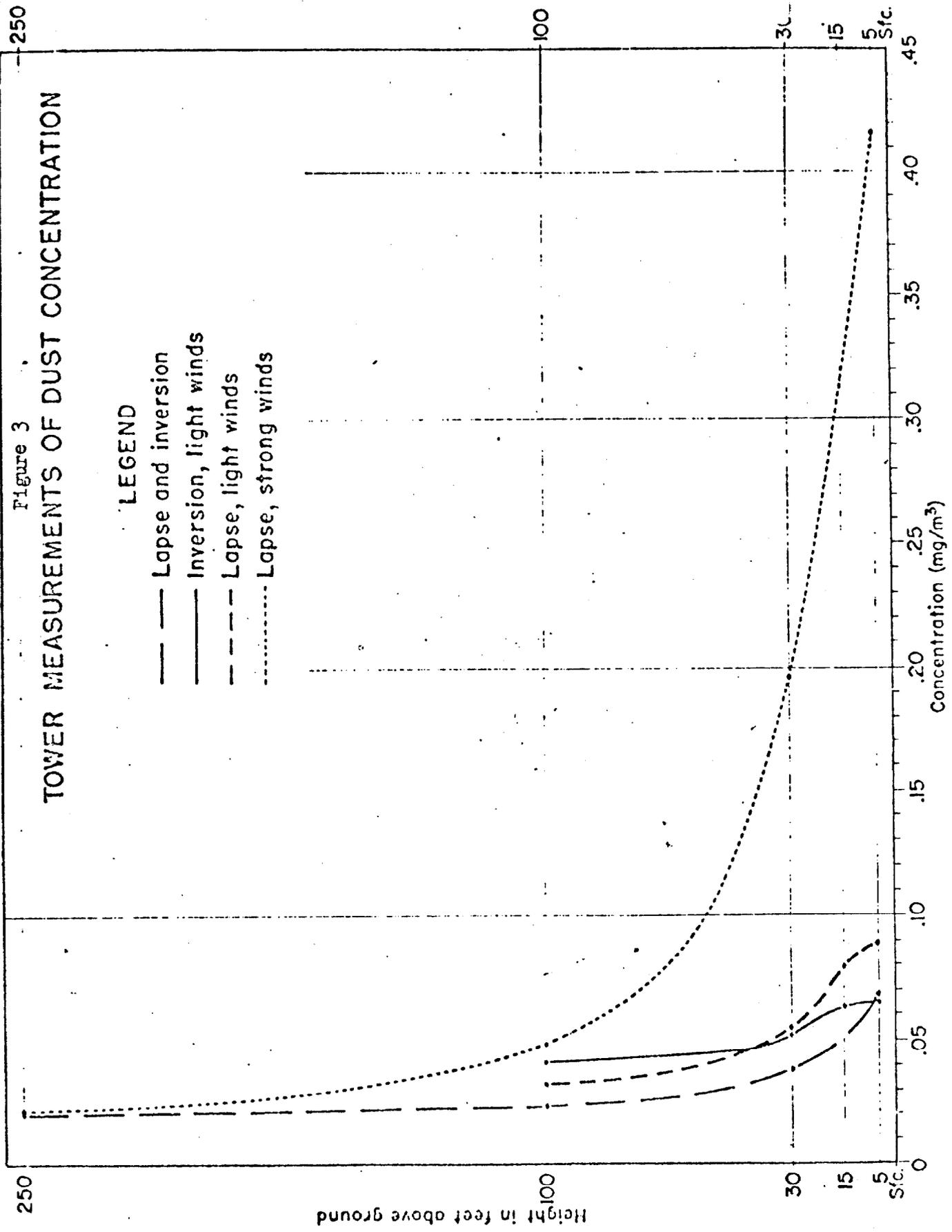
Figure 2

Figure 3

TOWER MEASUREMENTS OF DUST CONCENTRATION

LEGEND

- Lapse and inversion
- Inversion, light winds
- - - Lapse, light winds
- · · Lapse, strong winds



250

100

30

15

5

Sfc

8.0

250

100

30

15

5

Sfc

3.0

Height in feet above ground

Figure 4 σ_g VS HEIGHT

LEGEND

- Lapse and inversion
- Inversion, light winds
- - - Lapse, light winds
- Lapse, strong winds

Standard geometric deviation (σ_g)

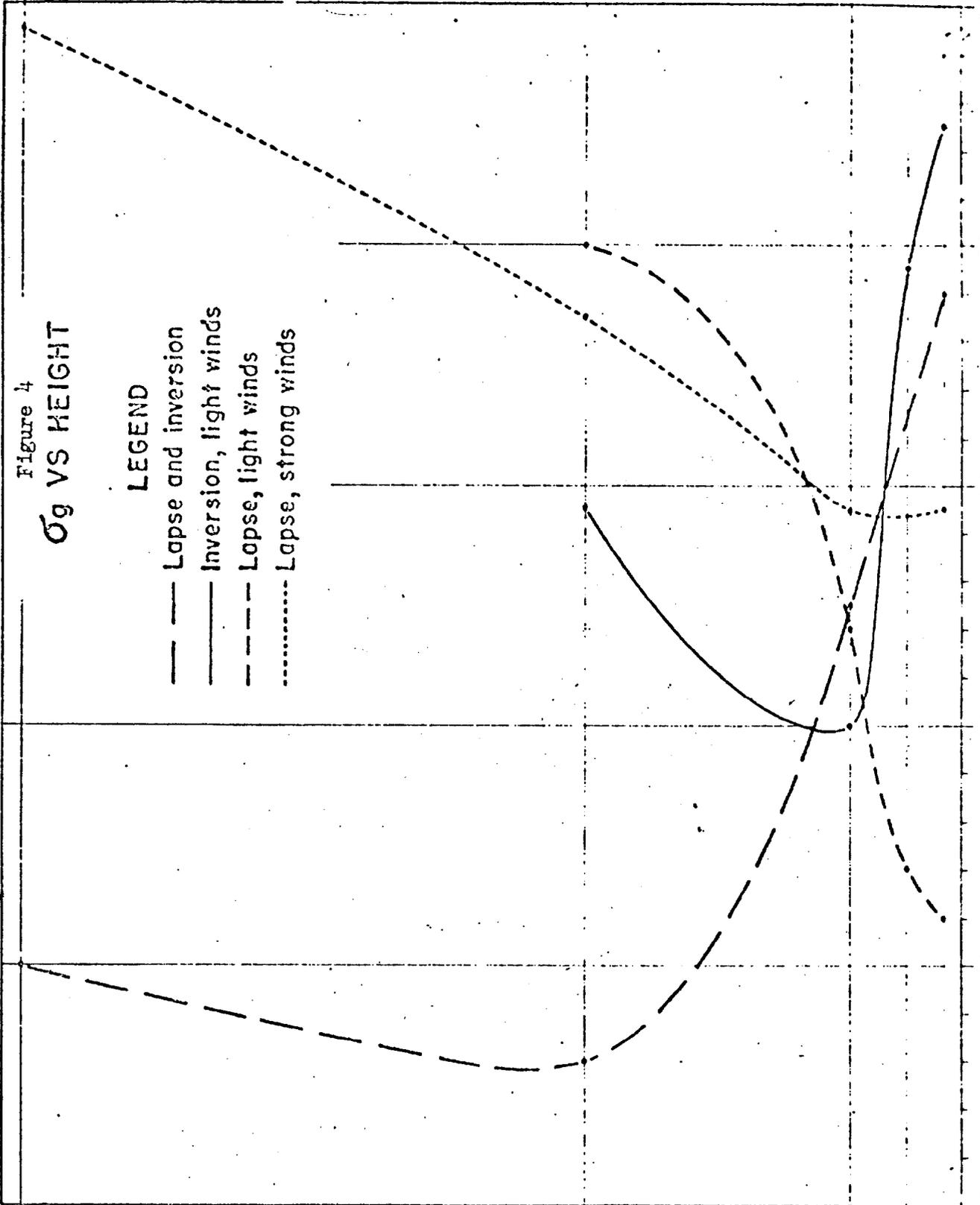
4.0

5.0

6.0

7.0

8.0



ADDENDUM

Meteorological conditions during test periods considered in Figures 3 and 4. Wind given for 20 feet. Temperature gradient considered for 5 feet to 250 feet.

LAPSE AND INVERSION

On: 0805 MST, August 25, 1953 - Off: 0805 MST, August 28, 1953

Duration: 72 continuous hours

Wind Speed: Moderate during day and light at night

August 25. Hourly averages, calm to 8 miles per hour from beginning of test until almost noon then increasing to 12-19 miles per hour and dropping to 2-9 miles per hour after late afternoon. Peak gust 30 miles per hour at 1428 MST.

August 26. Hourly averages, 2-10 miles per hour until mid-morning, increasing to 12-19 miles per hour during afternoon and then decreasing to 5-8 miles per hour after early evening. Peak gust 33 miles per hour at 1136 MST.

August 27. Hourly averages, calm to 5 miles per hour until mid-morning, becoming 12-16 miles per hour during afternoon and then dropping to 2-8 miles per hour at night. Peak gust 29 miles per hour at 1447 MST.

August 28. Hourly averages, calm to 6 miles per hour until terminated at 0805 MST. Peak gust 9 miles per hour at 0100 MST.

Stability
Condition:

August 25. 10 hours lapse, maximum 6.2°F. 6 hours inversion.

August 26. 12 hours lapse, maximum 6.9°F. 12 hours inversion.

August 27. 12 hours lapse, maximum 5.4°F. 12 hours inversion.

August 28. 2 hours lapse, maximum 2.0°F. 6 hours inversion.

Sky Condition: Mostly clear skies for entire period.

Weather: None

INVERSION, LIGHT WINDS

On: 1909 MST, August 10, 1953 - Off: 0815 MST, August 11, 1953
 On: 1915 MST, August 11, 1953 - Off: 0815 MST, August 12, 1953
 On: 1903 MST, August 12, 1953 - Off: 0843 MST, August 13, 1953
 On: 1832 MST, August 13, 1953 - Off: 0750 MST, August 14, 1953

Duration: 53 hours 4 minutes

Wind Speed: Light for entire period except for 2 hours moderate

August 10. Hourly averages, 5-9 miles per hour until midnight. Peak gust 15 miles per hour at 2100 MST.

August 11. Hourly averages, calm-4 miles per hour in morning, 3-8 miles per hour at night. Peak gust 14 miles per hour at 1900 MST.

August 12. Hourly averages, calm-5 miles per hour in morning, 7-10 miles per hour at night. Peak gust 16 miles per hour at 1900 MST.

August 13. Hourly averages, 1-8 miles per hour in morning, 7-17 miles per hour at night. Peak gust 28 miles per hour at 2130 MST.

August 14. Hourly averages, calm-4 miles per hour until termination. Peak gust 8 miles per hour at 0100 MST.

Stability
Condition:

August 10. Inversion began 1917 MST.

August 11. Inversion ended 0636 MST, began 1914 MST.

August 12. Inversion ended 0710 MST, began 1859 MST.

August 13. Inversion ended 0708 MST, began 1819 MST.

August 14. Inversion ended 0647 MST.

Sky Condition: Mostly clear August 10, 11, and 12, partly cloudy 13 and 14.

Weather: None

LAPSE, LIGHT WINDS

On: 0810 MST, August 4, 1953 - Off: 1610 MST, August 4, 1953

On: 0757 MST, August 5, 1953 - Off: 1612 MST, August 5, 1953

On: 0755 MST, August 6, 1953 - Off: 1611 MST, August 6, 1953

On: 0745 MST, August 7, 1953 - Off: 1545 MST, August 7, 1953

Duration: 32 hours 31 minutes

Wind Speed: Mostly light with some moderate

August 4. Hourly averages, 13-17 miles per hour entire period.
Peak gust 29 miles per hour at 1600 MST.

August 5. Hourly averages, 3-9 miles per hour entire period.
Peak gust 15 miles per hour at 1600 MST.

August 6. Hourly averages, 4-10 miles per hour entire period.
Peak gust 20 miles per hour at 1600 MST.

August 7. Hourly averages, 3-9 miles per hour except 12-15
miles per hour last two hours of period. Peak gust 28
at 1538 MST.

Stability
Condition:

August 4. Lapse began 0655 MST, ended 1921 MST, maximum
6.5°F.

August 5. Lapse began 0646 MST, ended 1930 MST, maximum
5.6°F.

August 6. Lapse began 0700 MST, ended 1808 MST, maximum
5.5°F.

August 7. Lapse began 0716 MST, ended 1845 MST, maximum
6.0°F.

Sky Condition: Mostly clear August 4, 5 and 7, partly cloudy on 6.

Weather: None

LAPSE, STRONG WINDS

On: 0643 MST, August 24, 1953 - Off: 1857 MST, August 24, 1953

Duration: 10 hours 14 minutes

Wind Speed: Mostly strong with some moderate

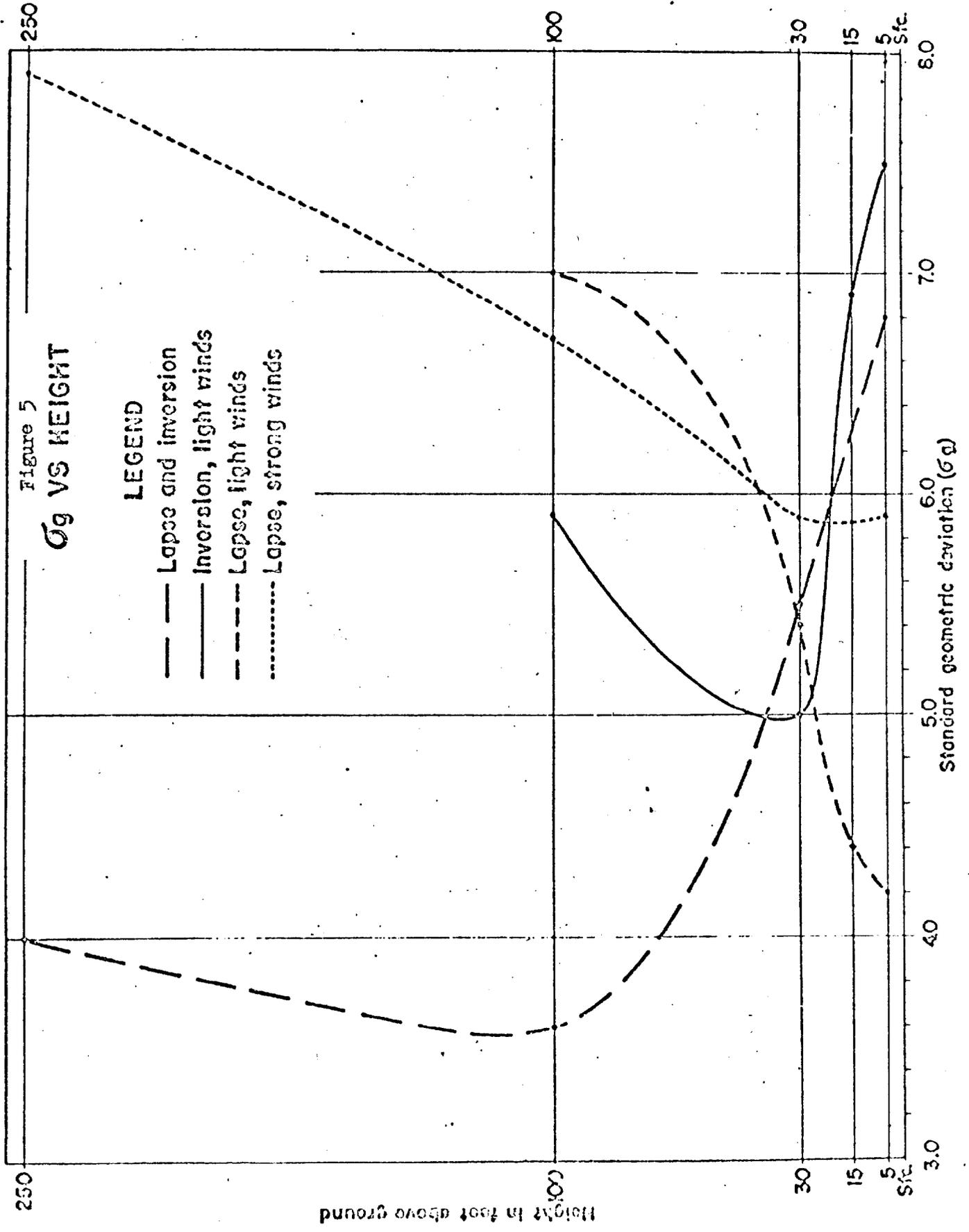
August 24. Hourly averages 24-25 miles per hour most of time with 12-21 miles per hour at beginning and end of period. Peak gust 41 miles per hour at 1403 MST.

Stability

Condition: August 24. Lapse began 0728 MST, ended 1900 MST, maximum 7.6°F.

Sky Condition: Scattered cloudiness

Weather: In addition to the general dustiness of the air, individual clouds of blowing dust from numerous sources of loose soil were visible in all directions. Dust clouds from nearby points of origin frequently blew across the sampling site.



250

250

Figure 6

TOWER MEASUREMENTS OF DUST CONCENTRATION

LEGEND

- Lapse and inversion
- Inversion, light winds
- - - Lapse, light winds
- Lapse, strong winds

Height in feet above ground

100

100

30

30

15

15

5

5

5/c

5/c

.45

.40

.35

.30

.25

.20

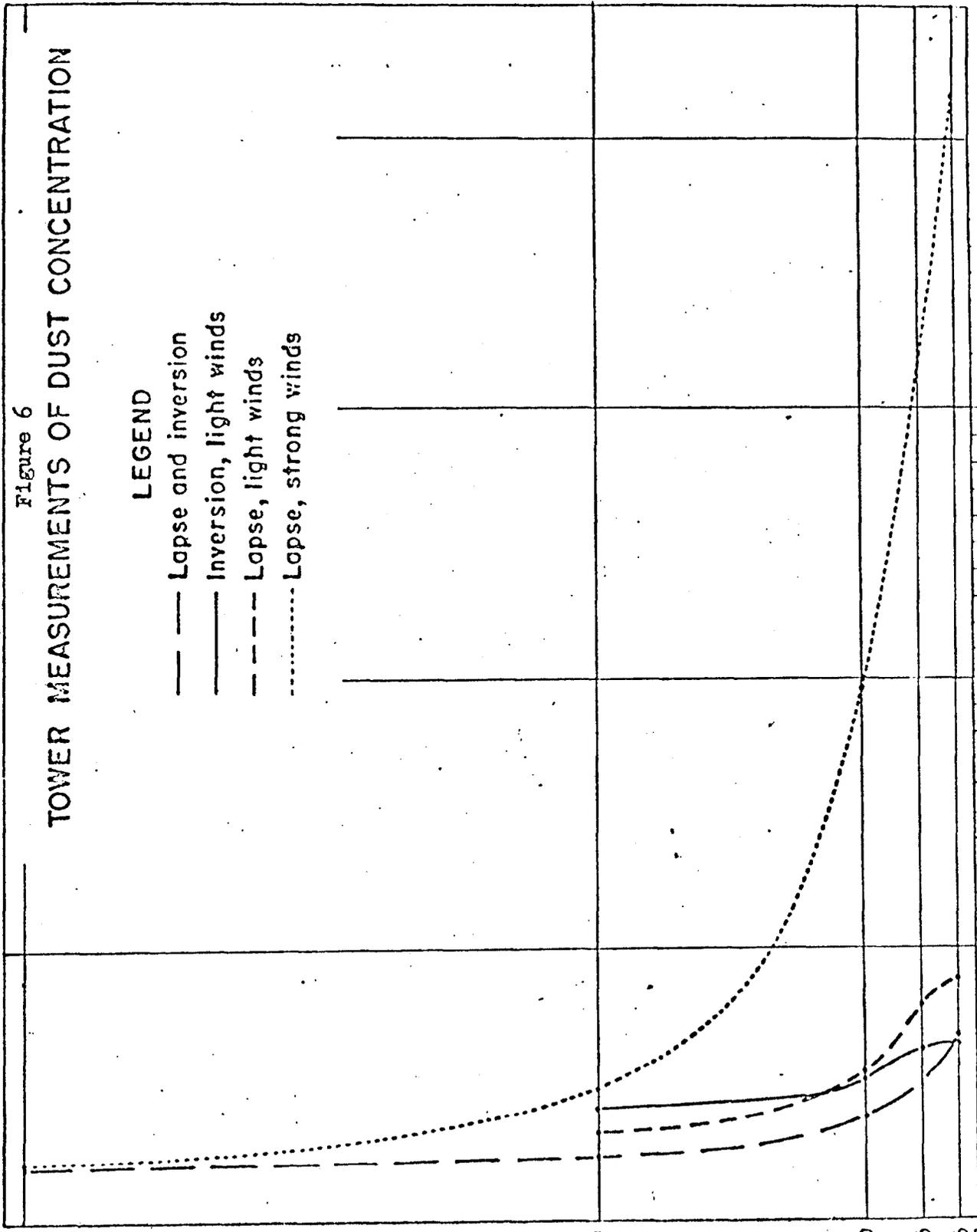
.15

.10

.05

0

Concentration (mg/m³)



KAPL AIR CLEANING PROGRAM

By L. J. Cherubin and J. J. Fitzgerald, GE, KAPL

ABSTRACT

A brief description of the air cleaning requirements at the Knolls Atomic Power Laboratory is given. A total of 407,600 cfm of air is cleaned in which the CWS-6 filter units are used to clean approximately 80 per cent of the air at the Laboratory. Caustic scrubbers and an electrostatic precipitator are utilized in specific air cleaning operations.

The efficiency of the air cleaning units is indicated by the low concentrations of radioactive and toxic materials in the environs which are tabulated.

The collection efficiencies of six filter media used for air cleaning and air sampling are tabulated as a function of face velocity and particle size.

INTRODUCTION

Before discussing the air cleaning requirements and investigations at the Knolls Atomic Power Laboratory, it seems appropriate that one should describe the Laboratory and its program. The Knolls Atomic Power Laboratory is operated by the General Electric Company under contract with the United States Atomic Energy Commission. Mr. Karl R. Van Tassel is the General Manager. Dr. Kenneth H. Kingdon is the Technical Department Manager while Mr. F. E. Crever, Jr., is the Engineering and Projects Department Manager.

The Knolls Atomic Power Laboratory is primarily concerned with the development, design, manufacture, and installation of an intermediate reactor for submarine propulsion. This reactor, first of its type, uses uranium as fuel and sodium as a coolant and will be installed in an actual portion of a submarine under construction at our West Milton Site. The reactor and engine room compartment of this submarine prototype will be enclosed in a tank of water located within a gas-tight 225 foot steel sphere, the largest ever built. The Laboratory is also engaged in developing a submarine intermediate reactor for actual installation in a sea-going vessel. In addition to this type of work, KAPL is responsible for furnishing the necessary development work as assistance to the Hanford and Savannah River operations offices. This effort is directed toward improving production facilities.

The work on these projects, illustrated in Figure 1, is carried on in the following facilities: the Knolls Atomic Power Laboratory, located in the Town of Niskayuna; Peek Street Site, located in the city of Schenectady; the Alplaus Site, located in the Town of Alplaus, and the West Milton Site, located in the Town of West Milton. The Knolls Atomic Power Laboratory (KAPL) is located on a plot of approximately 170 acres of land in the Town of Niskayuna, New York, about 5 miles east of the center of the City of Schenectady and about 1/2 mile from the General Electric Company Research Laboratory. It was completed January 1, 1950, at a cost of approximately \$28,000,000.

TABLE 1

| <u>Buildings</u> | <u>No. Exhaust Units</u> | <u>Capacity Cleaning System, in cfm</u> | <u>Air Cleaning System</u> | <u>Description of Areas Ventilated</u> | <u>Units Served or Zones Covered</u> |
|-----------------------------------------------|---------------------------|-----------------------------------------|-----------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|
| Chemistry and Chemical Engineering (E-1, G-1) | 5(E-1, 2,6,7,8) | 154,000 | Glass Wool and CWS | Laboratories, hoods hot caves, basements | 197 |
| Liquid Waste Processing (H) | 2(475-3, 475-4) | 43,000 | Glass Wool and CWS | Cells, evaporator areas, hot drain tunnels, control and change rooms | 62 |
| Separations Pilot Plant (G-2) | 2(E-4, 475-1, 475-2) | 103,500 | Glass Wool and CWS | Weigh tank and constant head areas, offices, hot cave, crane gallery, cell access corridors, sampling and rotameter aisles, cells | 94 |
| Separations Pilot Plant (G-2) | 1 | 200 | NaOH Spray Column - 13' | Dissolver off-gas and head end process vessels vent air scrubber | --- |
| Separations Pilot Plant (G-2) | 1 | 1,400 | NaOH 30" I.D. x 47' high porcelain-ring packed, column 23' high | Hold-up and feed, recycle tanks, banks, and decontamination room | --- |
| Manufacturing (D-3,4) | 1(E-1) | 78,600 | Multiclone precipitator, electrostatic precipitator, glass wool | Machine shop ventilation, metal working laboratory, laboratory hoods, vault, change areas, (high and low velocity systems) | 122 |
| Manufacturing (D-1, D-4, Q-4) | 7(E-4,12,13) (E-3, A,E,B) | 21,600 | Glass Wool and CWS | Health Physics Laboratory, laboratories and hoods, furnaces and filling room, vault, degreaser | 38 |
| Physics and Metallurgy (F, Z-3, A-2) | 4(B-3,4) | 4,500 | Glass Wool and CWS | Hoods | 4 |
| Radioactive Materials Laboratory (E-2) | 3 | 6,800 | Glass Wool and CWS | Cave Area, decontamination area, hot boxes | 12 |
| Total | 26 | 407,600 | --- | --- | 529 |

The Atomic Power Laboratory, as shown in the composite photographs, consists of a main group of five interconnected buildings providing space for administration, cafeteria, physics laboratory, general shops, and metallurgical and engineering laboratories. In addition, there is another group of three interconnected buildings housing a chemical laboratory, pilot plant laboratory, and Separations Process Research Unit. There are also 12 detached buildings providing for service facilities. There is approximately 371,000 square feet of gross floor space in these facilities. Additional site facilities include a Preliminary Pile Assembly which is a flexible mockup for the intermediate nuclear reactor, a Thermal Test Reactor, used primarily for research purposes, and Test Cells for a Radioactive Materials Laboratory.

Approximately 20 per cent of the staff is employed at the Peck Street Site located in Schenectady about one mile north of the center of the city, and the liquid metal research work is conducted at the Alplaus Site which is situated in the Town of Alplaus, approximately 3 miles northeast of Schenectady.

The West Milton Site is located on a plot of about 4,000 acres in the County of Saratoga, approximately 18 miles north of Schenectady. The construction of the 225 foot sphere to house the submarine prototype, shown in the composite photograph, has been completed and the sphere has been successfully pressure tested. Six permanent-type buildings will be erected at this site. There are approximately 2,000 people employed at the Knolls Atomic Power Laboratory and its facilities.

AIR CLEANING REQUIREMENTS AT KAPL

To describe the KAPL air cleaning program, the air cleaning requirements will be enumerated by a consideration of the numbers and types of air cleaning systems used together with the capacities of these systems and the areas serviced. The efficiencies of these air cleaning systems will be indicated by the concentrations of toxic elements in the stack air effluents and environs.

However, before illustrating the data on the KAPL air cleaning systems and the concentrations of toxic materials in the stack effluent and the environs, a few pictures of the stack air cleaning systems, typical areas ventilated and the environmental monitoring equipment will be presented to aid in the description of the KAPL air cleaning program.

A 100-foot stainless steel stack serving the Separations Pilot Plant is shown in Photograph 1120906. The Liquid Waste Processing building which is situated to the left of the main building in the photograph has a 50-foot high stainless steel stack. To the right of the 100-foot stack is a caustic vent scrubber serving in series with a glass wool CWS filter unit. Separations Process gases and entrained particulate material are vented through this scrubber and CWS filter. On top of the Pilot Plant Building you can see one of many typical stubby air exhaust pipes utilized at KAPL. These exhaust pipes are approximately 16 to 20 feet above roof levels.

A typical filter unit enclosing glass wool and CWS filters is shown in Photograph 1120929. A portion of the cyclone separator which precedes the electrostatic precipitator in the Special Materials Machine Shop where beryllium and uranium are machined is depicted in Photograph 1086995. A hood in which highly radioactive materials are manipulated is illustrated in Photograph 1120898. Photograph 1086992 shows ventilation provided in the Special Materials Machine Shop. Photograph 1120928 depicts a cave area in which highly radioactive materials are studied for radiation damage or effect on reactor structural material or fuel elements. A typical air monitoring instrumentation employed at KAPL is shown in

Photograph 1096993. A GM counter and an air ionization chamber are used for the monitoring of air in the environs.

Photograph 1107715 depicts an environmental continuous air particulate monitoring unit employing a GM counter, a vibrating reed electromotor and continuous recorder, scalars and recorders for the two GM counters.

An I-131 scrubber used for stack and environmental air monitoring purposes is illustrated in Photograph 1104414. Not shown, however, is a Kanne Chamber unit used to detect the radioactive noble gases and tritium.

The data in Table 1 indicate the various buildings on the Knolls Site, the number of air exhaust units, the total capacity of the air cleaning units, the type of air cleaning systems, a general description of areas ventilated, and a number of units served or zones covered. You can readily see that the glass wool CWS filter systems predominate, that the cyclone separator-electrostatic precipitron is a major system while the caustic scrubbers are confined to serving the venting of process vessels in the Pilot Plant and treat a very small volume of the laboratory air at KAPL.

The nature and amounts of toxic elements emitted in 1952 from the various laboratory buildings are listed in Table 2. Emission of radiogases is associated with short periods (a few hours) and dilution in large volume of stack air. These gases have presented no significant health hazard problems at KAPL. All these toxic elements are released into stacks discharging from 40,000 cubic feet of air per minute or more. The Separations Pilot Plant stack effluent is the most important factor in the contamination of atmosphere with fission products and alpha activity. The stack effluent from the Special Materials Machine Shop building (D-3) is the major potential source of beryllium contamination in the environment.

The data in Table 3 indicate to some degree the radiation levels at contact associated with the particulate filters. As one would expect process cell air filters are the highest.

The range of concentrations of the various toxic elements in the KAPL stack air effluents are illustrated by the data in Table 4. The data indicate that atmospheric air dilution must be relied upon for the Separations Pilot Plant stack exhaust air but the dilution factors required are low even at the maximum concentrations.

The data in Table 5 indicate that atmospheric dilution is also required to reduce I-131 concentration emitted from the Separations Pilot Plant, and the beryllium concentration released from the Special Materials Machine Shop building to permissible concentrations in the environs. The data indicate that the CWS filters are very effective in removing beryllium from laboratory hood exhaust air.

The data listed in Table 6 show that no concentration of beryllium above the prescribed limit of $0.01 \mu\text{g}/\text{M}^3$ was detected in the environs. The radioactive particle count represents sampling of three on-site and two off-site locations and is diluted by data from the West Milton Site. These data also reflect outside influences as well; however, maximum particle counts from KAPL operations exceed those associated with outside influence. The local particle problem results from the entrainment of particulate material from the separations process operations rather than from stack corrosion.

The filterable particulate fission product concentrations which were determined at the environmental stations at KAPL and West Milton are illustrated in Table 7. These concentrations represent 3- or 4-day averages. Building M-2 is in the prevailing wind direction from the stack at a distance approximately 10 stack heights away. The West Milton data are considered background data for

TABLE 2

AMOUNTS OF TOXIC ELEMENTS DISCHARGED INTO ATMOSPHERE - 1952

| Building Stack | Beryllium Milligrams | Non-Volatile | | I-131 MilliCuries | Radioactive Gases Curies | Alpha Activity Curies |
|-------------------|-------------------------|----------------------------|-----|----------------------|-----------------------------|--------------------------|
| | | Fission Products Curies | | | | |
| D-3 | 110 | -- | --- | --- | --- | --- |
| D-4 | 11 | -- | --- | --- | --- | --- |
| E-1 | --- | -- | --- | --- | ~500 | --- |
| E-2 | --- | -- | --- | --- | --- | --- |
| S.P.P. | --- | 40 | --- | 113 | 91 | 0.7 |
| Total | 121 | 40 | --- | 113 | 591 | 0.7 |

TABLE 3
ACTIVITY LEVELS OF AIR CLEANING SYSTEMS

| <u>Building</u> | <u>Area</u> | <u>Radiation Levels</u> (Contact Measurement) | |
|-----------------|-------------------------------------|--------------------------------------------------|----------------------|
| | | <u>mrep/hr</u> | <u>mr/hr</u> |
| E-1 | Laboratory Hood Filter | 500 | 50 |
| E-2 | Radioactive Materials Laboratory | 10 | 5 |
| G-1 | Laboratory Hood Filter | 175 | 10 |
| G-2 | Hood Filter Cell 1 Filter | 370 20,000 | 14 1,500 at 3 ft. |
| H | Pipe Tunnel Filter | 950 | 150 |

TABLE 4
STACK EFFLUENT CONCENTRATIONS AFTER AIR CLEANING

| Building | ALPHA ACTIVITY | | | | Maximum $\mu\text{c}/\text{cc}$ |
|----------------------|----------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|---------------------------------|
| | No. Samples | No. < $3 \times 10^{-13} \mu\text{c}/\text{cc}$ | No. > $3 \times 10^{-13} \mu\text{c}/\text{cc}$ | No. > $3 \times 10^{-13} \mu\text{c}/\text{cc}$ | |
| G-2 (S.P.P.) | 572 | 384 | 188 | 5.7 x 10^{-11} | --- |
| G-2 (Laboratory 151) | 248 | 248 | --- | --- | --- |
| H | 521 | 521 | --- | --- | --- |
| H-2 | 73 | 66 | 7 | 1.8 x 10^{-12} | --- |
| E-1 | 502 | 502 | --- | --- | --- |
| G-1 | 246 | 246 | --- | --- | --- |

| Building | FISSION PRODUCT ACTIVITY | | | | Maximum $\mu\text{c}/\text{cc}$ |
|----------------------|--------------------------|----------------------------------------|----------------------------------------|----------------------------------------|---------------------------------|
| | No. Samples | No. < $10^{-11} \mu\text{c}/\text{cc}$ | No. > $10^{-11} \mu\text{c}/\text{cc}$ | No. > $10^{-11} \mu\text{c}/\text{cc}$ | |
| G-2 (S.P.P.) | 572 | 43 | 529 | 6 x 10^{-7} | --- |
| G-2 (Laboratory 151) | 247 | 247 | --- | --- | --- |
| H | 504 | 495 | 9 | 1.4 x 10^{-11} | --- |
| H-2 | 72 | 26 | 46 | 6.7 x 10^{-11} | --- |
| E-1 | 502 | 502 | --- | --- | --- |
| G-1 | 246 | 246 | --- | --- | --- |

TABLE 5
STACK EFFLUENT CONCENTRATION AFTER CLEANING

| Building | No. Samples | No. > 10 ⁻¹¹ µc/cc | Maximum µc/cc |
|-------------------------------------|-------------|-------------------------------|---------------------------|
| G-2 (S.P.P.) | 464 | 154 | 4.7 x 10 ⁻⁸ |
| I-131 | | | |
| URANIUM | | | |
| Building | No. Samples | No. < 10 ⁻⁶ µg/cc | Maximum µg/cc |
| D-3 (Machine Shop and Laboratories) | 700 | 486 | 8.1 x 10 ⁻⁶ |
| URANIUM (ENRICHED) | | | |
| Building | No. Samples | No. < 10 ⁻¹² µc/cc | Maximum µc/cc |
| D-4 (Laboratories) | 656 | 655 | 4.1 x 10 ⁻¹² |
| BERYLLIUM | | | |
| Building | No. Samples | No. < 0.10 µg/N ³ | Maximum µg/N ³ |
| D-3 (Machine Shop and Laboratories) | 694 | 693 | 0.2 |
| D-4 (Laboratories) | 655 | 655 | 0.02 |

No. > 10⁻⁶
< 5 x 10⁻⁵ µg/cc

214

No. > 10⁻¹²
< 3.3 x 10⁻¹¹ µc/cc

1

No. > 0.1
< 1.0 µg/N³

1

TABLE 6

KAPL ENVIRONMENTAL AIR MONITORING - 1952

| <u>Beryllium</u> | <u>No. Samples</u> | <u>No. < 0.01 $\mu\text{g}/\text{M}^3$</u> | <u>Maximum $\mu\text{g}/\text{M}^3$</u> |
|-------------------|--------------------|----------------------------------------------------------|----------------------------------------------------|
| <u>Location</u> | | | |
| On site, downwind | 136 | 136 | < .01 |

| <u>Radioactive Particle Count</u> | <u>No. Samples</u> | <u>Daily Average Number of Particles/10^3M^3</u> | <u>Maximum Monthly Average Number of Particles/10^3M^3</u> |
|-----------------------------------|--------------------|----------------------------------------------------------------------|--------------------------------------------------------------------------------|
| <u>Location</u> | | | |
| Three on site | 519 | 287 | 954 |
| Two off site | | | |

TABLE 7

KAPL ENVIRONMENTAL AIR MONITORING - 1952

Fission Product Activity, in 10⁻¹³ uc/cc

| Period | Locations | | | | |
|-----------|-------------|--------------|--------------|---------------------|-------------|
| | Building K | Building M-2 | Building A-1 | Research Laboratory | West Milton |
| January | Average <3 | 3.1 | <3 | <3 | <3 |
| | Maximum <3 | 8.6 | <3 | <3 | <3 |
| February | Average <3 | 5.7 | <3 | <3 | <3 |
| | Maximum <3 | 17.0 | <3 | <3 | <3 |
| March | Average <3 | 6.5 | <3 | <3 | <3 |
| | Maximum <3 | 18. | <3 | 5.8 | <3 |
| April | Average <3 | 40. | 7.1 | <3 | <3 |
| | Maximum <3 | 310. | 45. | 3.4 | <3 |
| May | Average <3 | 302. | 13. | <3 | <3 |
| | Maximum <3 | 2400. | 76. | 5.2 | <3 |
| June | Average 7.2 | 41. | 12. | 11. | 12. |
| | Maximum 6.4 | 190. | 34. | 38. | 43. |
| July | Average <3 | 6.8 | 4.7 | 5.6 | 3.4 |
| | Maximum 3.3 | 25. | 15. | 14. | 7.9 |
| August | Average 3.0 | 7.4 | 3.7 | 3.2 | <3 |
| | Maximum 6.3 | 15. | 7. | 8.3 | 3.5 |
| September | Average <3 | <3 | <3 | <3 | <3 |
| | Maximum 7.2 | 15. | <3 | <3 | 4.1 |
| October | Average <3 | <3 | <3 | <3 | <3 |
| | Maximum <3 | <3 | <3 | 5.4 | <3 |
| November | Average <3 | <3 | 3.7 | <3 | <3 |
| | Maximum <3 | 3.1 | 20.0 | 9.0 | 4.2 |
| December | Average <3 | 206.2 | <3 | <3 | <3 |
| | Maximum 14 | 1400.0 | 5.8 | 7.2 | 3.5 |

TABLE 8

KAPL ENVIRONMENTAL VEGETATION MONITORING (FISSION PRODUCTS) - 1952

| Period | Site Location | No. Sampling Points | No. > 20 x 10 ⁻⁶ $\mu\text{C}/\text{g}$ | Average in 10 ⁻⁶ $\mu\text{C}/\text{g}$ | Maximum in 10 ⁻⁶ $\mu\text{C}/\text{g}$ |
|-----------|---------------|---------------------|----------------------------------------------------|----------------------------------------------------|----------------------------------------------------|
| January | Knolls | 7 | 2 | 20.5 | 34 |
| | Near Knolls | 7 | 3 | 36.6 | 53 |
| | West Milton | no samples | | | |
| February | Knolls | 6 | 1 | 21 | 21 |
| | Near Knolls | 3 | 0 | * | - |
| | West Milton | 1 | 1 | 34 | 34 |
| March | Knolls | 6 | 4 | 22 | 36 |
| | Near Knolls | 3 | 2 | 20.5 | 25 |
| | West Milton | no samples | | | |
| April | Knolls | 7 | 7 | 27.8 | 95 |
| | Near Knolls | 8 | 7 | 31.4 | 86 |
| | West Milton | 2 | 2 | 29.5 | 59 |
| May | Knolls | 7 | 3 | 27.0 | 62 |
| | Near Knolls | 8 | 3 | 23.6 | 35 |
| | West Milton | 5 | 1 | 24 | 24 |
| June | Knolls | 7 | 7 | 57.1 | 176 |
| | Near Knolls | 9 | 8 | 95.2 | 287 |
| | West Milton | 5 | 4 | 66.0 | 209 |
| July | Knolls | 7 | 2 | 25.5 | 59 |
| | Near Knolls | 8 | 2 | 23.1 | 51 |
| | West Milton | 4 | 0 | * | - |
| August | Knolls | 7 | 0 | * | 22 |
| | Near Knolls | 9 | 0 | * | 20 |
| | West Milton | 5 | 0 | * | - |
| September | Knolls | 7 | 1 | 37 | 61 |
| | Near Knolls | 9 | 0 | * | 30 |
| | West Milton | no samples | | | |
| October | Knolls | 7 | 0 | * | 21.1 |
| | Near Knolls | 9 | 0 | * | - |
| | West Milton | 3 | 0 | * | - |
| November | Knolls | 7 | 4 | 28.7 | 84.2 |
| | Near Knolls | 9 | 8 | 25.9 | 128.0 |
| | West Milton | 3 | 2 | 41.3 | 89.0 |
| December | Knolls | 7 | 6 | 44.1 | 138.0 |
| | Near Knolls | 9 | 9 | 40.6 | 127. |
| | West Milton | 3 | 3 | 47.4 | 71.4 |

* < 20 x 10⁻⁶ $\mu\text{C}/\text{g}$

TABLE 9

KAPL ENVIRONMENTAL VEGETATION MONITORING (I-131) - 1952

| Period | Site Location | No. Sampling Points | No. >3 x 10 ⁻⁶ μc/g | Average x 10 ⁻⁶ μc/g | Maximum x 10 ⁻⁶ μc/g |
|-----------|---------------|---------------------|--------------------------------|---------------------------------|---------------------------------|
| January | Knolls | 7 | 5 | 6.4 | 15 |
| | Near Knolls | 7 | 1 | 5.3 | 5.3 |
| February | West Milton | 0 | | | |
| | Knolls | 6 | 0 | | |
| March | Near Knolls | 3 | 0 | | |
| | West Milton | 1 | 0 | | |
| April | Knolls | 6 | 0 | | |
| | Near Knolls | 3 | 0 | | |
| May | West Milton | 0 | 0 | | |
| | Knolls | 7 | 0 | | |
| June | Near Knolls | 8 | 0 | | |
| | West Milton | 0 | 0 | | |
| July | Knolls | 7 | 0 | | |
| | Near Knolls | 8 | 1 | | 4.4 |
| August | West Milton | 4 | 0 | | |
| | Knolls | 7 | 2 | 3.3 | 8.3 |
| September | Near Knolls | 5 | 0 | | |
| | West Milton | 7 | 0 | | |
| October | Knolls | 8 | 0 | | |
| | Near Knolls | 3 | 0 | | |
| November | West Milton | 7 | 0 | | |
| | Knolls | 9 | 0 | | |
| December | Near Knolls | 3 | 0 | | |
| | West Milton | 7 | 0 | | |
| | Knolls | 9 | 0 | | |
| | Near Knolls | 2 | 0 | | |
| | West Milton | 7 | 0 | | |
| | Knolls | 9 | 0 | | |
| | Near Knolls | 3 | 0 | | |
| | West Milton | 7 | 0 | | |

TABLE 10

EFFICIENCY OF FILTER MEDIA

| Filter Media | Maximum Efficiency | | | Minimum Efficiency | | |
|--------------|----------------------|-----------------------|------------------------|----------------------|-----------------------|------------------------|
| | Efficiency, Per Cent | Particle Size, Micron | Face Velocity, cm/sec. | Efficiency, Per Cent | Particle Size, Micron | Face Velocity, cm/sec. |
| W-40 | 99.7 | 2.1 | 100 | 59.3 | .2 | 10 |
| W-41 | 99.6 | 2.1 | 10 | 85.2 | .2 | 2 |
| H-70 | 99.9 | 2.1 | 5,50 | 97.0 | .2 | 10 |
| AEC-1 | >99.9 | 2.1 | 50,80 | 92.9 | .2 | 1 |
| CC-6 | >99.9 | 2.1 | 2 | 98.2 | .2 | 0.5 |
| AAA | >99.9 | 2.1 | 20,50,80 | 97.5 | .2 | 40 |

TABLE 11

EFFICIENCY OF FILTER MEDIA

| Filter Media | Per Cent Efficiency (at 50 cm/sec and for 0.2 micron particles) | Penetration | Relative Penetration |
|--------------|-----------------------------------------------------------------|-------------|----------------------|
| W-40 | 97.2 | 2.8 | 4.0 |
| W-41 | 98.4 | 1.6 | 2.3 |
| H-70 | 98.9 | 1.1 | 1.6 |
| AEC-1 | 99.3 | 0.7 | 1.0 |
| CC-6 | 99.2 | 0.8 | 1.1 |
| AAA | 98.8 | 1.2 | 1.7 |

estimating outside influences. These concentrations indicate no significant inhalation hazards at the Knolls Site. Alpha activity determinations were below statistically significant values.

The status of vegetation contamination on the Knolls Site, vicinity and West Milton is indicated in Table 8. Variations in natural potassium activity, and outside influences make it difficult to assess the sole influence of local operations. West Milton samples, however, are a guide to the influence of outside sources. Contamination of vegetation due to activity in precipitation (rain or snow) is probably the dominant effect rather than the deposition from fall-out.

An occasional evidence of I-131 contamination in the environs is indicated by the data in Table 9.

Summing up the air cleaning statistics at KAPL, the most significant amounts of alpha activity, fission product activity, and radioactive particles are emitted from the Separations Process stack (approximately 100 ft. high). The stack effluent from Building D-3 roof stack (approximately 16 feet high) contains the most significant concentrations of beryllium. Atmospheric dilution, though usually of a low order, must be relied upon occasionally, even after treatment, to reduce airborne contaminants to acceptable levels from the point of view of inhalation hazard and vegetation contamination. The Separations Pilot Plant stack air effluent has received the greatest attention with respect to isotopic identification of radioelements emitted, particle size, and proper sampling methods.

AIR SAMPLING AND AIR CLEANING INVESTIGATIONS

Air sampling and air cleaning investigations at the Knolls Atomic Power Laboratory during fiscal year 1953 were grouped into three categories: (1) efficiency studies of filter media, (2) efficiency studies of air sampling and air cleaning units, and (3) the evaluation of the KAPL separations process stack effluent. Some of the results of efficiency studies of filter media are briefly discussed here.

Filter Efficiency Studies

The efficiency of six air sampling filter media was determined in the particle size range of 0.2 to 2.1 microns under the light microscope using Millipore filters. The filter media, Whatman-40 and 41, Hollingsworth and Vose-70, AEC-1, Chemical Corp 6 (CWS-6), and AAA (1106-B) glass fiber paper were tested throughout the face velocity range of 0.5 to 100 cm/sec. Efficiency was expressed on a size count basis for solid particles of 2.7 gm/cm³ density. The maximum and minimum efficiencies for these filter media in the specified ranges are listed in Table 10.

The maximum efficiency for all filter media was greater than 99.5 per cent at various face velocities for 2.1 micron particles. The minimum efficiency for all filter media except the Whatman was greater than 92.8 per cent for particle sizes of 0.2 micron. It is indicated by the data in Table 11, however, that at operating face velocities of 50 cm/sec, the efficiencies of all filter media are greater than 97 per cent even for 0.2 micron particles.

These efficiency studies of the filter media are being extended to the sub-microscopic range by analyzing under the electron microscope the particles entering and passing through the test filter media.

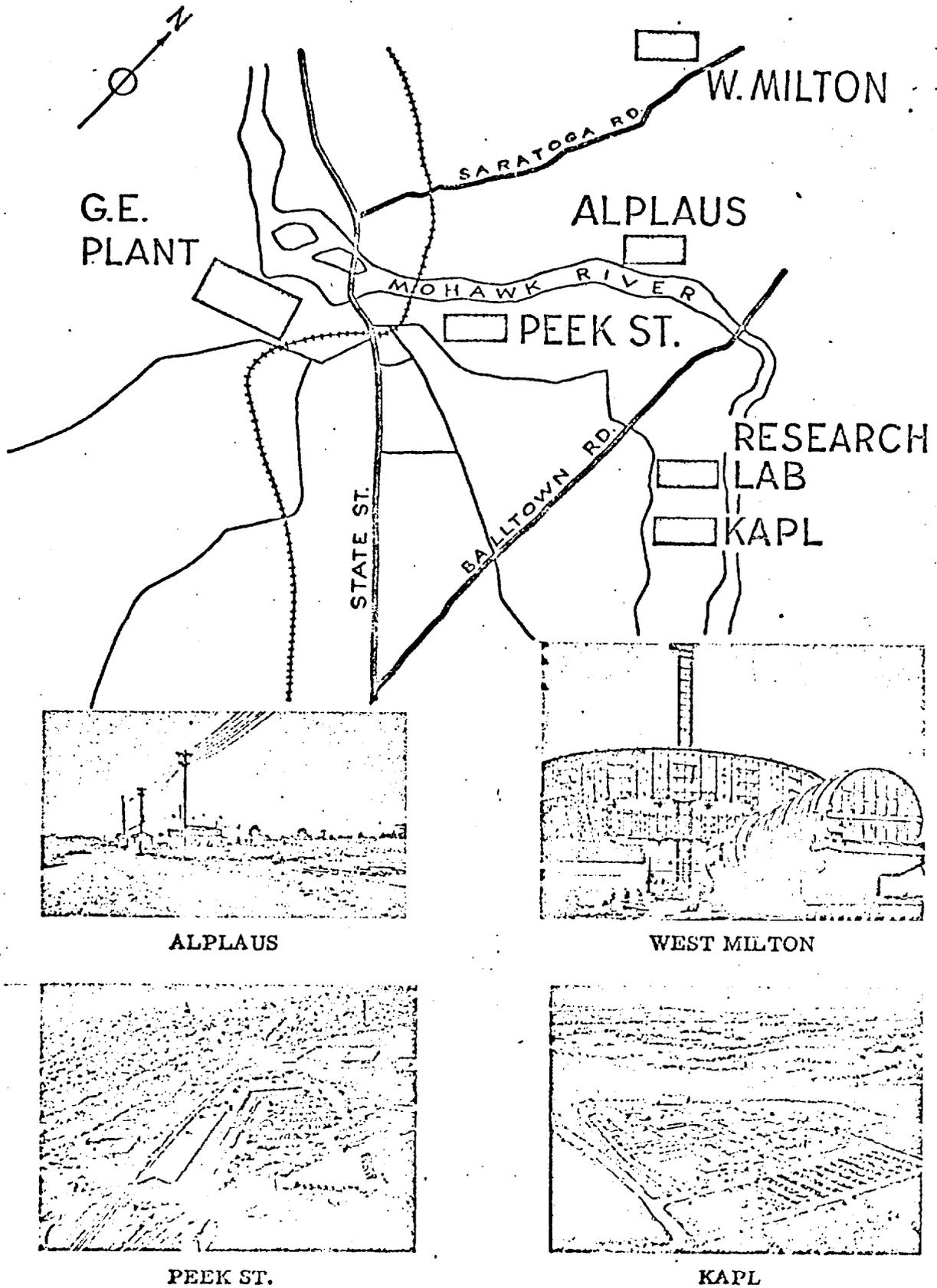
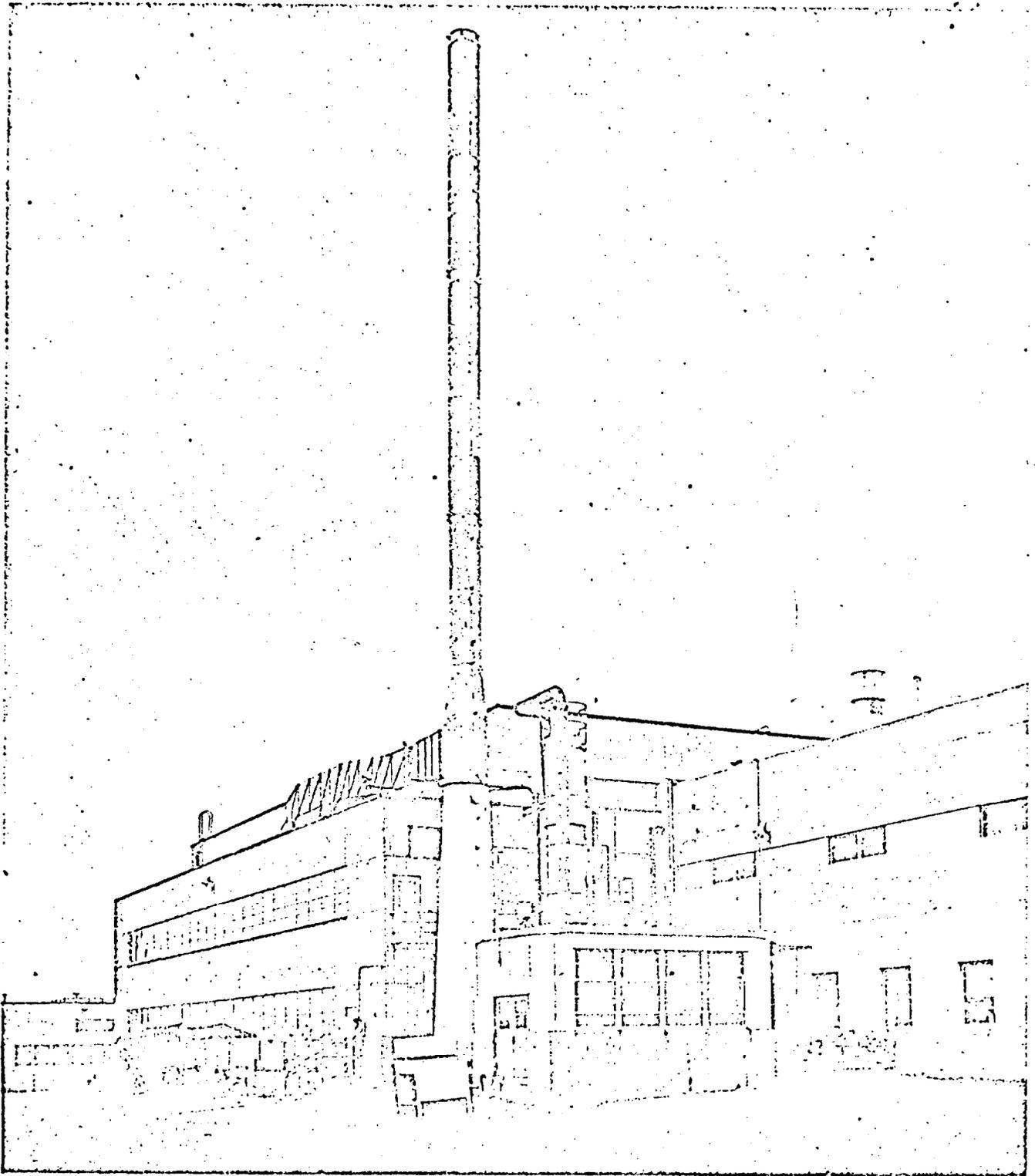
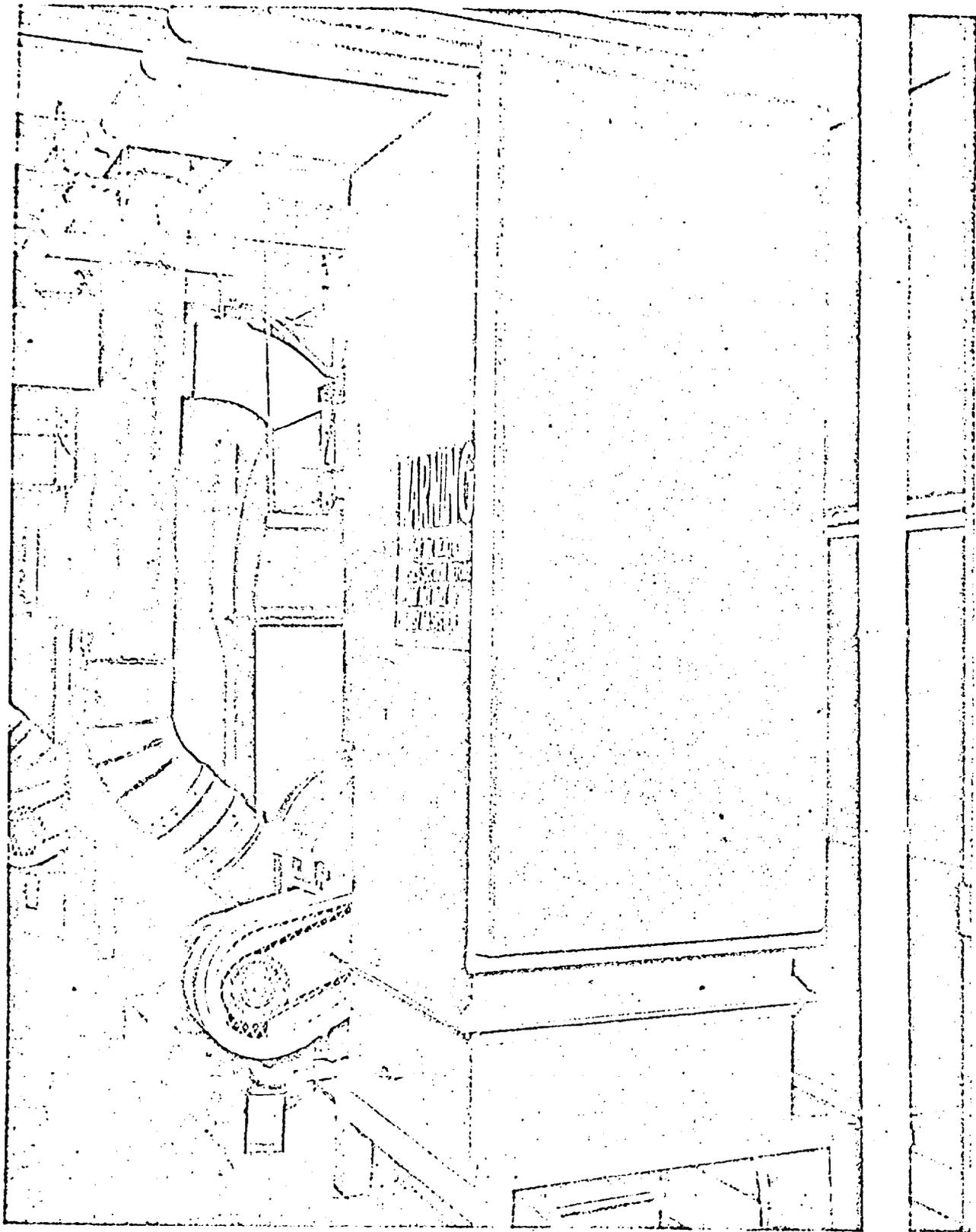


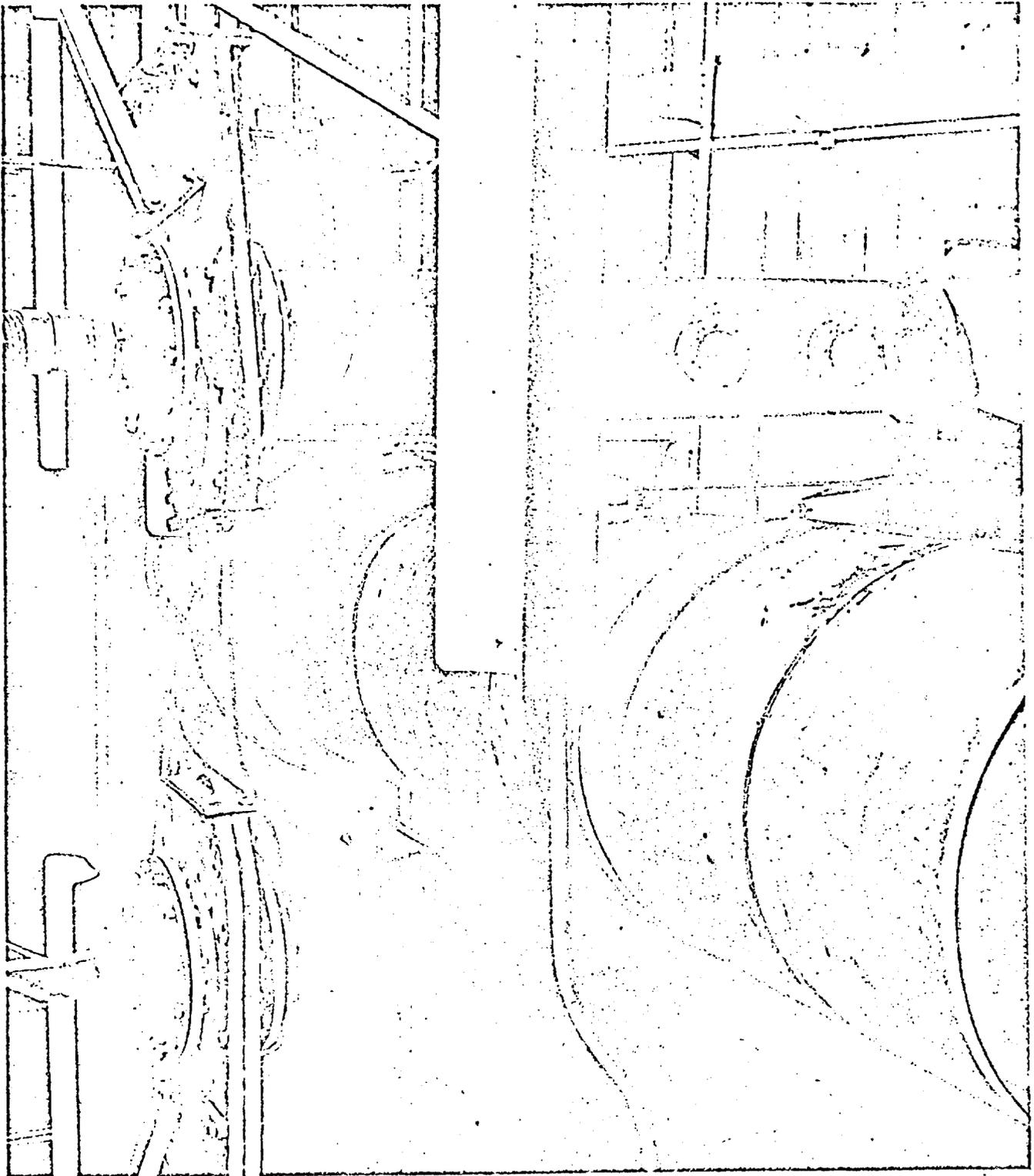
Figure 1



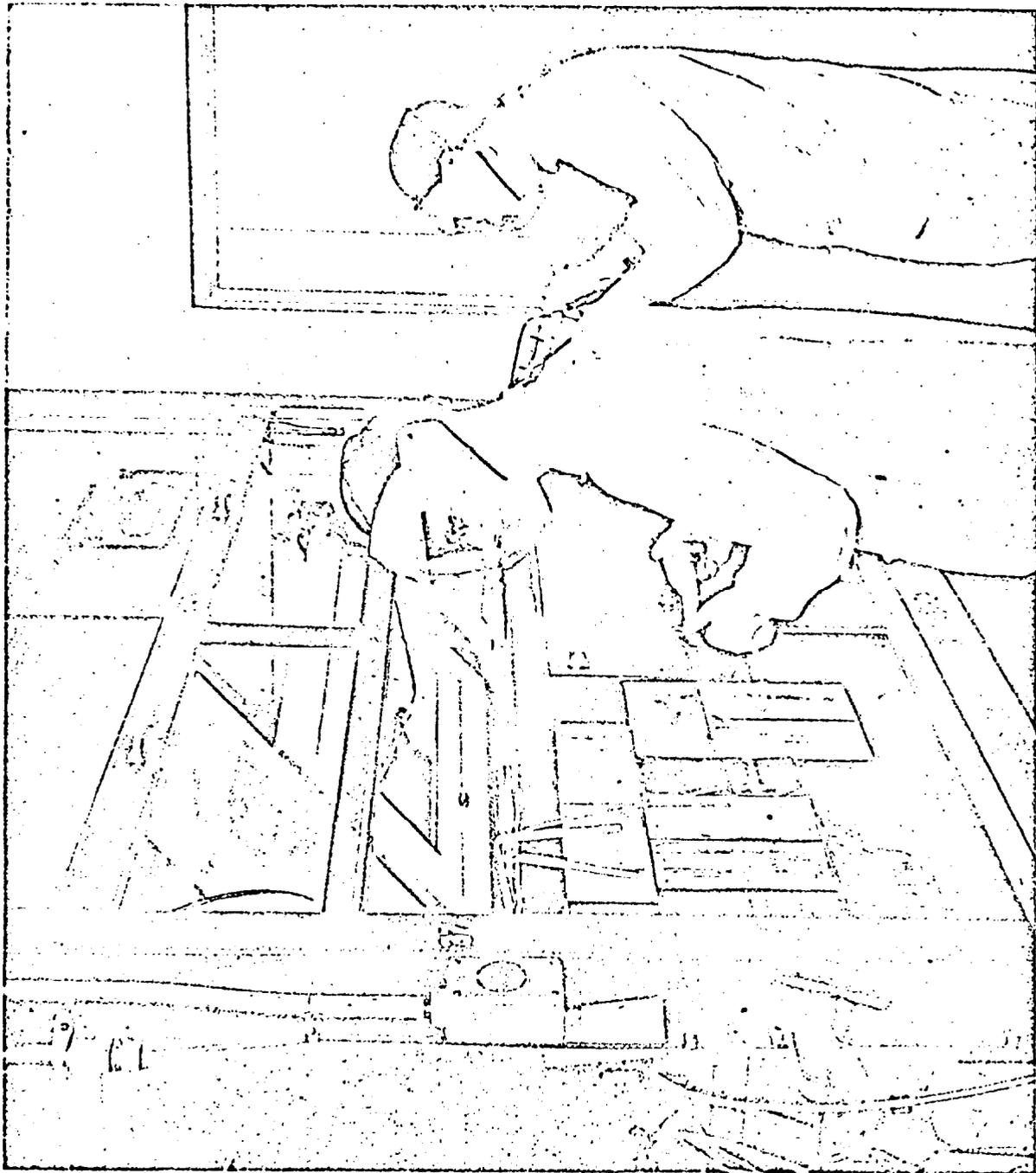
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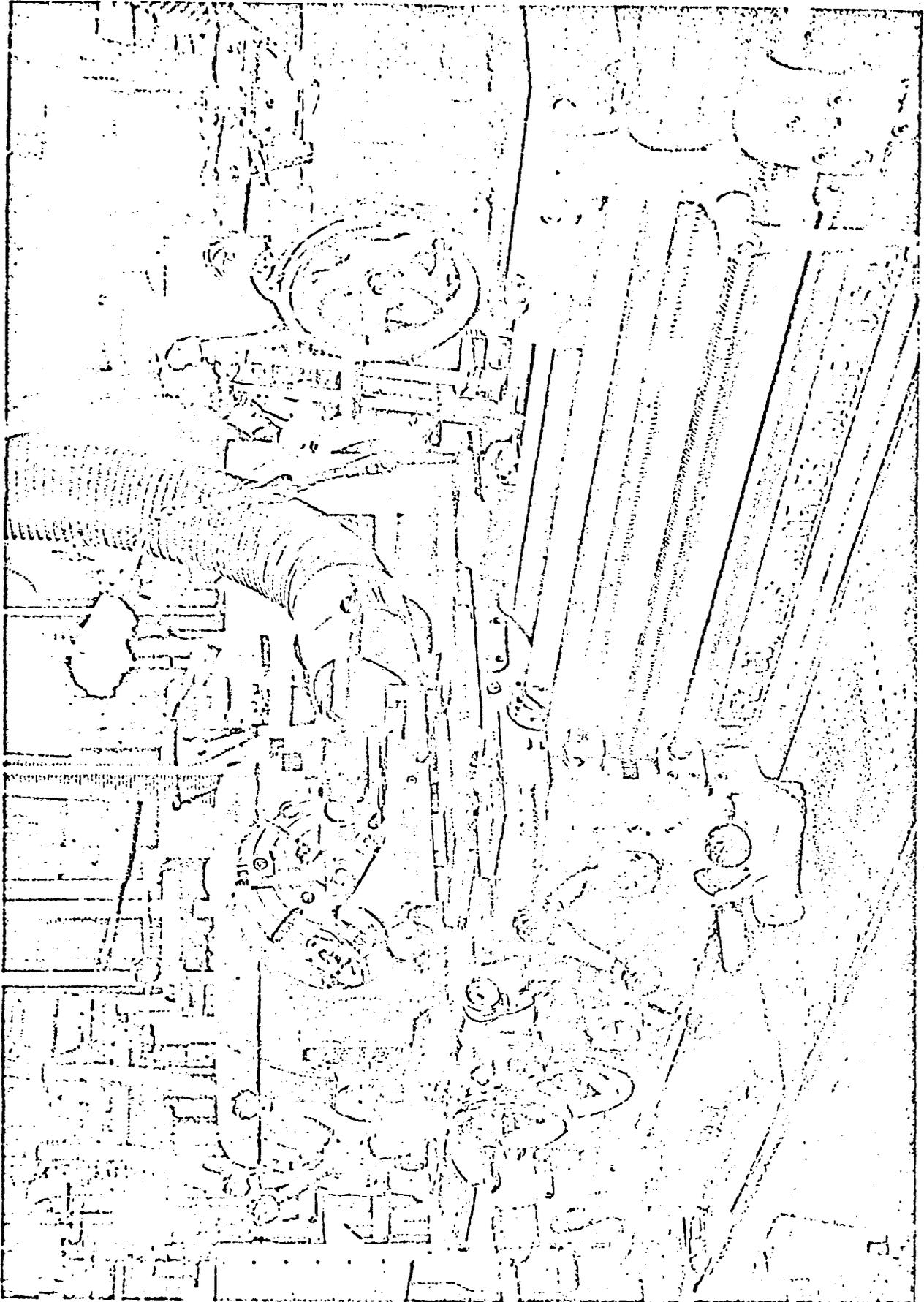
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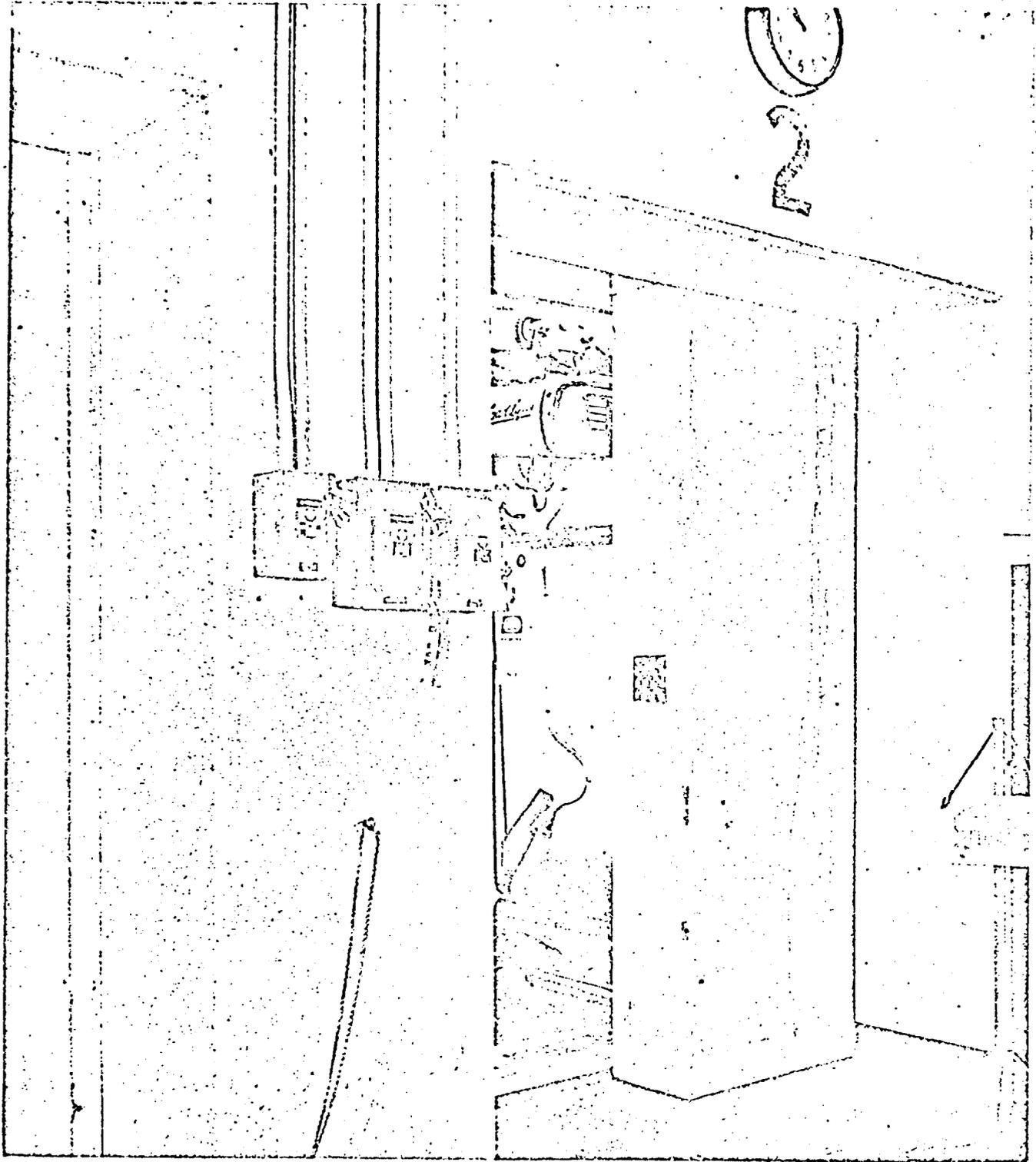
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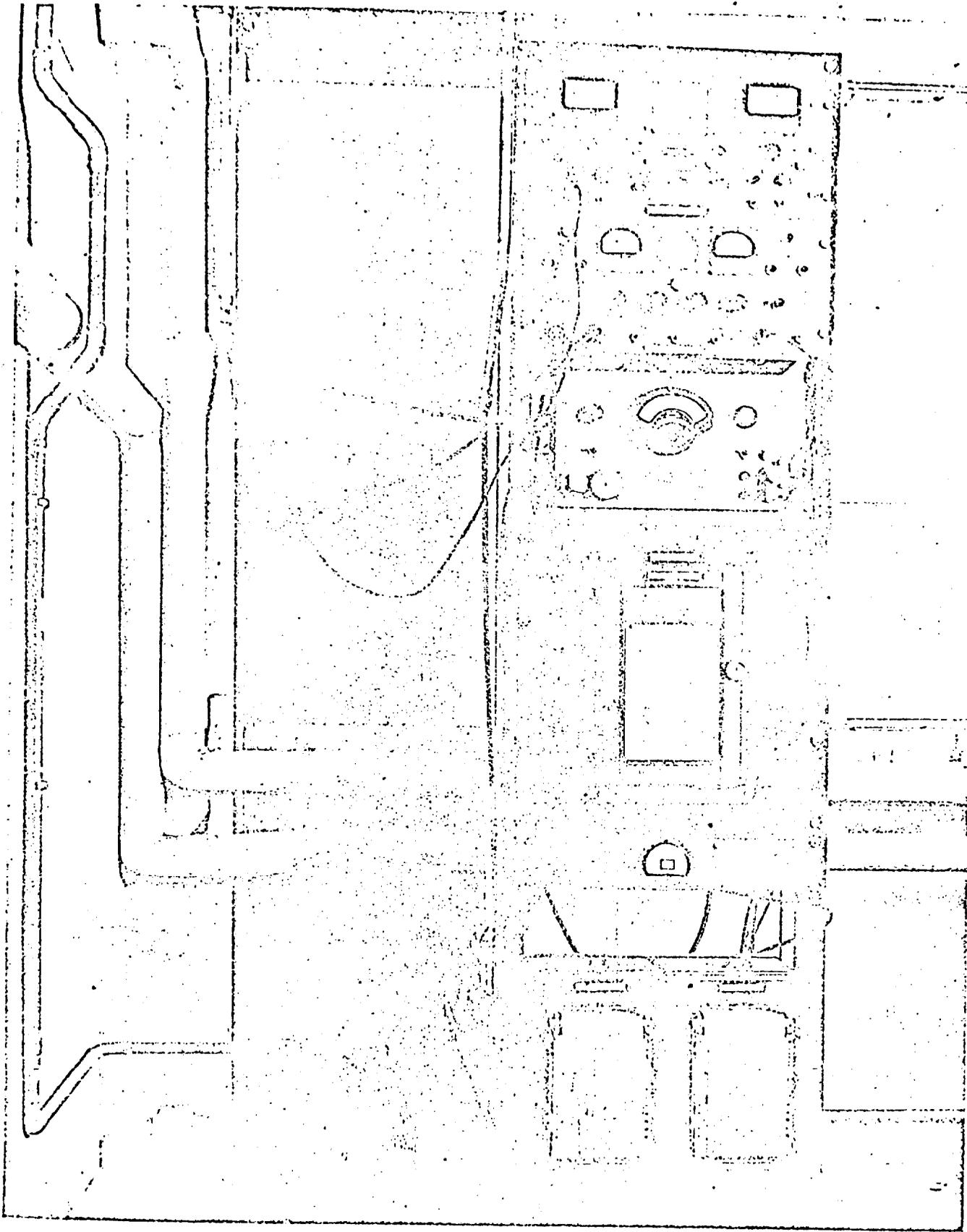
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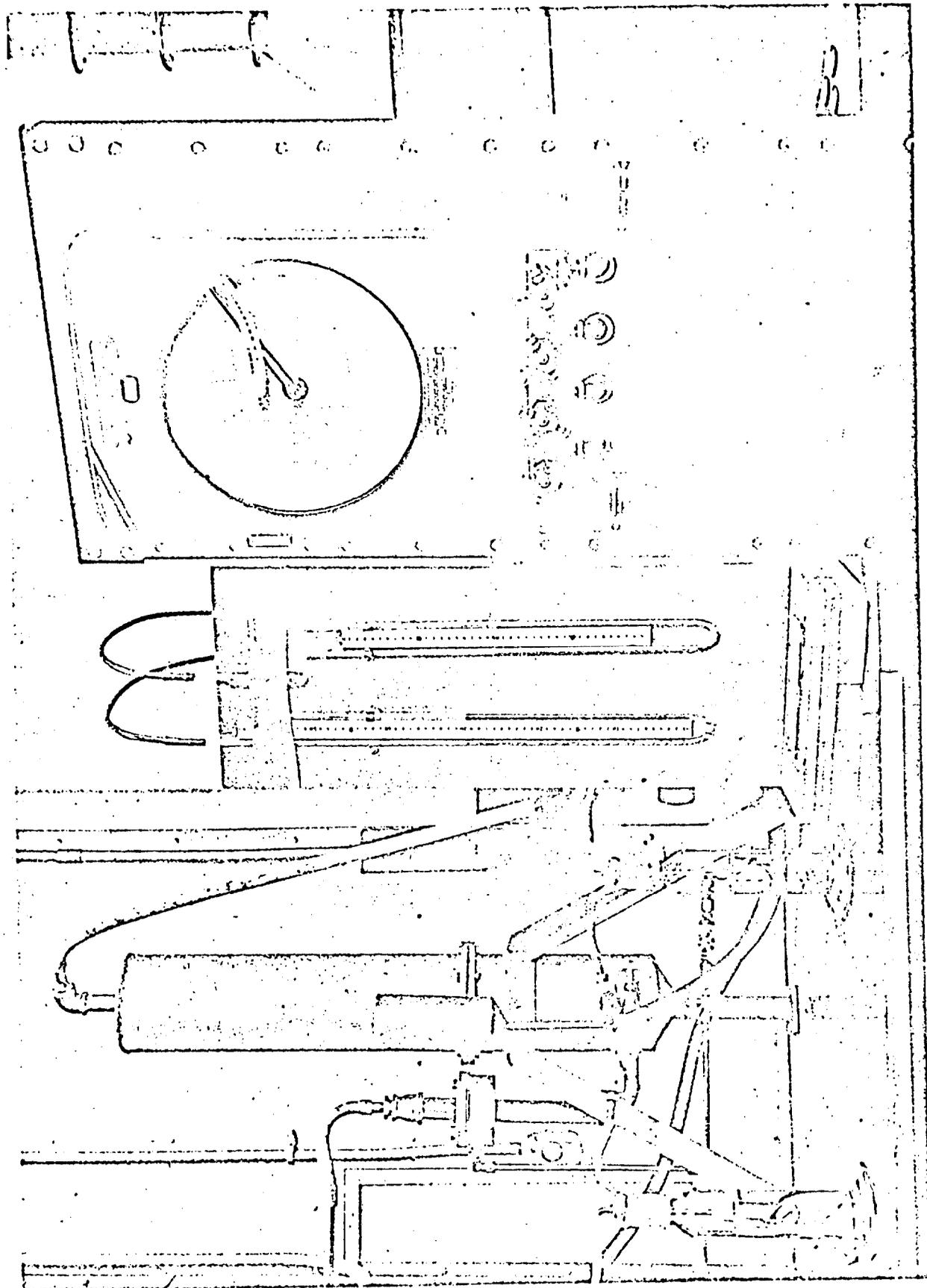
1120928



1096993



1107715



1104414

BROOKHAVEN AIR CLEANING OPERATIONS

Leo Gommell
Health Physics Div., Brookhaven Nat'l. Lab.

Nature has been kind to the Brookhaven area of Long Island by providing an unusually clean atmosphere. In 1949 continuous tests were run by the Meteorology Group to determine the dust loading over a period of six months from March to September. Fiberglas No. 25 and 50 and CWS paper filters were used with flow rates of .75 cfm and .375 cfm, respectively. A total of 200,000 cu. ft. passed through the fiberglas and 100,000 through the paper. The total weight of material collected on the fiberglas was only .2114 grams and on the CWS paper .1300 gms. Analysis showed the particulate material to be quartz grains, pollens, spores, a few salt crystals and considerable unidentifiable material, probably clay and humus.

This light loading of the atmospheric dust gives filters an extraordinarily long life. The cooling air intake filters at the Pile, for example, have been used about 3 years. Tremendous volumes of air have passed through them and still they show only slight loading.

The laboratory policy at Brookhaven states that there shall be no undesirable accumulation of contamination. The discharge of radioactive particulate contamination is to be avoided by the use of appropriate filters or suitable experimental techniques. For operations likely to involve serious air contamination, such as machining active metals or chemical processing of highly active materials, the use of dry boxes with suitable filters and ventilating blowers is required. As a result of this policy most lab hoods, where there is a chance of radioactive particulate being generated, are equipped with the CWS-6 type filters. These areas include Chemistry, Biology, Medical, Cyclotron Target Lab, Hot Labs, Hot Machine Shop, Metallurgy Labs, Nuclear Engineering Labs and Pile Labs. A total of 215 of

this type of filter is presently in use at BNL. Air conditioning at the Pile, Hot Lab, etc. are presently using American Air Filter Co., Air Mat material.

Of course, the greatest air cleaning operation at Brookhaven is in connection with the cooling air at the Pile. To cut down on particulates entering the Pile via the cooling air, two banks of deep pocket FG-25 and FG-50 filters are provided for precleaning. Each bank has 4350 sq. ft. of effective surface, to handle a design load of 140,000 cfm, which results in a face velocity of 32 ft/min. This face velocity gives an initial resistance of 1 inch of water. The efficiency of these filters is widely known.

The exit air from the Pile contains only those particles passed by the intake filters, undoubtedly a small amount of graphite dust and other impurities picked up by the scrubbing action of the air stream, and an amount of radioactive argon gas. This air is pulled along through two ducts, 10 ft. by 14 ft. each, by as many as five 1500 H.P. fans. The exit filters are made of glass fiber cloth known by the trade name "Glastex" manufactured by the Dollinger Corp. They were selected mainly because of low resistance and their ability to withstand temperatures to 500° F. The cloth was chosen because of the possibility of bonded materials failing under prolonged high temperatures and causing voids. The filtering efficiency is not high as compared to the intake filters. They are of the deep socket type, 10 ft. high, 4 ft. wide and 4" thick. Each panel weighs 450 lbs. in its frame, and there are 32 panels in each duct to satisfy 750,000 lbs. of air per hour at 347° F.

After leaving the effluent filters, the air is passed through a heat exchanger and then discharged from a stack about 320 feet high. The dilution of the atmosphere is sufficient to handle the activated argon whose half-life is only 110 minutes. Monitoring stations in the area have shown that there has been no significant rise in background due to Brookhaven operations.

Since the main concern is the prevention of radioactivity from getting into the environment, it seems appropriate to describe briefly certain safety devices that have been installed to show up any possible equipment failures. Less hazardous conditions such as excessive stack air activity, loss of battery-charging current, etc. actuates an alarm and an annunciator drop which shows the cause of the alarm at the control panel.

Beta-gamma monitors are installed at various points in the Pile building to monitor for external radiation from possible shield leaks or from high-level contamination. The readings are recorded by an 8-point recorder which gives an alarm above a certain radiation level.

In each duct, between the Pile and the exit air filter, a sample of the cooling air is drawn through a filter by a pump and then returned to one of the ducts. The filter is situated in an ionization chamber which is connected to a sensitive d.c. amplifier. The activities on the filter are recorded locally by a 2-point recorder, as well as remotely in the control room. Excessive activity activates the alarm system.

Immediately in front of the exit air filters are openings into the ducts. Long steel rods, with oily adsorbent material attached to the end, are extended through these openings into the air stream. The adsorbing material tends to collect particulate material. Periodically, these probes are removed and checked by some type of survey instrument. This gives an estimate of possible particulate contamination.

The final stack air is monitored for argon activity. A portion of the effluent flows continuously from a tap on the discharge duct, through a large ionization chamber (Kanno air chamber) and back into the suction duct. The chamber is

connected to a sensitive d.c. amplifier whose output is recorded both locally in the fan house and in the control room. Excessive argon or particulates actuate the alarm system.

Air samples are taken continuously in those places where air contamination is possible. Whenever assays show airborne contamination to be above the maximum permissible allowable, the worker is required to wear respiratory equipment that will reduce the breathing hazard to complete safety.

By J. R. Clark, Du Pont

DESIGN PHILOSOPHY

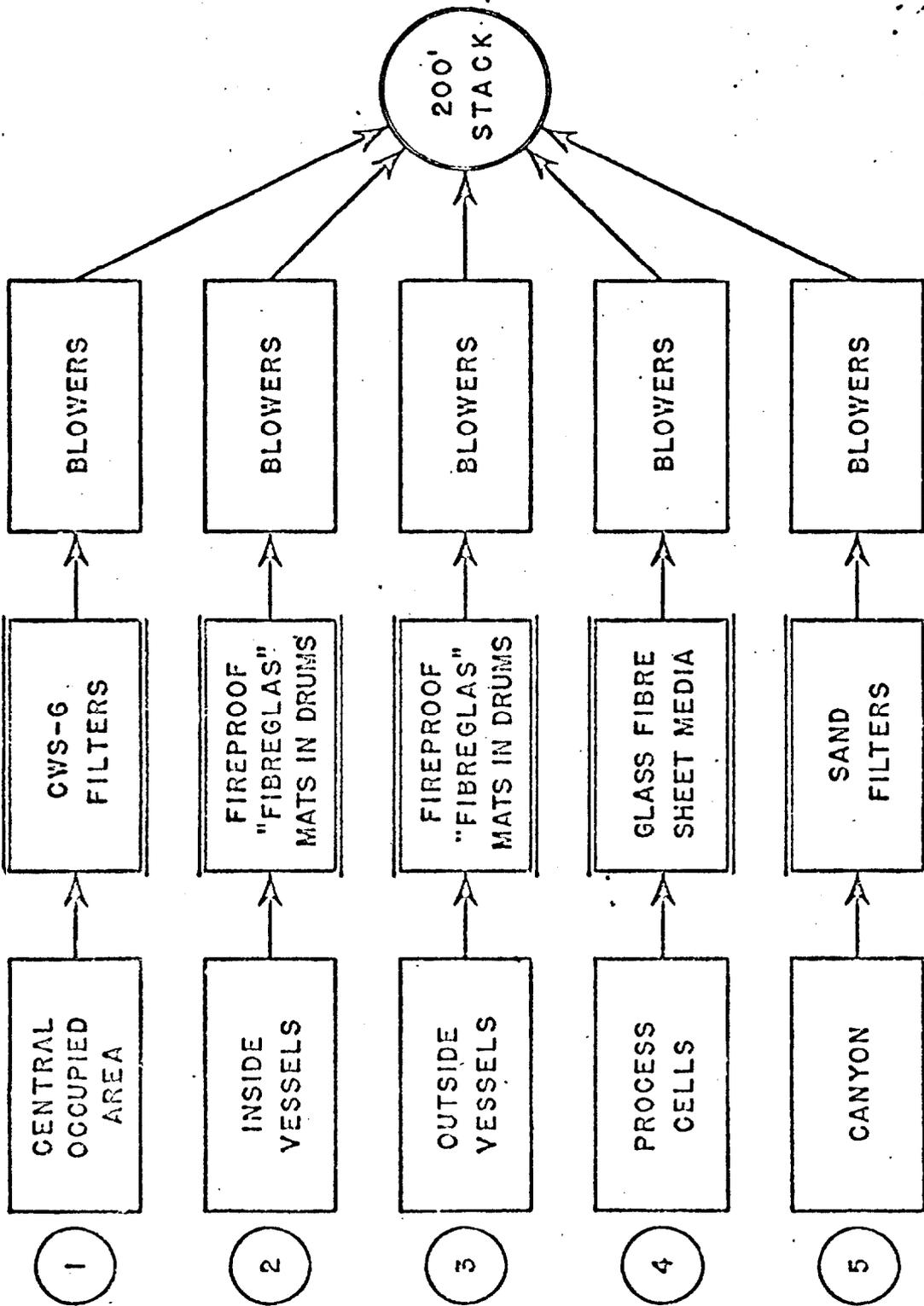
The Savannah River Plant design has had the benefit of the considerable experience in air cleaning problems which has been accumulated at other AEC sites. The intent has been to profit by the developments which have successfully withstood the test of time at other installations, to avoid past difficulties which have arisen when possible, and to adapt new developments to special or conventional problems where no new risk is assumed in so doing. The basic design philosophy has three main points:

- (1) All air streams containing radioactive particulates are cleaned — we do not depend upon dilution.
- (2) Contamination is confined to the smallest possible area. Therefore we have adopted individual venting of the process vessels in conjunction with area venting in the "hot" areas.
- (3) Considerable attention has been given to protecting outside areas from the release of radioactive contamination, by fires and spills, even where these occurrences may be extremely unlikely.

AIR CLEANING SYSTEMS IN A PROCESS AREA

The diagram shows schematically the air cleaning systems in a process area which for convenience is here divided into sub-areas. Five different types of sub-areas are equipped with individual air cleaning systems which include four different types of high-efficiency filters. The ventilation air stream from each of these sub-areas is pulled through a filtration system, by blowers, and all exhaust to a common stack 200 feet in height.

AN AIR CLEANING SYSTEM FOR PARTICULATE REMOVAL AT THE SAVANNAH RIVER PLANT



152

The fan house is equipped with emergency diesel-electric generating equipment for use in case of failure of the primary source of power. Spare equipment is provided to insure continuity of operation of the blowers. A minimum suction level is set for each of the process sub-areas shown. In the event that the suction falls below this set-point, indicating failure of a blower, an alarm is sounded, and a spare blower starts automatically.

The stack is of corrosion resistant construction. It is equipped with a stainless steel pan at the bottom for collection of condensate, which is transferred to the high activity waste system. Two samplers are provided in the stack, one at the level of 50 feet, and the second at 196 feet. These are designed to sample the gases satisfactorily either for particulate matter or chemical content.

Sub-area 1 on the diagram is the central area occupied by personnel. It is unlikely that the ventilation system in this area will ever become significantly contaminated with radioactive materials. It is equipped with filter units on the exit end in order to confine any such contamination within the building. The filter medium is CWS Type 6 paper. Each filter unit is divided into three compartments which can be individually isolated by remote control for maintenance.

Sub-area 2 as shown on the chart consists of the inside process vessels containing appreciable amounts of radioactive materials. The ventilation air from these vessels is filtered through assembled mats of "Fibreglas" packed into stainless steel drums which can be conveniently replaced as a unit.

The filter packing in the direction of air flow is as follows:

| | <u>Type</u> | <u>Density</u> | <u>Depth</u> |
|-----------|-------------|----------------|--------------|
| 1st Layer | 115 K | .75 | 12 in. |
| 2nd " | 115 K | 1.5 | 18 in. |
| 3rd " | 115 K | 3.0 | 12 in. |
| 4th " | 55 PS | 3.0 | 11-3/4 in. |
| 5th " | PF 105 AA | 1.2 | 1-1/4 in. |

Total pressure drop through the filter at 30 ft. per min. is 5.8 in. of water. Over-all efficiency is 99.996%.

The blowers on this system are equipped with butterfly dampers on both inlet and outlet side. These dampers are electrically operated to open and close as the blowers start and stop.

Sub-area 3 consists of process vessels having a low content of activity. The vent air from this system is heated to 150°F before filtering to prevent condensation in the filters. The filters are of the same replaceable drum "Fibreglas" type as used in Sub-area 2 on the diagram.

Sub-area 4 on the chart includes ventilation of mechanical cabinets enclosing process equipment. The individual streams of air in this system are filtered through small fire-proof "Fibreglas" base filters. This would prevent release of activity to the stack in the event of fire.

Sub-area 5 has the largest ventilation flow, accounting for about 60 per cent of the total stack gas. This stream is filtered through a deep bed sand filter which is modeled after the Hanford units. The air from the ventilation system enters the bottom of the filter

through a distribution system made up of clay tiles. The sand size decreases going upward through the bed. Above the main layer the filter contains two "hold-down" layers totalling 12 inches to prevent mounding. Efficiency of the 7 ft. sand filter is about 99.7%. The filter is equipped with an automatic dew point recorder operating on the gases entering the filter. Provisions have been made for sampling the entering and exit air continuously. Air from these points is drawn through filter paper contained in a sample unit which is part of the plant Health Physics monitoring system. The building design includes shielding to protect personnel while carrying out their normal assignments.

A stack gas dispersion study was made of the Savannah River Plant area by the Du Pont Engineering Department. The purpose of this study was to determine (1) the ground level concentrations of stack gas contaminants under various conditions, (2) the geometrical shape of the ground level dispersion pattern downwind, and (3) the relationship between short-time peak concentrations and the average concentrations at downwind points. The study also included weather conditions such as dry bulb and wet bulb temperature variations, frequency and duration of inversion conditions, and frequency and duration of rains. As a result of the study, working charts were developed for rapid computation of ground level concentration for various conditions. It was found that stable inversions are usually less than 300 feet thick at the Savannah River Plant site. A new diffusion equation was developed for the Savannah River Plant area based on the data obtained in the study. This is a modified form of the Bosanquet-Pearson Equation.

The Health Physics section at the plant has a rather comprehensive air sampling program for the plant buildings and the outdoor plant areas

as part of its regular HP survey work. Some of the buildings are equipped with vacuum lines exclusively for air sampling purposes. These are designed for a 10 cfm sampling rate assuming a 50% use factor for the multiple sampling points in each area. Other buildings are sampled with modified household vacuum cleaners. The sampling paper used in each case is a 4" x 8" rectangular sheet of CWS Type 6. At a sampling rate of 10 cfm a minimum sample of 300 cf is monitored, using a minimum sampling period of a half hour. Air samplers are counted routinely for α , β , and γ activity.

AIR HANDLING FACILITIES

at the

AMES LABORATORY

By R. W. Fisher, Ames

The Ames Laboratory installation is primarily concerned with two types of air handling: (1) a general type for supplying fresh air to the buildings proper and (2) special filtering centers for handling contaminated air from the various process areas.

SECTION 1 - General Air Supply for the Research Building

The air handling system in this building has recently been increased to handle 60,000 cfm fresh air at -20°F . The system was originally designed for 80% recycle of laboratory air to cut down on heating and air conditioning load. However, due to the number of hoods which are in operation throughout the building, it was necessary to increase our fresh air supply from 20,000 cfm to 60,000 cfm. The total air handling capacity is approximately 100,000 cfm.

The fresh and/or the recycled air is first passed through an oil-treated Farr filter, then through a bank of electrostatic filters and finally through carbon canisters which remove odors and other materials passing through the electrostatic filters. These carbon canisters are loaded with coconut-shell charcoal and have a life of approximately two years. We have found from operating experiences that these canisters must be given a protective coating to prevent corrosion. The estimated operating cost is approximately five cents per cfm per year. We believe that this cost is more than justified since it does permit the recycling of laboratory air which normally would not be permitted, resulting in a much lower operating cost both for steam in winter and chilled water in summer.

The air, after passing through the carbon canisters, goes across the heating or cooling coils, then through spray chambers which serve to cool or humidify, depending upon the requirements of the moment. The system is then divided into two zones with individual reheat coils at the duct entrances. In addition, each of these zones is sub-divided into a number of branch zones with additional reheat coils to permit balancing the system and altering temperatures for various areas. The building is kept under a positive pressure of approximately .02 to 0.1 inch of water by use of venturi dampers in the exhaust system.

SECTION 2 - Hot Canyon Air Handling System

This section of the Research Building is not air conditioned since the amount of air handled is too great to justify the cost. One hundred per cent of the air is discharged out of the stack. 15,000 cfm of air is brought in through a pre-filter consisting of a bank of Farr filters, then through a bank of deep-pocket FG-25 fiber glass filters. The air enters the Canyon through a perforated ceiling. All of the air is exhausted through the stainless steel cave and other dry box systems. This exhaust air is filtered through a bank of FG-25 deep-pocket filters, then through a bank of FG-50 deep-pocket filters and finally through a bank of CWS high-efficiency filters. The exhaust system consists of welded metal ductwork located outside the building proper extending up to the roof where it is discharged straight up into the atmosphere. The exhaust fan is powered by a two-speed, high-head blower, enabling the system to operate at the lower speed during shut-down times and in evenings when no work is being carried on. This maintains a negative pressure in the work area at all times preventing back-contamination.

In addition to the two-speed blower, an auxiliary, high-head, 6,000 cfm blower is installed in the line which serves as a safety factor in case the large motor should fail. With the above set-up it is possible for us to selectively discharge 6,000 cfm, 12,000 cfm, or 17,000 cfm depending on the needs of the moment. All of the Canyon exhaust system is further protected by an auxiliary power supply which cuts in automatically within four seconds in case of a power failure.

Monitoring devices have been placed in the filter system to enable us to check the activity of the filters and to remove them before the activity reaches a dangerous level. In case of an emergency, light weight diving suits have been provided to enable operating personnel to enter the filter chamber and remove highly active filters.

In addition to the gross air handling facilities, the air for each of the individual operations including glove boxes, etc., is prefiltered by a small CWS type filter before being discharged into the general system. By this method the general filter should run for a number of years before any maintenance and filter replacements will be required. In addition, the activity will be confined to a relatively small volume, aiding in the disposal.

SECTION 3 - Thorium Production

Approximately one year ago, the thorium production activity at the Ames Laboratory was shut down as a result of a survey which showed the dust levels to be abnormally high. As a result of this survey all of the process equipment was redesigned with a view toward reducing these levels to the tolerances prescribed.

In the oxalate precipitation step, the unloading of the thorium nitrate tetrahydrate is done by a closed system using a special hood which reduces the dust level in this area below tolerances. The area where the oxalic acid had been handled was completely hooded by a closed, plexiglass hood. A vent line terminating in a canopy was run to the rotary filter to pick up whatever dust might be generated from the damp filter cake. The hood, which is used to handle the wet and dry oxalate, was revamped by the addition of a pivoting plexiglass front, reducing the open area and thereby increasing the face velocity of the hood. A curb was placed on the front edge of the loading table to prevent powder from spilling onto the floor. As a further means of reducing dusting to the atmosphere, an enclosed grinder was installed in the hood through the work table surface, discharging into a sealed container below.

The rotary calciner was equipped with a vented hopper permitting drums of dry oxalate to be discharged into it with no leakage into the room. The discharge side was completely sealed by use of a pneumatic lift, permitting the oxide to go directly into a stainless steel drum in a closed system.

The off-gases of this process (approximately 70 cfm) at 550°C are filtered by means of a venturi scrubber utilizing a steam jet, and, thence, into the stainless steel cyclone separator. These hot gases are then additionally filtered through a heat-resistant, high-efficiency filter which is periodically cleaned and replaced. The efficiencies of the above system are as follows:

Cyclone separator alone gives approximately 80% efficiency by weight.

The addition of the steam spray and venturi scrubber brought the efficiency up to approximately 95% by weight.

The HF furnace is a new type not previously used at the time of the shut down. This continuous furnace is loaded by means of a hopper similar to that used for the calciner and is discharged by means of an auger to a vented, five-gallon container. The off-gases, containing hot, wet HF, thorium oxide, and thorium fluoride, are passed through an inconel cyclone separator and then through a carbon filter with automatic blow-down feature. This system works quite well but requires considerable maintenance of the carbon filter. The HF is then condensed in a spray chamber and the acid solution is automatically neutralized with a sodium carbonate solution by means of a Beckman dipping electrode located on the discharge side. The effluent from this chamber is then discharged into the sanitary sewer system.

In addition to the above-mentioned equipment, all of the mixing and loading equipment used in the reduction step were given additional hoods which discharged first to a cyclone separator and then into a Type N roto-clone before being discharged outside the building. Air samples, which are taken periodically, show our dust levels to be low enough so as to present no problem to the surrounding areas. We feel that the process area, as a whole, was improved up to a point that the Ames Laboratory thorium operation could be very well carried out in a thickly populated community.

It is realized that improvements could be made to the above-mentioned equipment. However, since this was a crash program of a limited duration, it was felt that further work would be unnecessary and uneconomical.

SITE AND CONTRACTOR ACTIVITIES AND PROGRAMS
U. C. RADIATION LABORATORY

By M. D. Thaxter, UCRL

The Radiation Laboratory handles I should guess over 99% of its isotope curies in Berkeley boxes. Our air cleaning problems are so intimately connected with this concept that it would perhaps be helpful to show a few slides about boxes.

SLIDE 1 Observe in the middle a simple box shell. It is mounted on a so-called dolly with casters. Various kinds of equipment may be added to suit the job. Left and right are shown boxes equipped for fairly high levels of routine alpha work. On top notice filters in series terminated in a blower. The blower may discharge to a nearby hood or to manifolds constructed for the purpose. In passing, note each box is a complete laboratory.

SLIDE 2 Shows a closer view of a simple box. Note air inlet tubes at left and right lower corners. They distribute air which comes in the rear of the box via 1.3 micron fiberglass media. Observe the glass fume hood for close capture of airborne material during evaporating, fuming, grinding, etc.

SLIDE 3 Shows a box in a hood. Our hoods have two purposes (1) Stink chemistry with or without tracer work (2) secondary enclosures for "hot" boxes.

SLIDE 4 Showing two boxes hooked together for linear operations in this case housing (1) preparation area and (2) DC sparking area for spectrographic work. The spark is lit within a quartz tube; the resultant aerosol is flushed thru a 1st sampler, two CWS 6 filters, a final sampler, thence to another CWS 6 with general box air and out the stack. We have never had an airborne alpha contamination in the room although some of the sparked samples contained more than 10^{10} counts per minute. During the trial periods we captured the exhaust in evacuated tanks but never found any counts, hence the stack.

SLIDE 5 Showing how any room can be a multipurpose lab; four boxes exhausted via a common manifold. We've had nine boxes in one room.

SLIDE 6 When gammas are involved, we wheel a lead shield up, replace gloves with manipulators, add lead glass windows and continue. No change in ventilation requirements.

SLIDE 7 A shielded box for simple work.

SLIDE 8 A shielded box for a complex chemical sequence. The control panel handles electrical equipment inside.

SLIDE 9 Shown are some of the complex gear: hot and cold baths, reagents on a rotating rack; manipulator, pipettors and sampler in front.

SLIDE 10 A recently used shielded box with equipment in place.

SLIDE 11 A sequence of boxes for handling pile slugs: cutting, unloading, dissolving, complete chemistry, column separation and purification. Exhaust capacity about 30 CFM. A recent count showed we have put 266 boxes of all sorts to use; 135 of these are currently at work. The average exhaust rate each is possibly 10 CFM. Our air cleaning volume then for "hot" work is 1350 CFM. We have over 100 hoods handling either no activity or tracer and short half life stuff; they average about 1000 CFM each; a total of 100,000 CFM for the project. We don't clean this air. We think we can make a good case on ventilation alone for saving many thousands of dollars in not employing large CWS 6 filters and the costly gear: blowers, plenums, etc., needed by them in contaminated room-hood type operations. The hidden savings in manpower hours by not requiring special clothing, respirators, etc. is an incidental and valuable benefit difficult to assess cost-wise. Our associated waste disposal problems are reduced bulkwise because our little 8" x 8" filters operate on rigorously precleaned air and some have lasted more than 3 years as a consequence. This all sounds rosy. But the future is getting cloudy in the aircleaning field as we see it. Where we used to deal with microcuries we are with increasing frequency handling curie and larger quantities in a box. The usual air cleaning train ending with a CWS type filter is not always enough. A few counts are coming thru. Someone has to invent a better air cleaner; 99.96 % is not good enough for materials requiring confinement to the 10th decimal point of 9's. We are making a few advances in trying to prevent aerosolization at the operating point but this is difficult because some processes just can't be avoided or tinkered with. The use of ion exchange resins is a blessing in this direction removing as it does in many cases the requirement for extensive heavy chemistry and its concomitant aerosol formation

and dispersion.

One of our continuing problems regarding air cleaning is mainly psychological. Graduate chemists come to us with a long training behind them dealing with non-radioactive materials. They are used to bench and hood work and the total enclosure or box idea is at first felt to hamper them. Conversion takes days for some, months for others. Occasionally, a convert is made dramatically as in the case of a gross spill on a bench top rendering months of work invalid in a lab now uninhabitable. Spills in boxes relatively speaking are easy to handle: we give the chemist a new box (sometimes in a matter of minutes) and he continues his work in the same room where he eats his lunch, smokes and writes his reports. And the contaminated ductwork and filters are a part of the removed box, not a part of the building.

In the slides, I showed a more or less standard basic box unit. Some applications demand special shapes. For instance in handling tritium we house an entire vacuum rack of glass apparatus in a box about 50 cubic feet in volume. We have enclosed sputtering devices, metal production units, mass spectrograph units and a host of other special equipment in odd sized enclosures. Ventilation-wise each supplies the same virtues: small air volumes, pre-cleaned operating air, a positive barrier between operators and contaminated air, small air cleaning equipment, readiness of disposal, small investment. It is true this concept seems suitable only to research lab scale work. We are realistic in not claiming to be able to box up an operating pile or separations plant. Yet it is interesting to find at times one of our chemists working in a box with quantities of materials which at some other site would be called production quantities, curie-wise. We don't place blind faith in any equipment, including boxes. We collect over 1000 air samples per month, analyzing for alpha and beta-gamma contamination. We have never had a beta-gamma contamination exceeding 10% of the daily maximum permissible exposure. Our alpha contamination has crept up in the last four years so that we now find about two samples a month reaching the level permitted for everyday exposure. This is disturbing even when one realizes the curies of material handled today is at least 100,000 times what it was in 1949.

Part of the cause lies in pure arithmetic: where a 0.01% loss was undetectable in 1949, today it is detectable. Part is due to higher specific activities of the isotopes being handled. They seem to behave differently.

Up to this point my remarks have been emphasizing our air cleaning problems as regards keeping the activity confined to the operating volume of the enclosure. We should also recognize the impact of what gets into the operating enclosure from the outside. Since the results of much research work are based on a final sample wherein perhaps a few counts per hour may be the basic data it is apparent that cross contamination can be dictating the validity of much research endeavor. Thus non-contaminated supply air is essential; this demands an air cleaning program of good efficiency. Our boxes have enjoyed this all along, as mentioned. There is a threat however. As contaminants increase in quantity the requirements must be beefed up. As atmospheric background goes up due to Uncle Joe's shots we can possibly forecast the need for supplying cleaned air to counting devices not normally so supplied. Recently we collected atmospheric contaminants blowing in off the Pacific containing 0.2 counts beta-gamma per hour in a 500 cc volume with an apparent half life of 19 days. This is a substantially greater quantity than previously found at Berkeley. The trend has been rapidly up in the last 24 months. What the next few years will bring I cannot estimate. These remarks pertain of course to purely technical problems, not health hazards. These latest air pollution values are still 1/150th the health hazard level.

To summarize, we can report from the Radiation Laboratory:

A. As to the past:

1. Our stack gas air cleaning program has worked pretty well. We handle about 1350 CFM of air at good cleaning efficiency, at minimum cost in investment and maintenance.

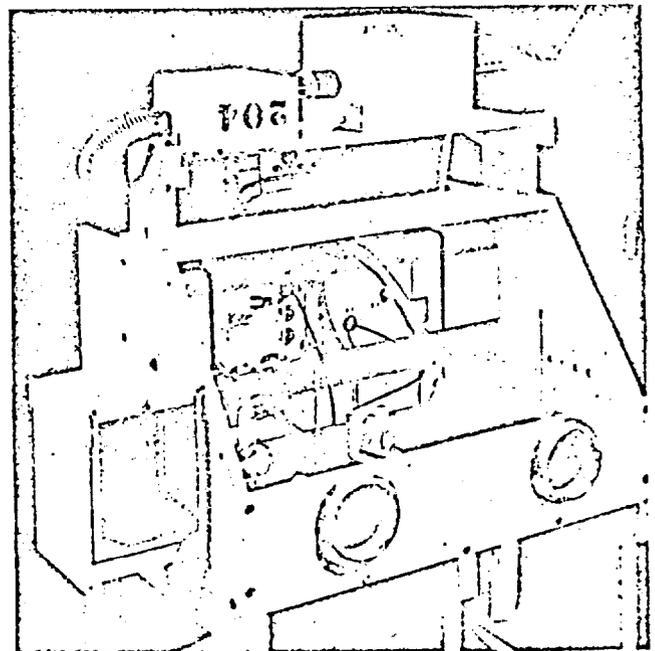
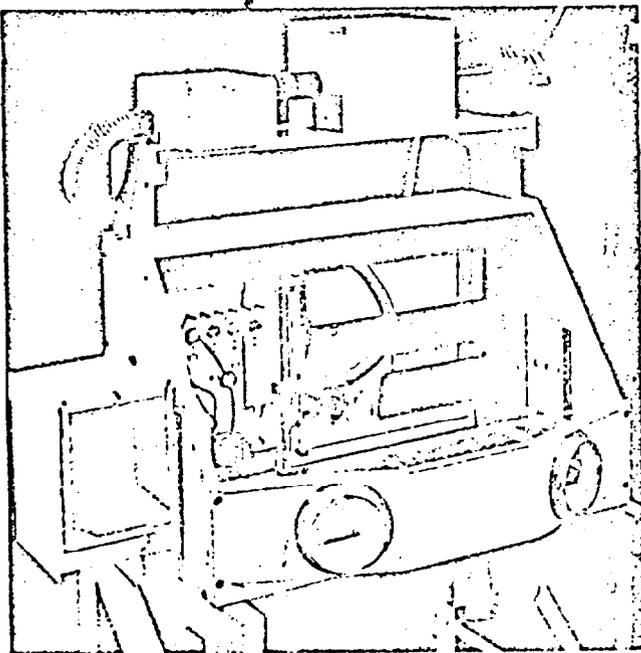
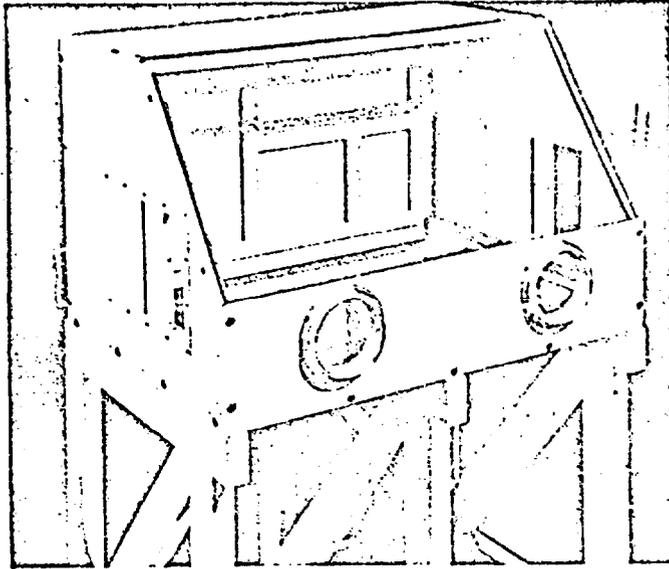
2. Our supply air cleaning program likewise has been technically adequate.

B. Regarding the future:

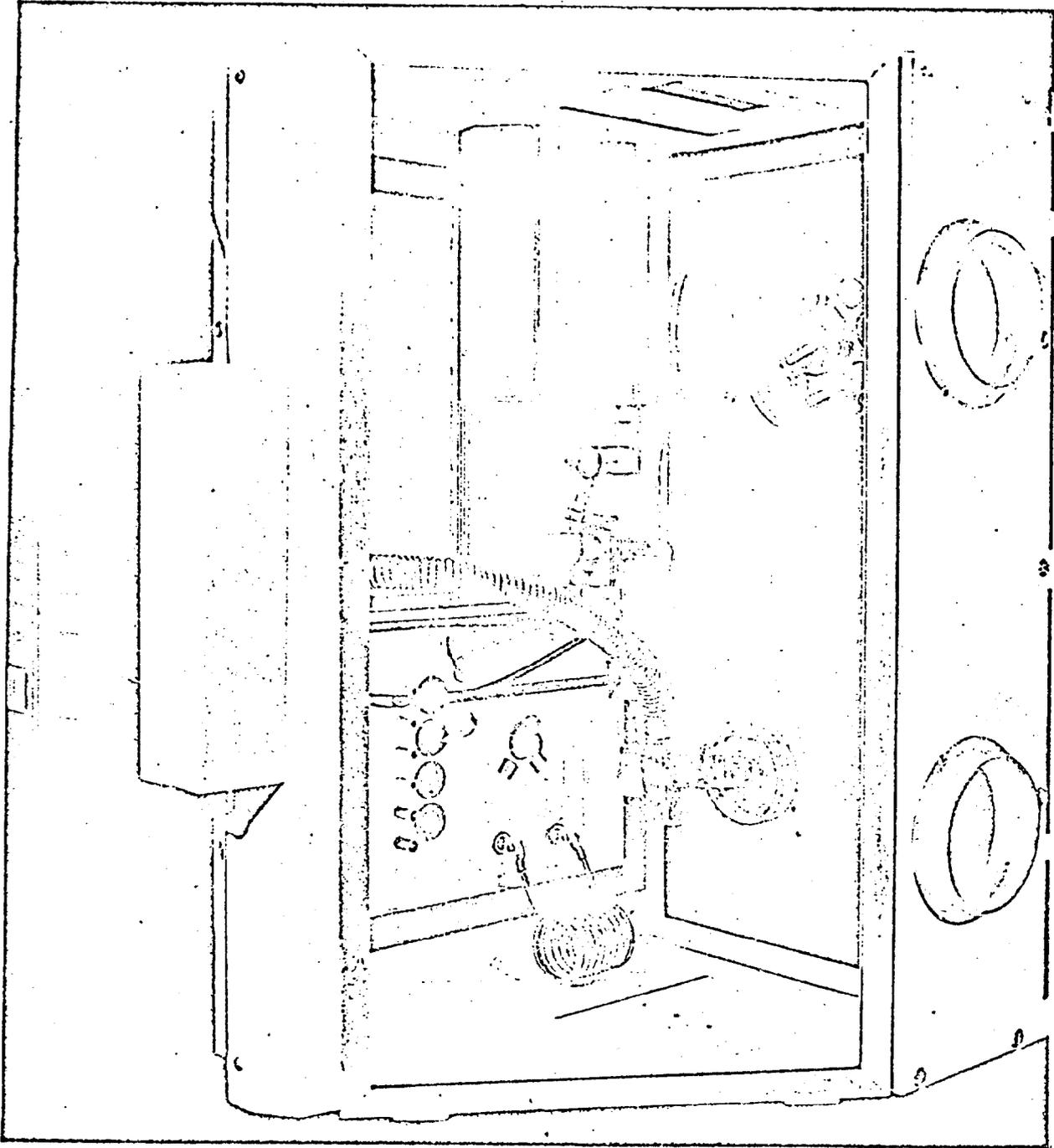
1. Recent and probable future increases in specific activity and quantities of research material handled suggest the need for greatly increased off-gas air cleaning

efficiency beyond that obtainable from traditional devices ending in CWS 6 type filters.

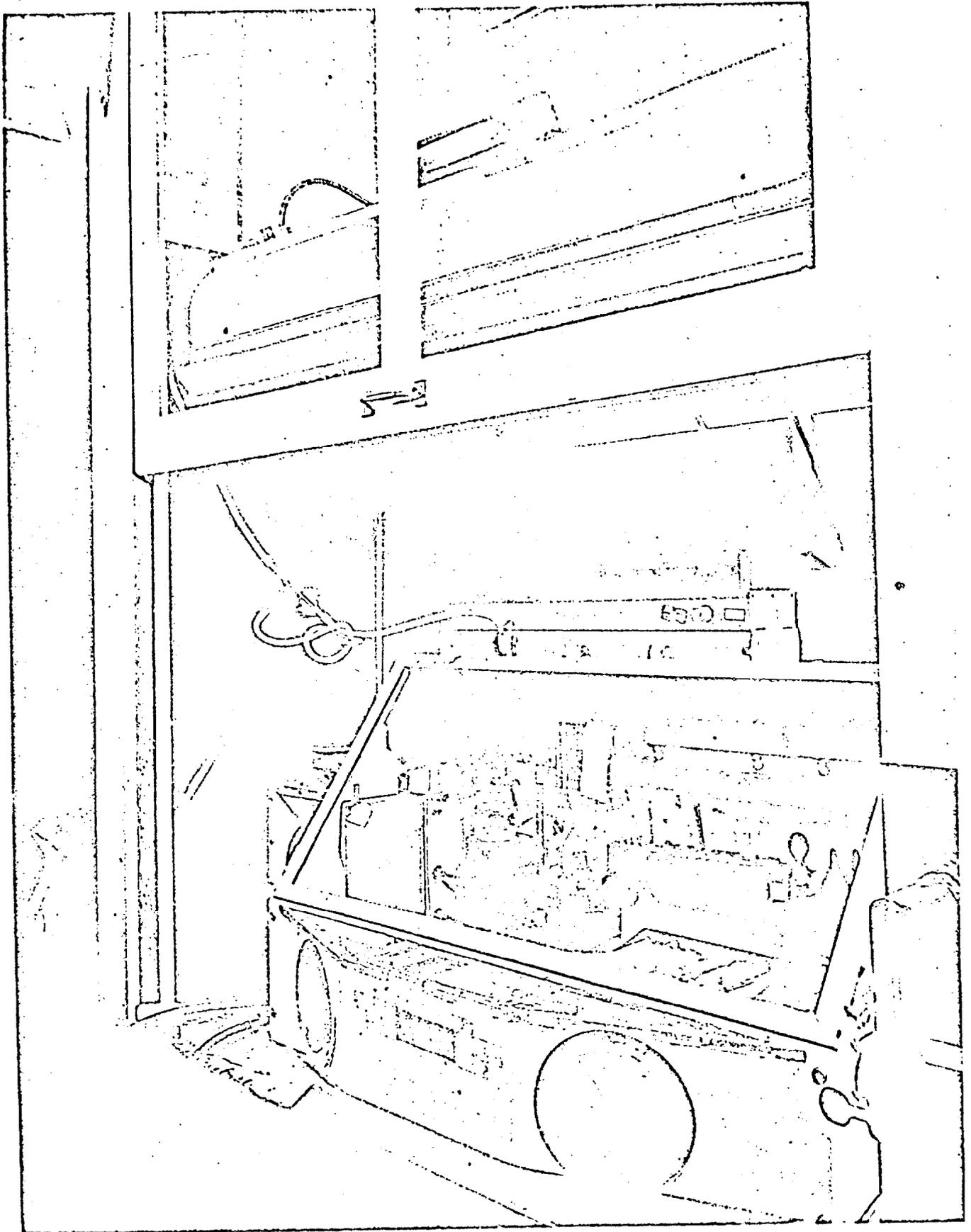
2. Cleaned supply air may be required in certain research devices and areas not now needing it because of increases in radioactive atmospheric pollutants resulting from detonations of foreign and domestic nuclear devices.



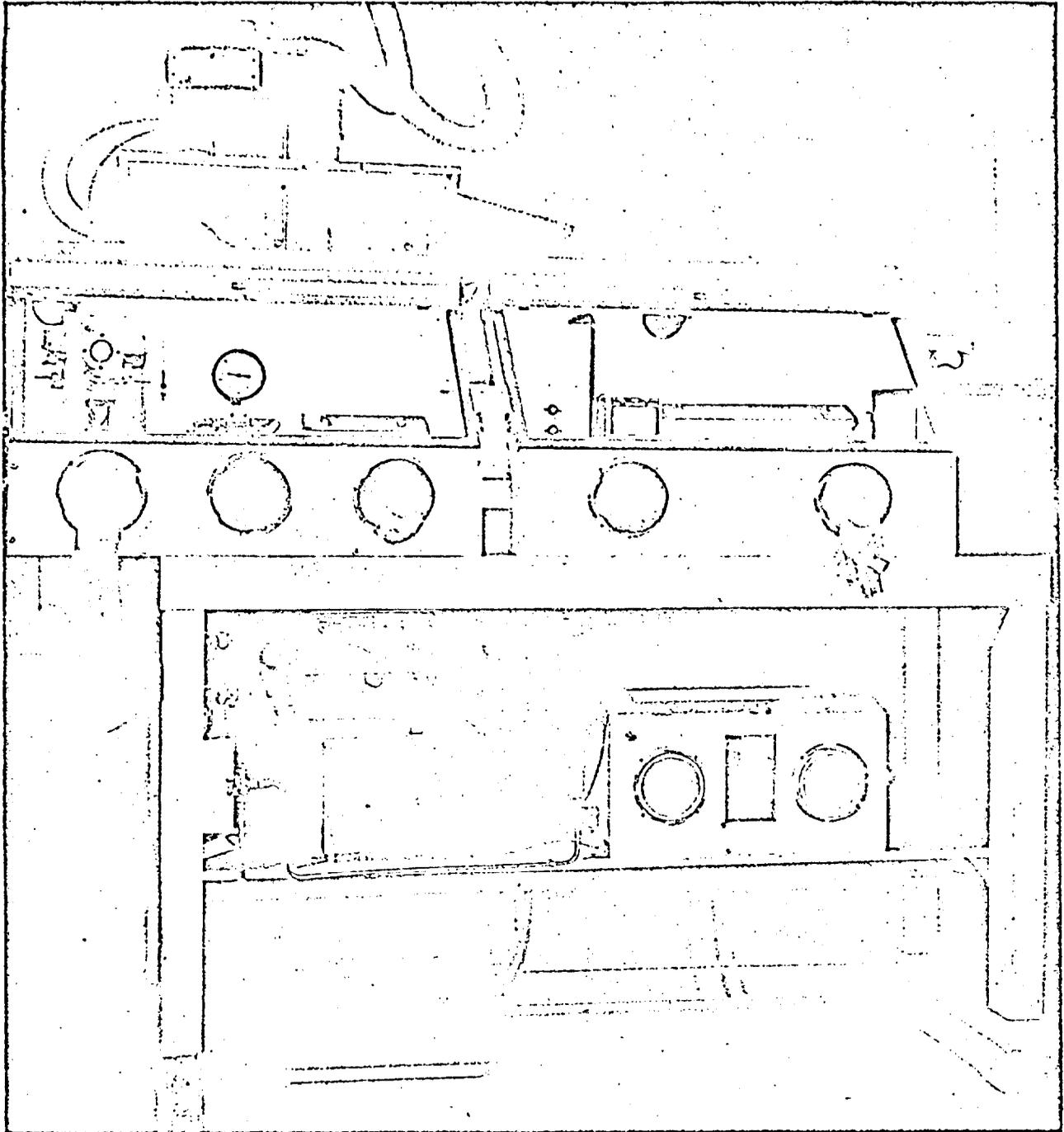
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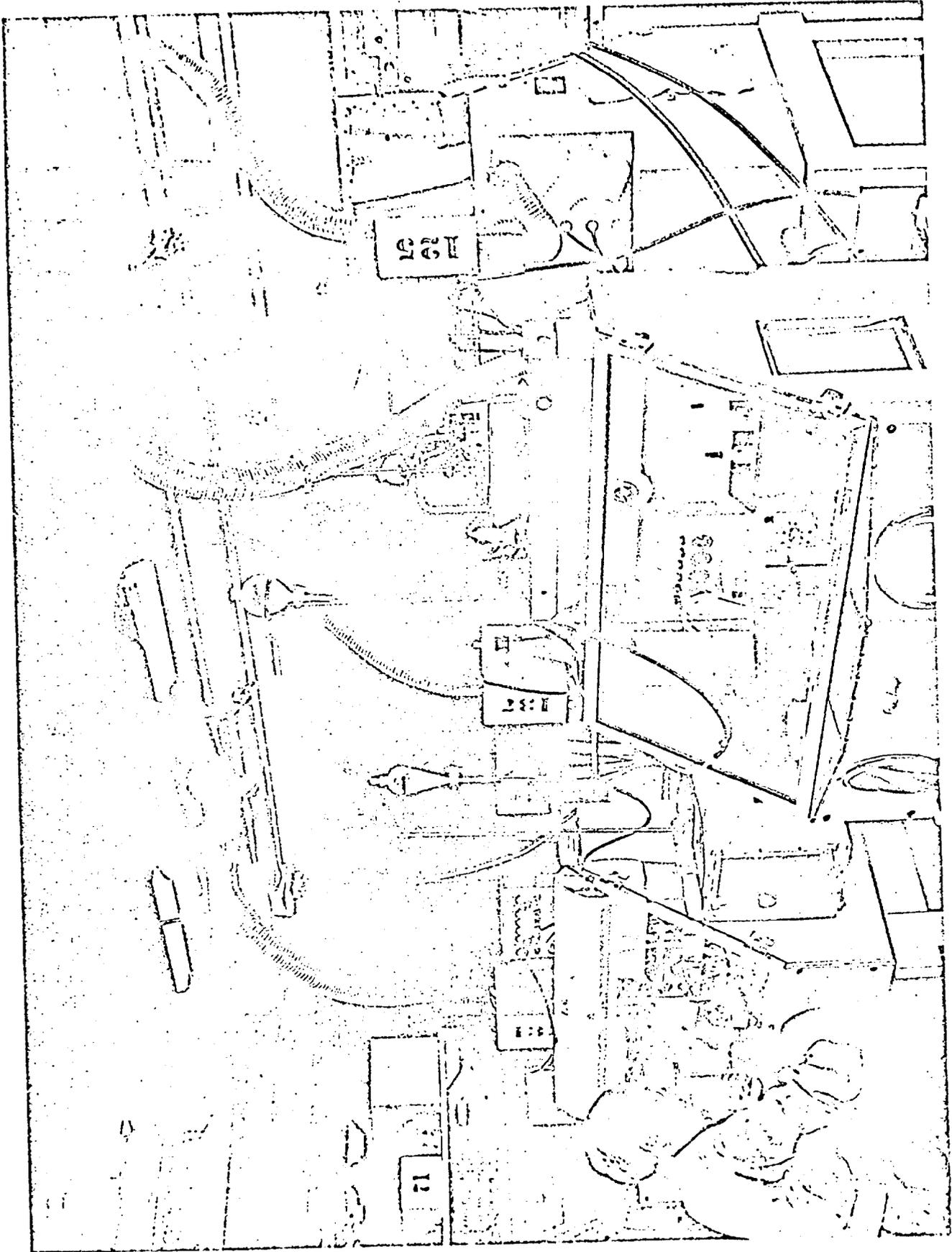
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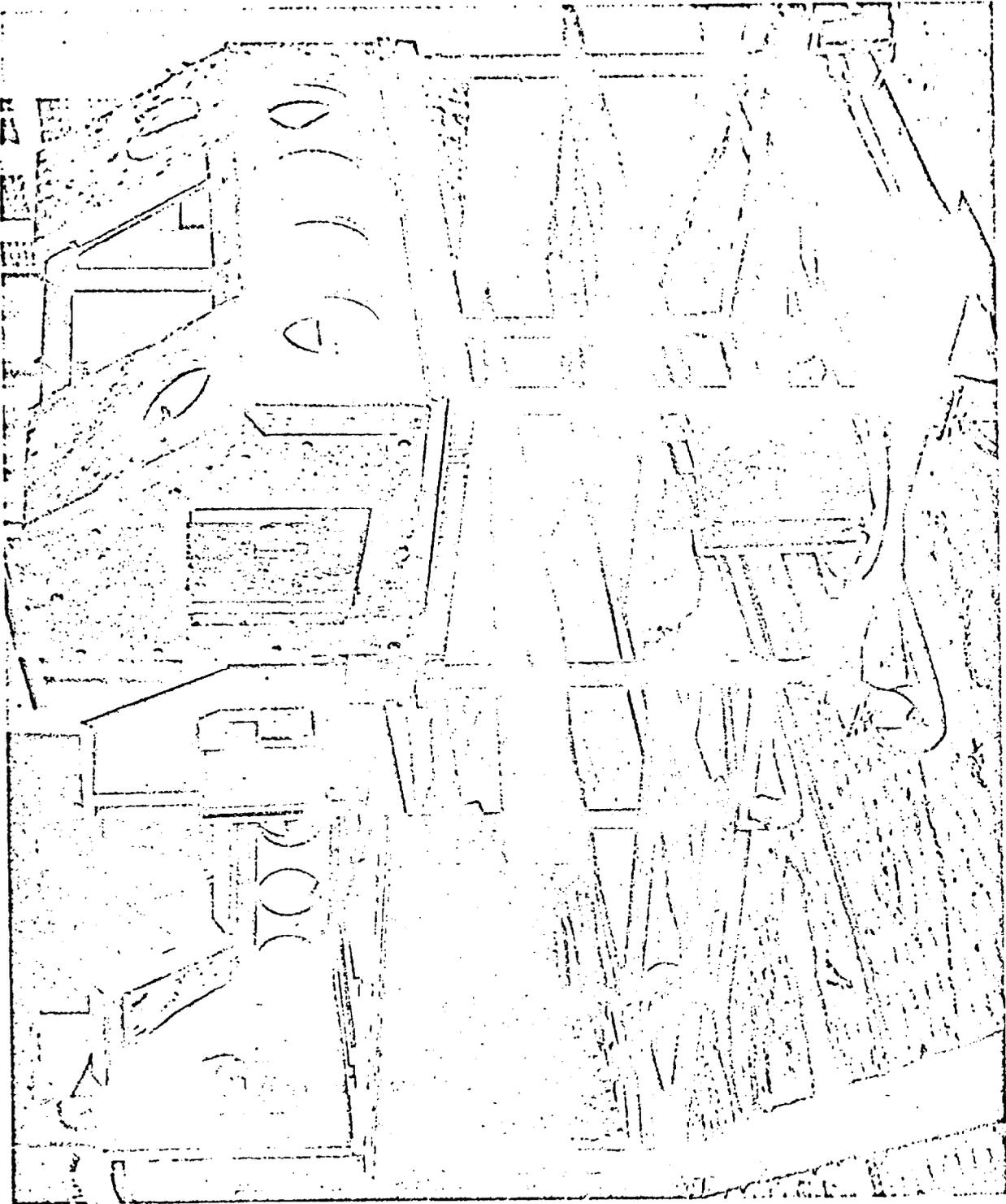
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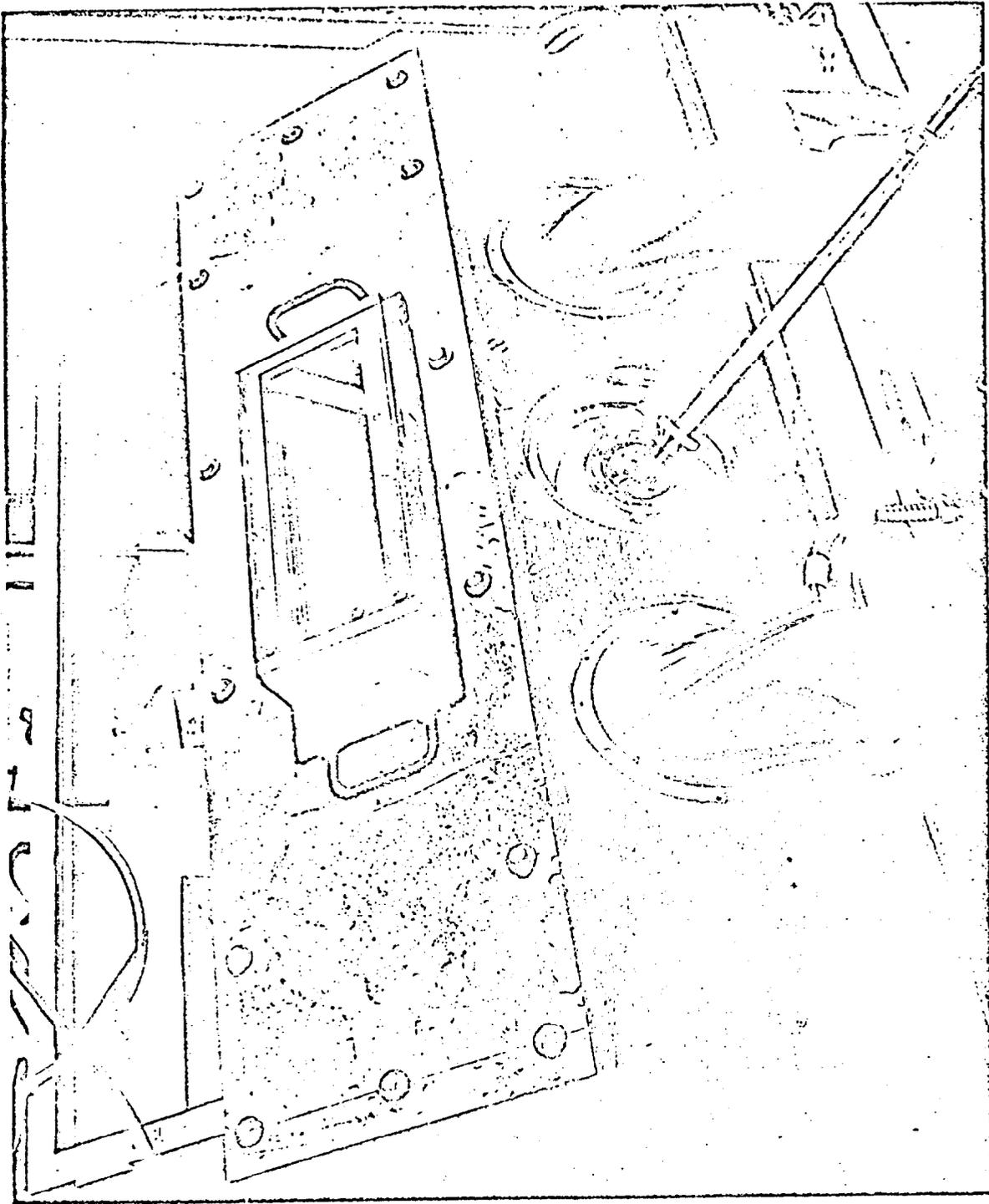
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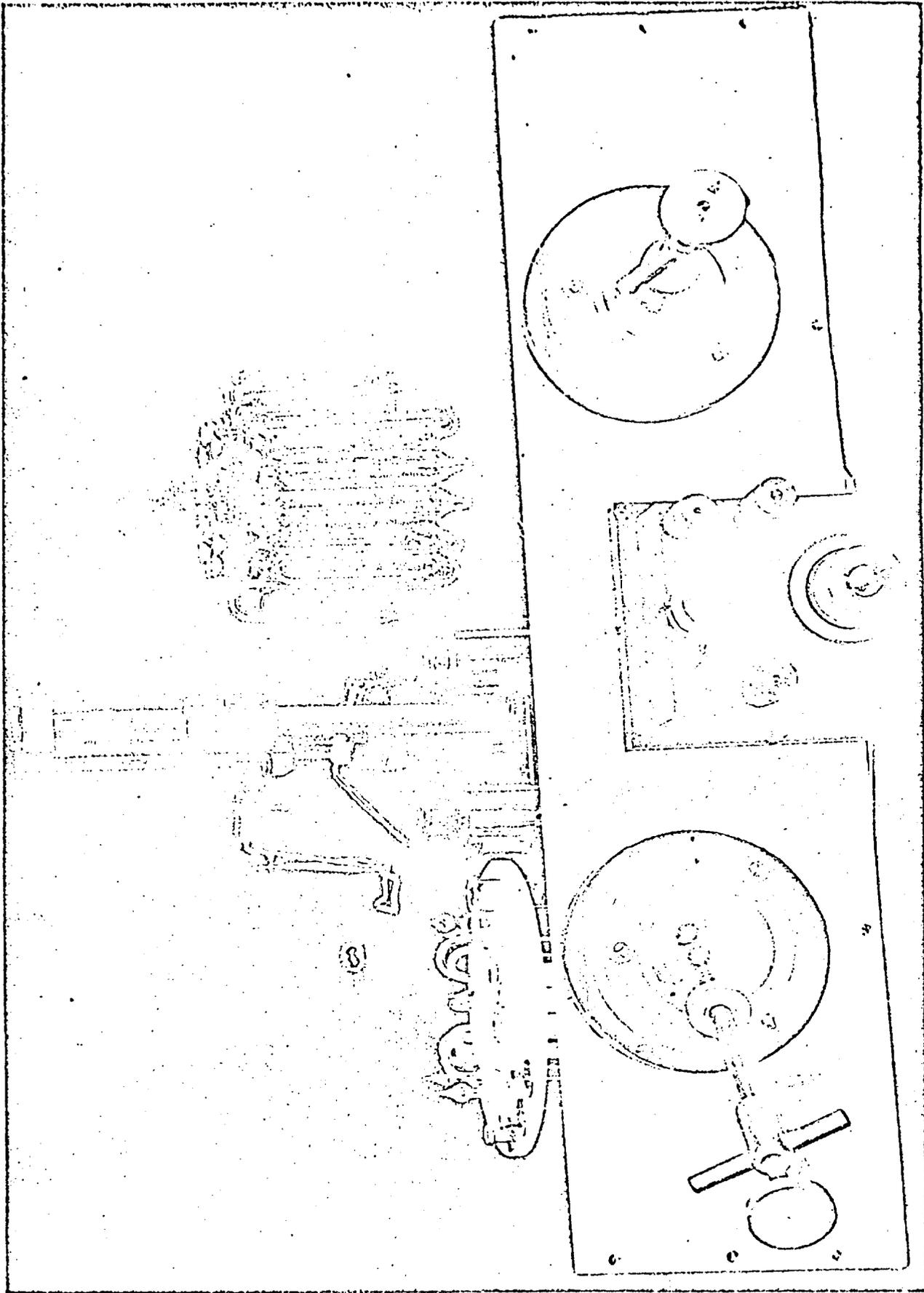
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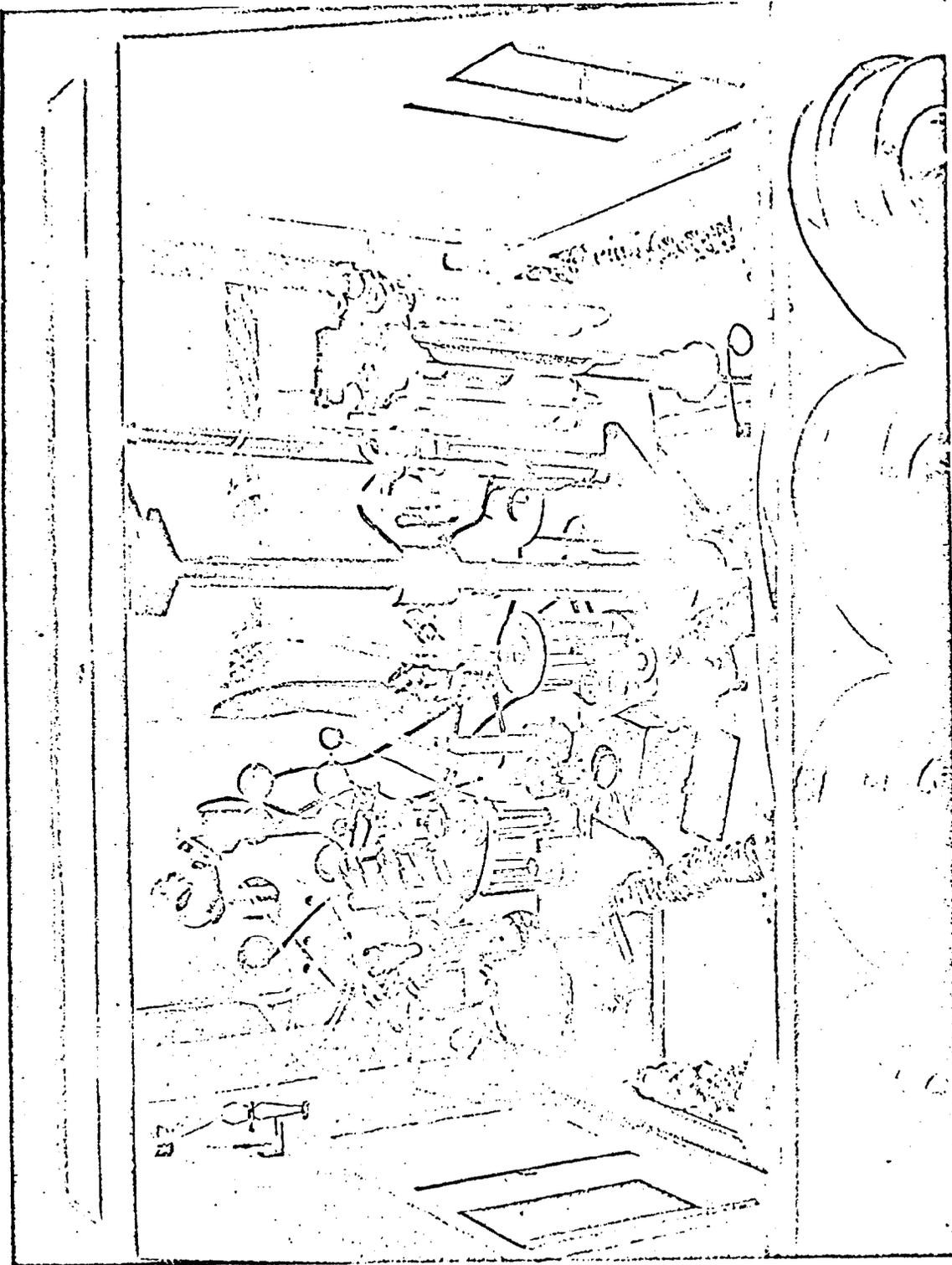
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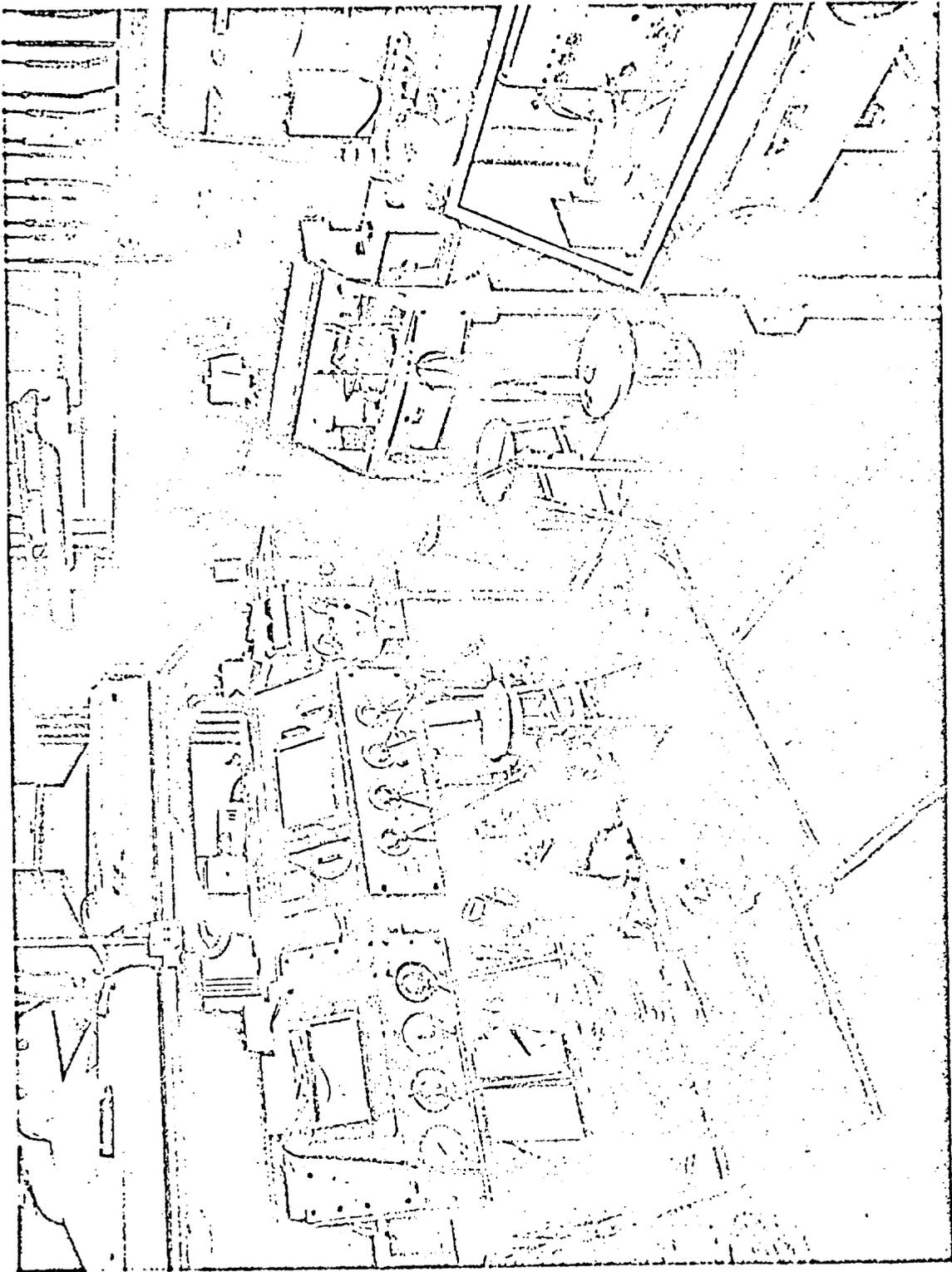
Slide 8



6 OPTS



Slide 10



Slide 11

AIR CLEANING PROGRAM AT THE LIVERMORE RESEARCH LABORATORY

By G. T. Saunders, CR&D

To appreciate the air cleaning program at the Livermore Research Laboratory operated by the California Research & Development Company, it is necessary to place ourselves geographically, meteorologically and problem wise.

Livermore, California is located approximately 45 miles east and south of San Francisco, at the eastern end of the Livermore Valley. The outline of the valley itself is roughly an elongated oval - or football shape - with the long axis on the east west line, and it is relatively small being some 13 miles long and six miles wide. The surrounding hill structure averages some 1700 feet with a small opening in the southwest corner. So that the valley, when viewed from above, resembles a large bowl with a flat bottom. Figure 1.

The region is wholly an agricultural area: the largest crop being wine grapes, and secondly cattle raising.

The meteorological conditions can best be stated, as extracted from a United States Weather Bureau report on this area as prepared by Paul Humphrey of the Arco Idaho Office.

"The expected meteorological conditions at the Livermore, California Site are, from a practical viewpoint, entirely favorable as far as the more familiar climatic elements are concerned. Surface temperatures, winds, and rainfall are of comparatively little concern when considering construction problems or the comfort of personnel. Primarily, meteorology must be considered because of the effects of atmospheric conditions upon harmful effluent which might be released from stacks during various operations. In that respect, considering the fact that the Livermore Site is in a bowl-shaped valley surrounded by an important agricultural area and a significant population, the meteorological conditions are less favorable. High stacks alone, such as are used at some other sites, would not be practical as a method for the elimination of harmful concentrations of effluents. Such stacks would lessen ground contamination on the site itself, but would not significantly reduce average ground concentrations within the Livermore Valley. It appears that safe routine operations as far as stack effluents are concerned should be brought about by properly engineered devices for cleaning off-gases rather than by consideration of meteorological conditions."

The atmospheric conditions present three basic points: (1) Prevailing SW wind during summer days. (2) Prevailing NE wind during winter days. (3) Stable (calm) conditions at least ten percent of the nights, and some four percent of the days during the winter months.

Problem-wise: At the request of the Atomic Energy Commission, the Standard Oil Company of California formed the California Research & Development Company, some three years ago, to work on the MPA program. This new company presented a very fine situation from the health physics standpoint, as the engineers were very receptive to suggestions and ideas. Few, if any, were bound by any predetermined concepts of radiation control, etc. As a practical result, the health physics staff was able to institute its own predetermined concepts of radiation control.

The assigned problems to the company were principally basic research, and as such necessitated chemistry and physics laboratory space: metallurgical test cells, process cells, etc.

Thus, to the engineers we gave the following base-lines we wanted to follow:

1. All potentially contaminated air will be:
 - a) Cleaned
 - b) Sampled
2. All duct work will be:
 - a) Readily accessible
 - b) Easily replaceable
3. All filters-assemblies will
 - a) Have pre-filters
 - b) Be accessible for ease of change
 - c) Have a simple indicating device for loading effect.

To a great extent we succeeded and our active air cleaning program is essentially this:

"All potentially contaminated air is filtered as close to its source as is practicable: this air is then sampled as it is discharged to atmosphere."

"The general atmospheric contamination is checked by constant air sampling in and around the entire Livormore Valley."

To accomplish this, we have standardized, in general, our units to certain filtering equipment and procedures. The fume hoods, for example, are all equipped with 2' x 2' x 2" fiberglass prefilters and 2' x 2' x 5-7/8" CWS #6 equiv. back-up filters. Gloved-boxes have "thaxter" PF105 prefilters and 8' x 8" x 5-7/8" CWS #6 equiv. final filters. Figure III. The glove box manifolds (each having a capacity for 12 boxes) are equipped with an additional back-up, or insurance filter (CWS #6 equiv.). The filters are either incorporated into plywood throwaways or are top loading for ease of change. The only filter units not at shoulder level (or lower) are the gloved box insurance filters; however, the anticipated rate of change for these units is once every four years.

The effluent air is sampled in each duct run, the samples being so arranged that any detectable activity can be in turn traced to its source. For this purpose, we use a sampler that is injected into the duct stream and operated in the Isokinetic Region of flow. Figure IV.

The laboratory room air is sampled by use of "Filter Queen" type vacuum cleaners and we extract the air through a 3-1/2" diameter disc of HV-70 paper. The 3-1/2" diameter was chosen to meet the maximum sized scintillation counter that was constructed at the time our program was initiated. Figure V.

The valley air is sampled at various points throughout the countryside and for this purpose, we have used a "moto-air" unit and again, we have used the 3-1/2" diameter discs. Figure VI. These units operate continuously and the papers are changed once each week. In addition to a radio-count of the papers, for both alpha and beta-gamma, we run a radioautograph of the papers. We actually find that the particle count is a much more sensitive device than the counting procedures.

To summarize our program for air cleaning which is really a four point plan, we can keep with the modern trend and call it operation "test".

1. Test new equipment
2. Educate engineers
3. Sample effluent laboratory air
4. Take continuous environs backgrounds

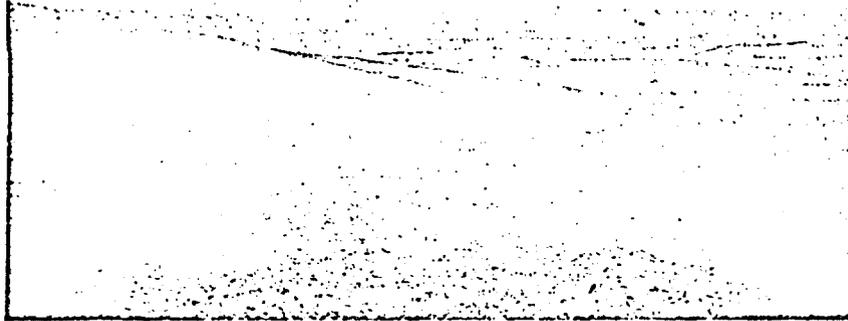


FIGURE I

PICTURE OF THE LIVERMORE VALLEY

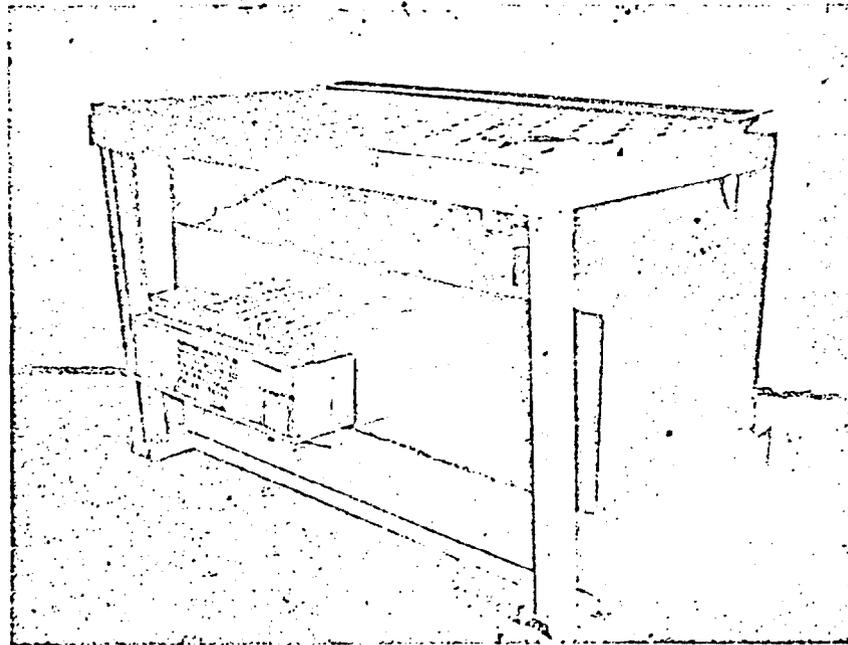
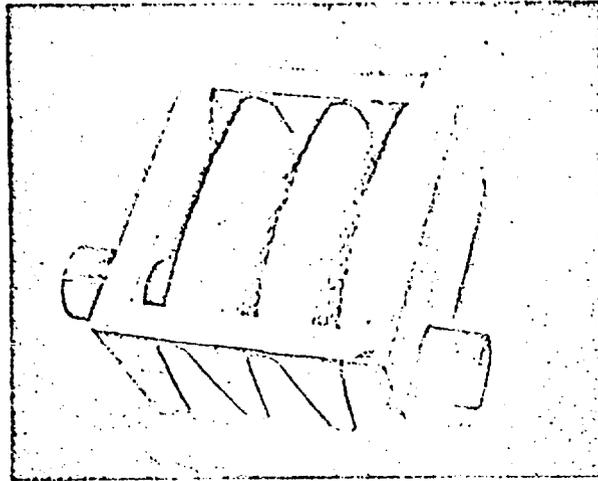
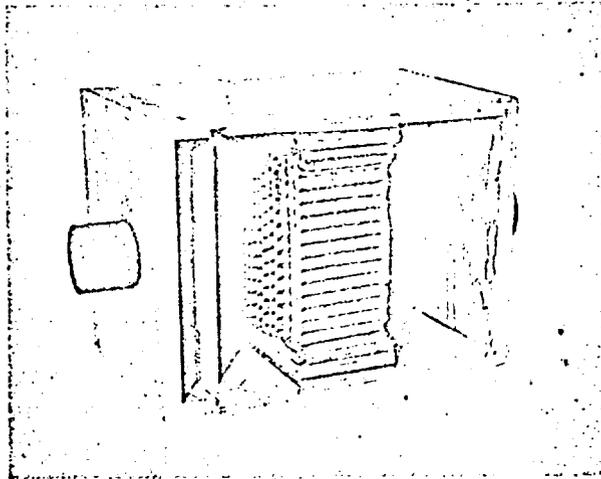


FIGURE II

FILTER BED IN FUME HOODS



A. "THAXTER PREFILTERS"



B. CWS 6 (EQUIV.) FILTERS

FIGURE III
GLOVED BOX FILTERS

CONFIDENTIAL

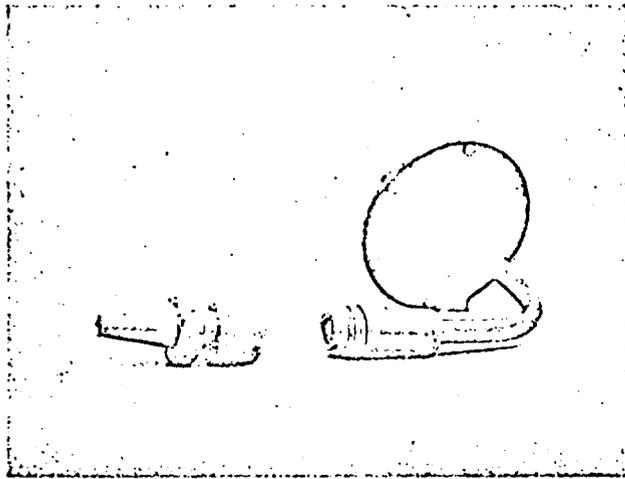


FIGURE IV
ISOKINETIC SAMPLER

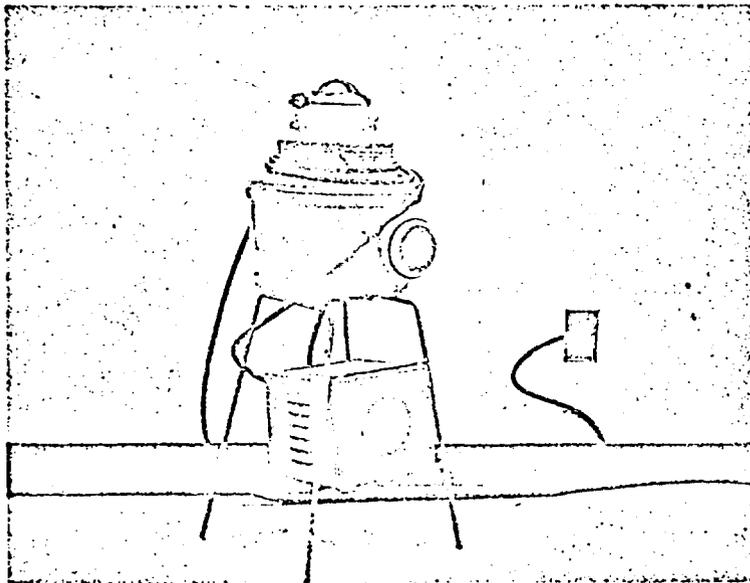


FIGURE V
"FILTER QUEEN" SAMPLER

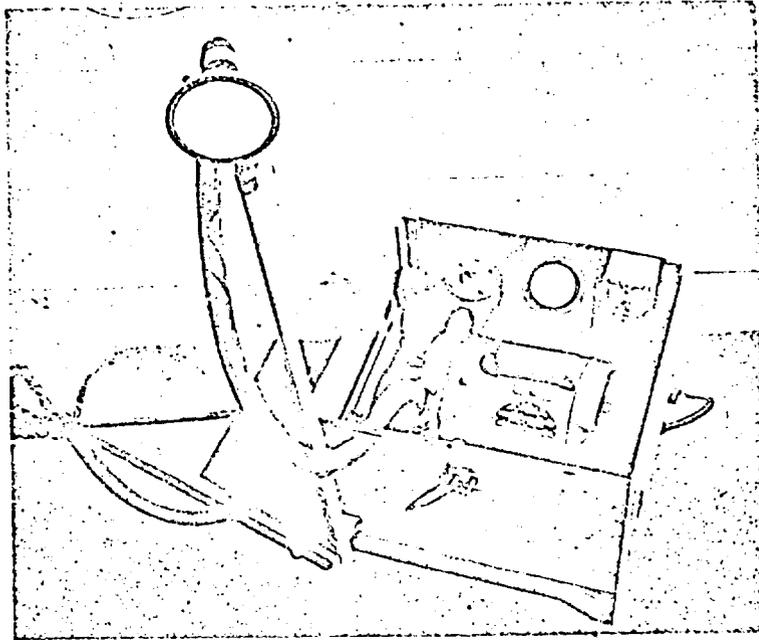


FIGURE VI

"MOTO-AIR" SAMPLER

METEOROLOGICAL ASPECTS OF AIR CLEANING

By P. A. Humphroy and E. M. Wilkins, USWB, IOO

Although there are many topics which should be mentioned while considering meteorological aspects of air cleaning, this opportunity is being used to review the effects of vertical temperature gradient on stack gas behavior and to show some photographs from the National Reactor Testing Station illustrating typical conditions.

The appearance of stack effluent plumes is regulated largely by the configuration of the vertical gradient of air density, or temperature. With respect to a high stack on nearby level terrain there are five different configurations of the vertical temperature gradient that occur, and these usually have a diurnal cycle.

These configurations, along with the expected behavior of an effluent plume, is shown schematically in Figure 1.

Looping - occurs with a superadiabatic (very unstable) temperature lapse rate. The stack effluent, if visible, appears to loop because of relatively large thermal eddies in the wind flow. Diffusion is rapid, but sporadic puffs having strong concentrations are occasionally brought to the ground near the base of the stack. Looping is favored by fair weather with relatively light winds.

- occurs with a gradient lying between dry adiabatic and isothermal. The effluent stream is shaped like a cone with axis horizontal. The distance from the stack that effluent first comes to the ground is greater than with looping. Mechanical mixing predominates. Although this condition is ideal for

calculating ground concentrations by means of diffusion equations, it does not often persist except during cloudy, windy weather. During fair weather, it is transitional and is most likely to occur only for a brief interval about sunset as the strong daytime lapse condition is converted to an inversion.

Fanning - occurs with temperature inversion conditions. Such laminar flow may also occur in a layer of air that is isothermal, depending on wind speed and roughness of terrain. The stack effluent diffuses practically not at all in the vertical, and the effluent trail may resemble a meandering river, widening very gradually with distance from the stack. Depending on the duration of the stable period and the wind speed at stack level, the effluent may travel for many miles with little dilution. With level terrain ground concentrations of effluent do not occur; however, isolated objects which extend up into the plume, or hillsides which are encountered, can receive large concentrations even though miles away from the stack.

Lofting - is usually associated with the transition from lapse to inversion, but may persist at times for one to several hours. Occasionally the inversion does not build up to stack level during an entire night due to interference of winds and/or cloudiness. The zone of stronger effluent concentration, as shown by shading, will depend on the height of the inversion. It is caused by trapping by the inversion of effluent carried into the stable layer by turbulent eddies that penetrate the layer for a short distance.

Except when the top of the inversion is very near the ground, this type may be considered as the most favorable diffusion situation to be encountered. The inversion prevents effluent from reaching the ground; and at the same time the effluent may be rapidly diluted in the lapse layer above the inversion.

Fumigating - occurs at the time that the nocturnal inversion is being dissipated by heat from the morning sun. The lapse layer begins at the ground and works its way upward, rapidly in summer, but slowly in winter. At some time the inversion is just above the top of the stack, and acting as a lid, forces the effluent stream to dilute within the shallow lapse layer near the ground. Large concentrations are brought to the ground along the entire effluent stream by thermal eddies in the lapse layer. Sustained concentrations near the ground will be higher with this situation than with any other.

Smoke experiments were performed by the Weather Bureau using the 250-foot Chemical Plant stack to determine the validity of the associations of plume behavior with the temperature gradient configurations just shown. Pictures of smoke behavior during some of these experiments are shown on the slides to follow.

Figure 2 - Looping condition. 0945 MST, April 9, 1952.

Temperature lapse rate was more than three times the dry adiabatic rate (which is $0.54^{\circ}\text{F./100 ft.}$) in the lower 250 feet.

Figure 3 - Coning conditions. 1910 MST, April 16, 1952.
Lapse rate in lower 250 feet was slightly less than the
dry adiabatic rate.

Figure 4 - Fanning condition. 0722 MST, April 11, 1952.
Pronounced temperature inversion from the surface to
somewhere above 500 feet.

Figure 5 - Lofting condition. 1945 MST, April 16, 1952.
Inversion, surface to 200 feet, with lapse above 200 feet.

Figure 6A - Fumigating condition. 0746 MST, April 11, 1952.
Lapse layer has worked up just to the 250-foot level. Note
that eddies in the lapse layer have begun to penetrate the
smoke-bearing layer, as evidenced by streamers extending
downward from the concentrated plume.

Figure 6B - Fumigation (continued). 0748 MST. The first
streamer reached the ground about 10 stack lengths from
the stack about two minutes after streamers began to descend.
Inversion based about 300 feet.

Figure 6C - Fumigation (continued). 0802 MST. By this
time strong smoke concentrations appeared on the ground
along almost the entire visible length of the plume. Note
that the concentrated smoke layer aloft that was visible
in Figures 4, 6A and 6B is no longer visible. The entire
plume appears to have been mixed downward. Inversion
based about 380 feet.

It was mentioned earlier that the types of temperature gradient usually have a diurnal cycle. This is illustrated by figure 7 which gives plots of temperature soundings on a clear day. Note that the fumigating condition (for a 250-foot stack) was present at 0900 MST. By 1100 MST the inversion had dissipated, and looping conditions prevailed until the inversion began to form in the evening. Lofting conditions were present at 1830 and 2000 MST, and fanning conditions at 0200 through 0700 MST the following morning.

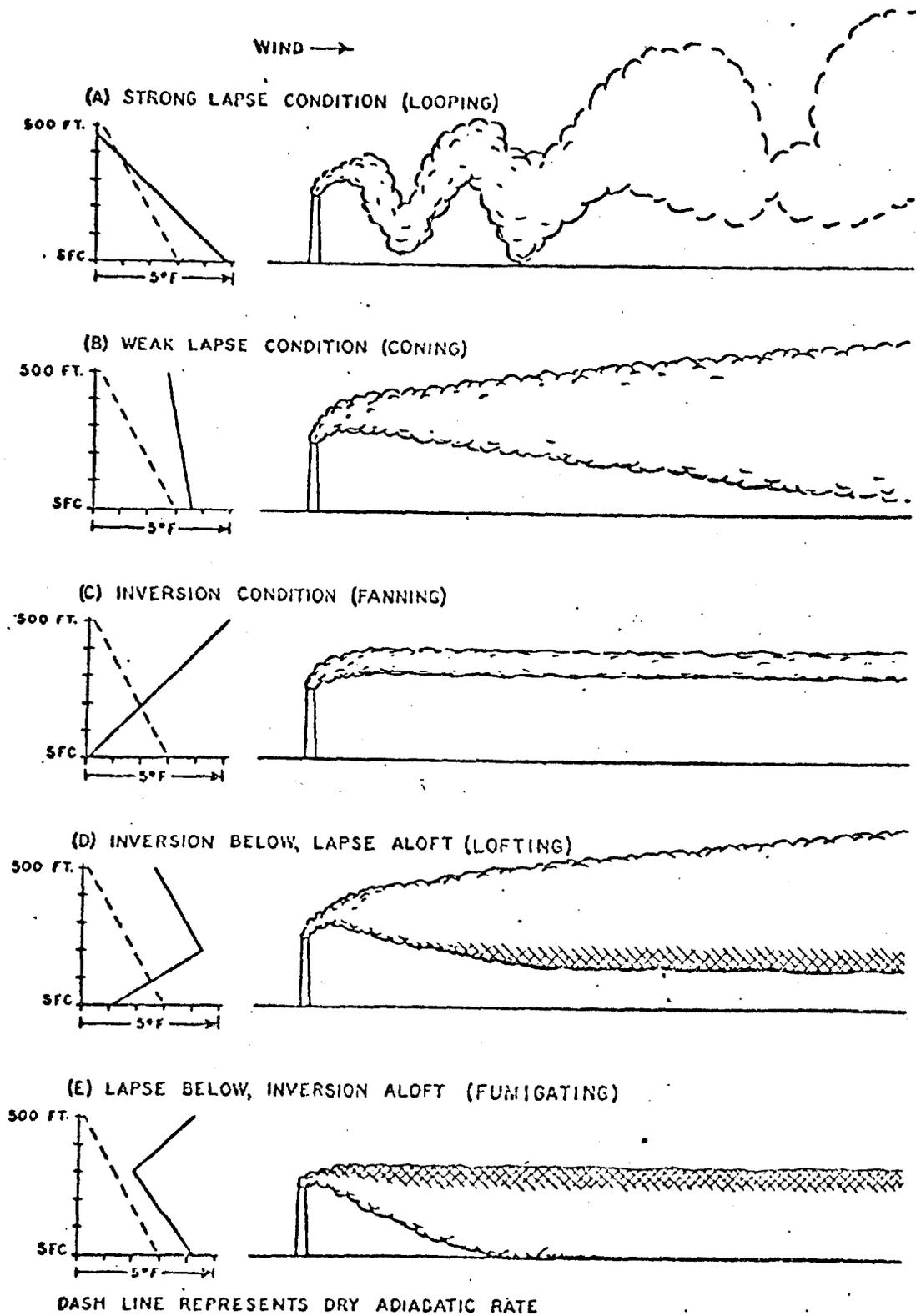


Fig. 1--Schematic representation of stack gas behavior under various conditions of vertical stability.

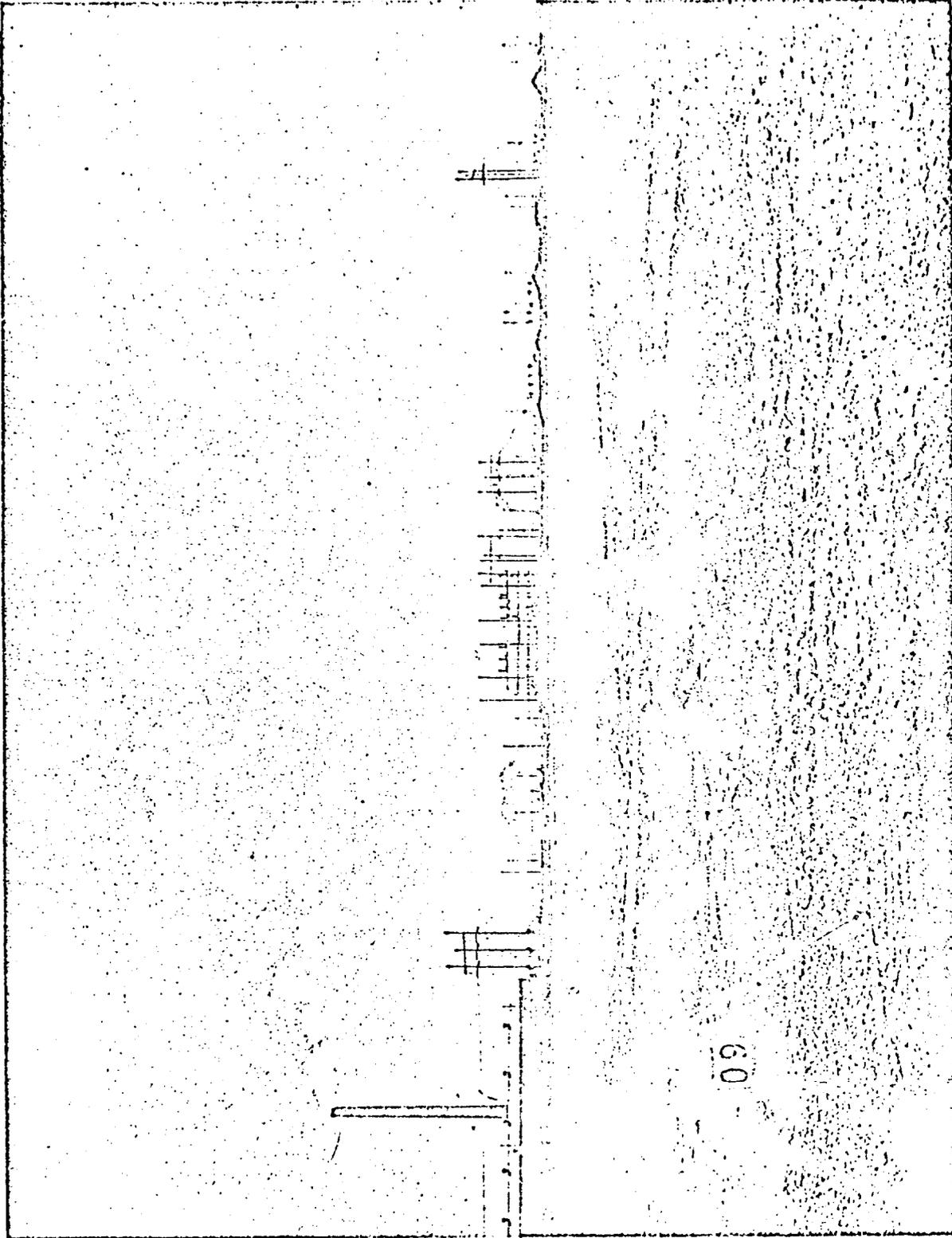


FIG. 2

60

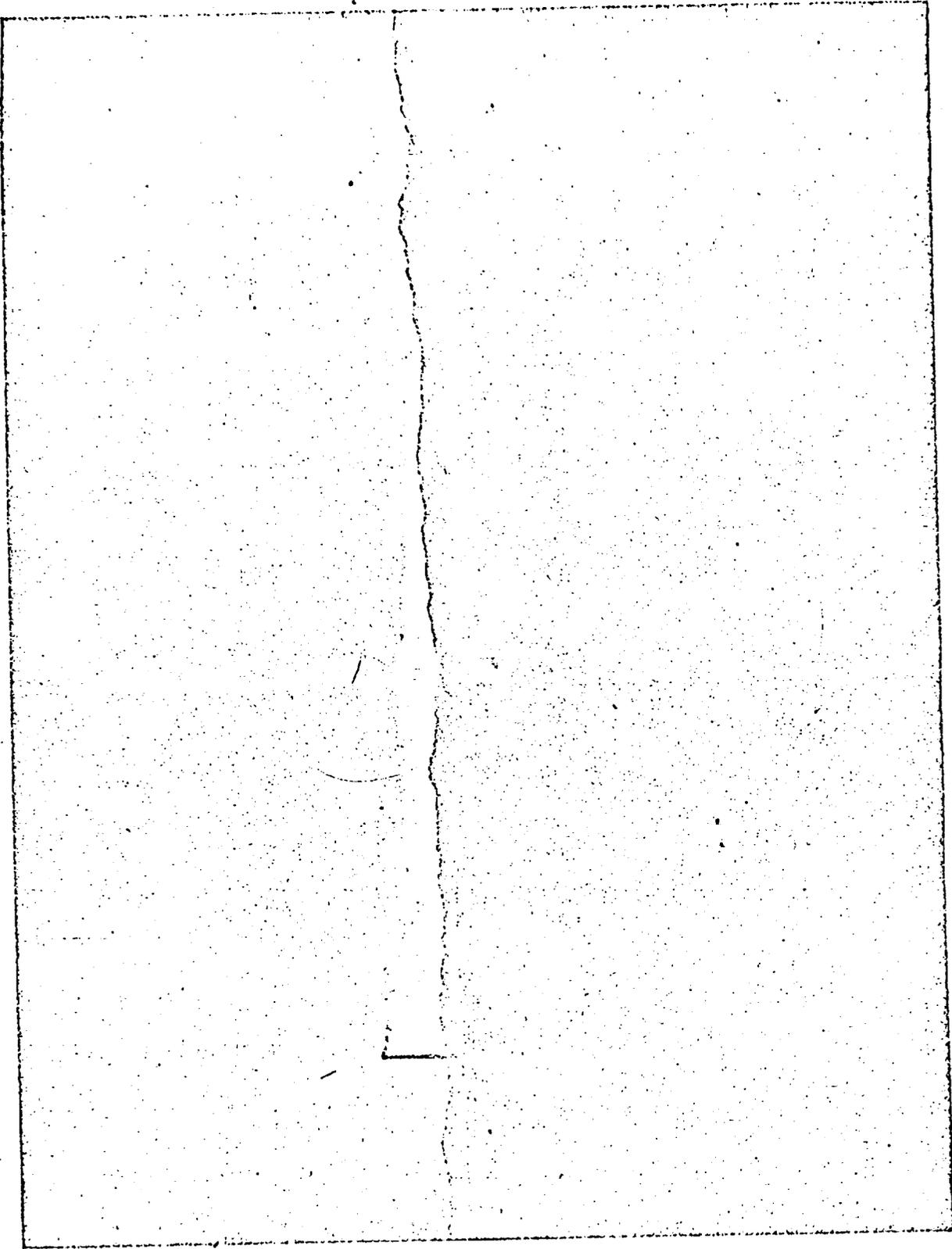


Fig. 3

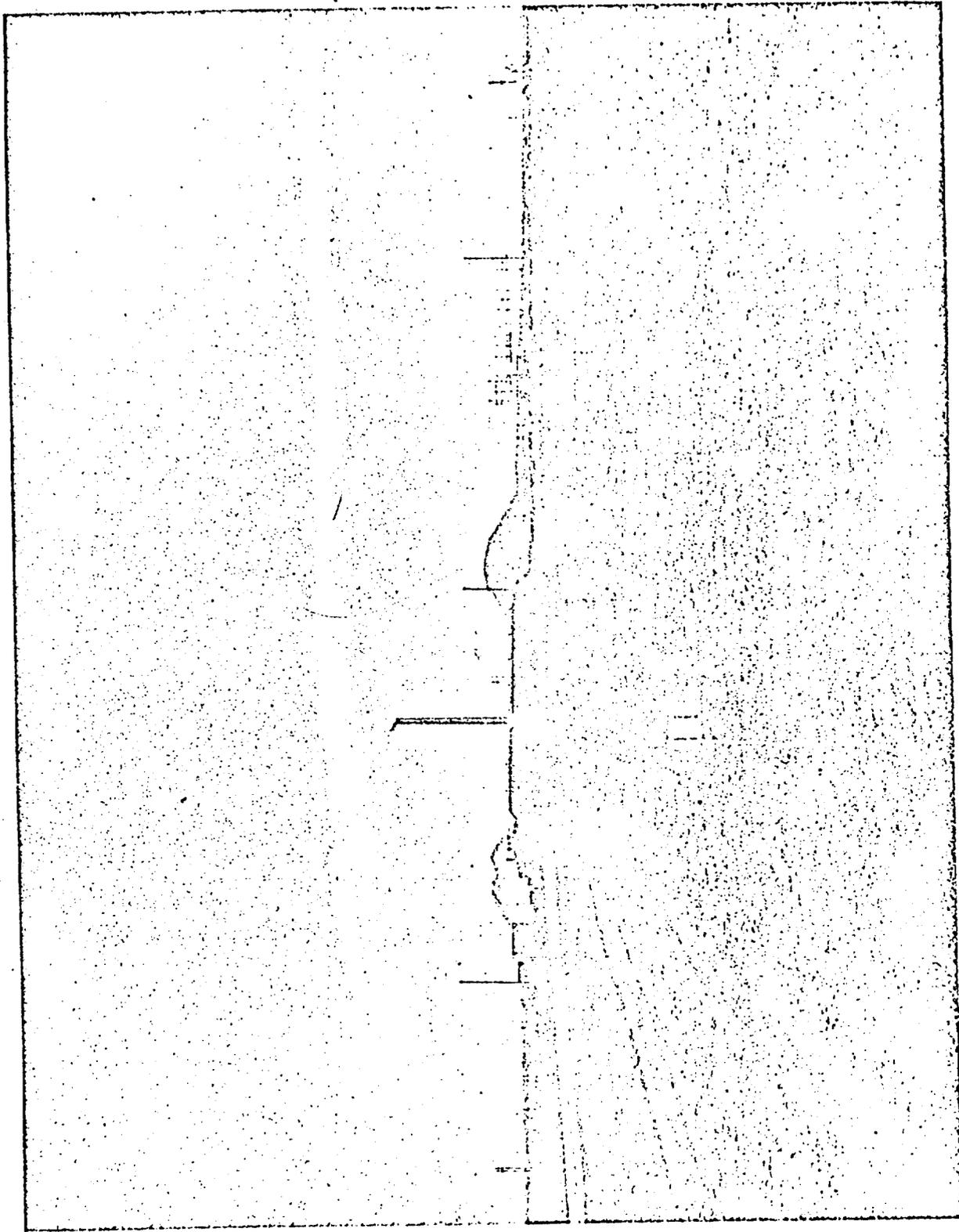


FIG. 4

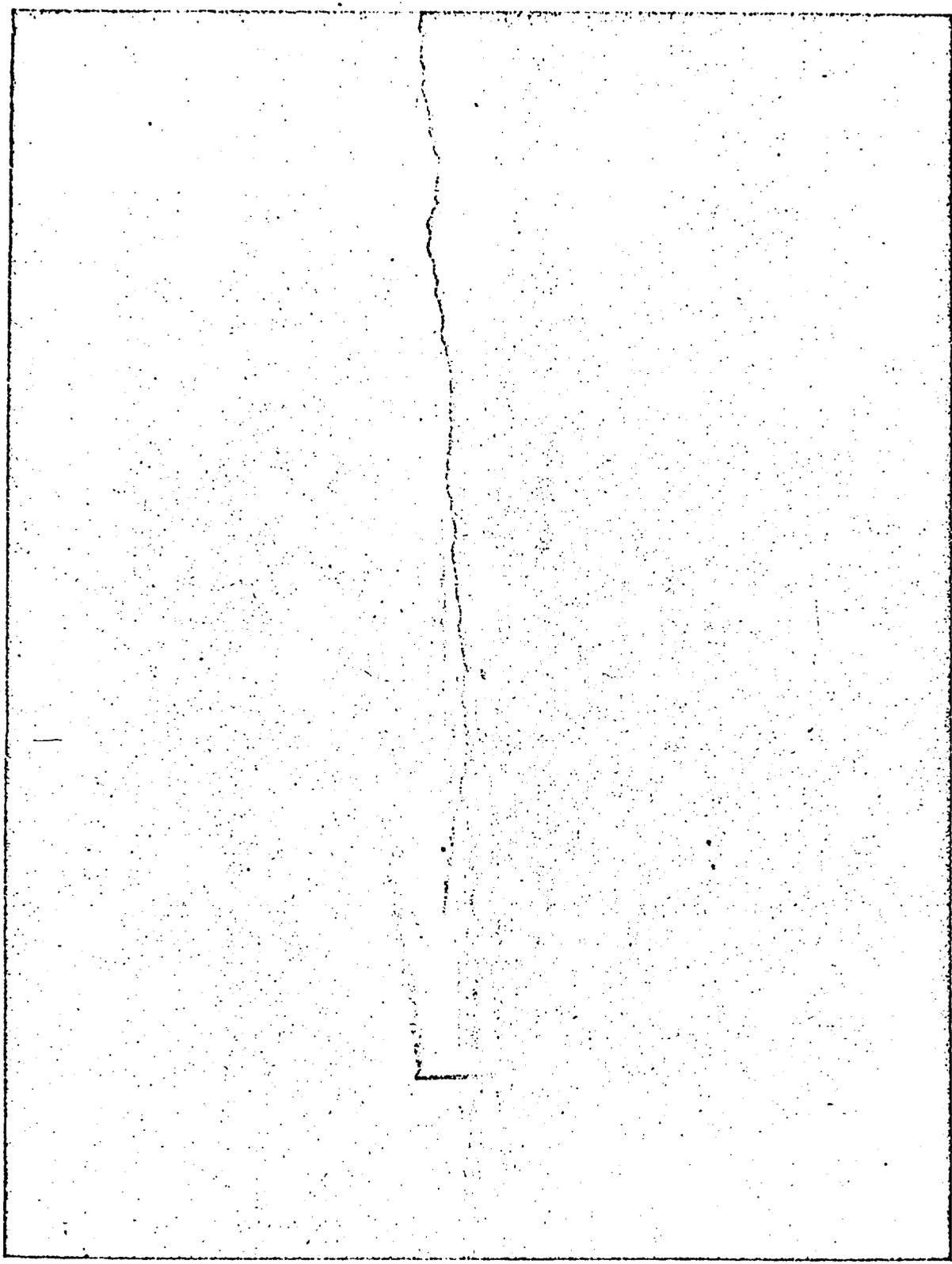


FIG. 5

SECRET

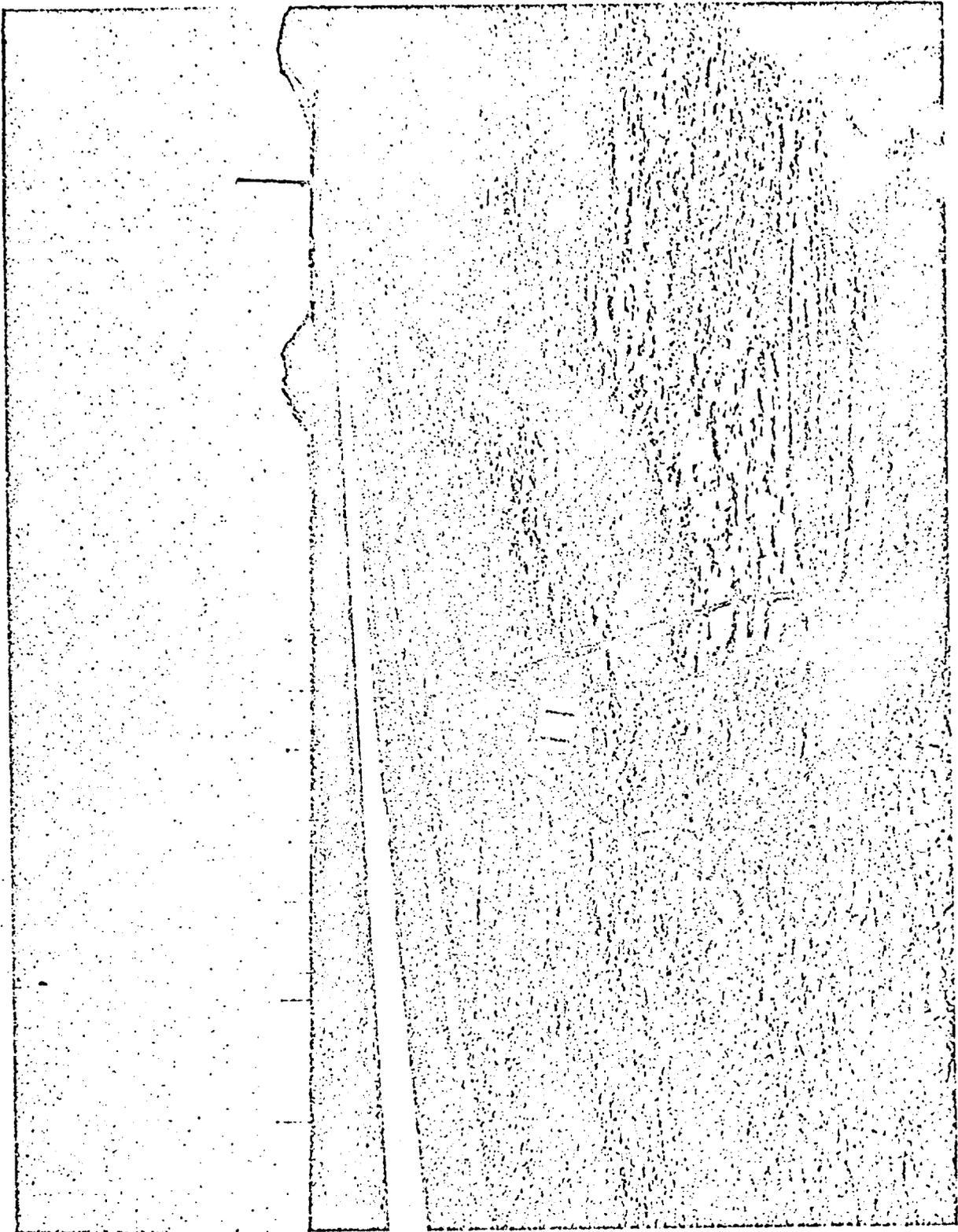


FIG. 6A



Fig. 6B



FIG. 6C

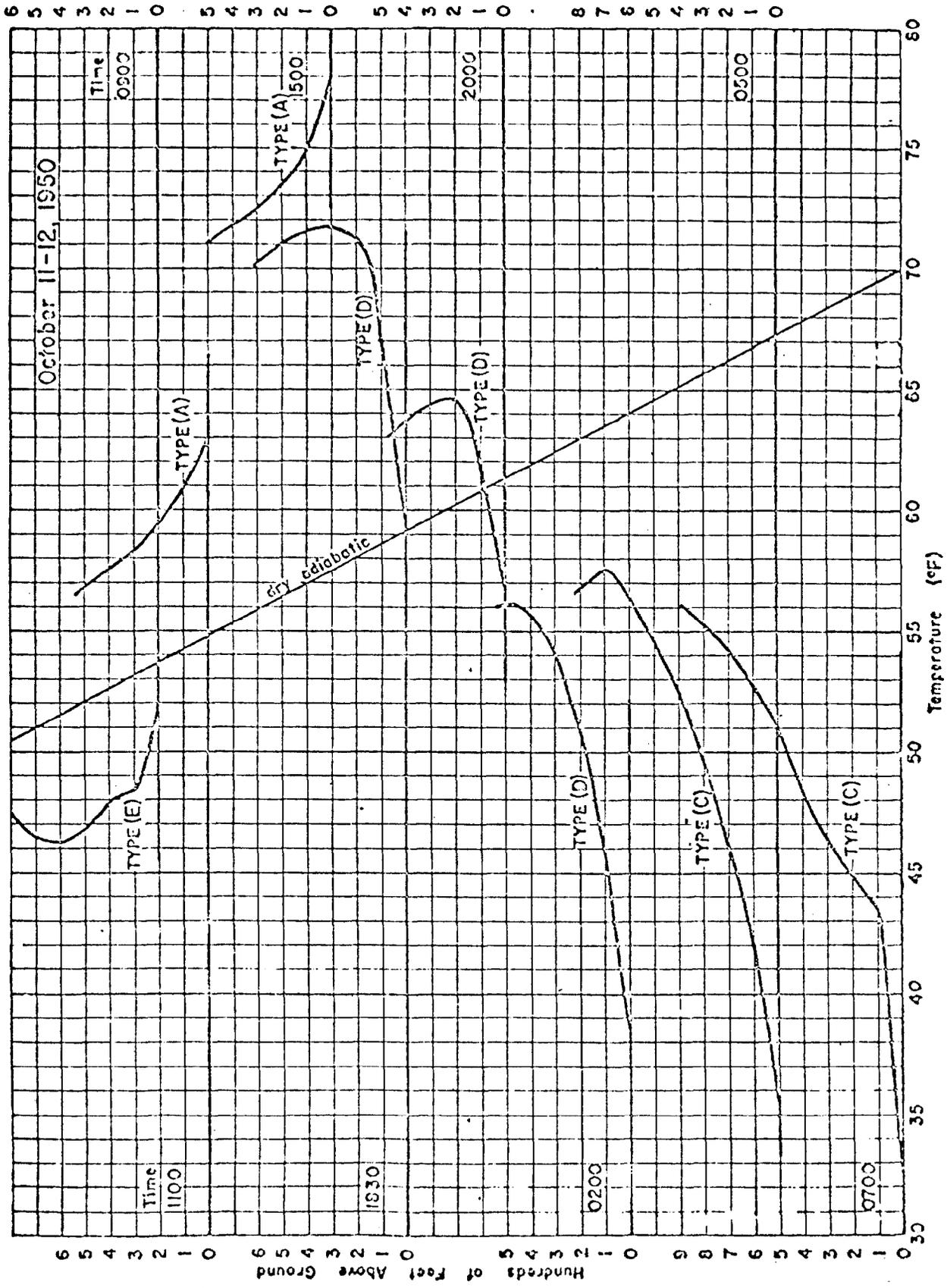


Fig. 7--Temperature soundings on a day with clear skies and light winds.

FIBROUS AEROSOL FILTERS

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INTRODUCTION

There are, in general, two basic types of fibrous filters, the so-called "paper" or thin-bed filters and the deep-bed filters. The distinction between the two is primarily one of philosophy of application. The deep-bed filters are designed to be maintenance-free with a life corresponding to that of the entire installation or process. Once they become plugged with dust, the entire unit is abandoned. The paper filters, on the other hand, are usually designed for a limited life, to be replaced or cleaned periodically. They can, however, also be designed on an abandonment basis.

A discussion of deep-bed filters was presented at the Ames meeting in the Fall of 1952. These filters can be considered in two basic categories, the granular or sand types and the fibrous types. The discussion at that time dealt largely with the relative merits of these two types from the standpoint of design, performance, and cost. It was shown at that time that fibrous units possess a considerable economic advantage over sand filters although long-period large-scale experience was relatively meager for the fibrous type whereas the sand filters had an extended backlog of successful operation.

It is the purpose of the present paper to discuss the fundamental performance characteristics of fibrous filters. This discussion is essentially a preview of recent developments arising from regular thesis work at Ohio State University (12).

BASIC CONCEPTS

Methods of Expressing Collection Efficiency: While the collection efficiency of a filter is normally expressed as the fraction, η , of incoming aerosol particles that are collected in the filter, it is often more convenient to express collection efficiency in terms of number of transfer units, N_t , where the number of transfer units is related to the fractional collection efficiency by

$$\eta = 1 - e^{-N_t} \quad (1)$$

or

$$N_t = \ln \left(\frac{1}{1 - \eta} \right) \quad (2)$$

It should be noted that the term N_t is identical to the corresponding term used in mass transfer for the case where there is a negligible vapor pressure of an absorbed gas or vapor from the liquid phase. It should also be noted that the term N_t is directly related to the decontamination factor, D.F., which has been widely used in atomic energy applications (1),

$$N_t = 2.303 \text{ (D.F.)}$$

(3)

The deposition of aerosol particles on body surfaces, such as cylinders or spheres, has been customarily expressed in terms of a target efficiency, η_t , defined as the ratio of cross sectional area of the original gas stream, from which particles of a given size are removed because the particle trajectory intersects the collecting surface, to the projected area of the collector in the nominal direction of flow.

For cases where the fibers are normal to the direction of flow, it is readily shown that

$$\eta_t = \pi \rho_b A N_t / s_v m \quad (4)$$

In the derivation of Equation 4, it is assumed that η_t is a constant throughout the filter and either that the fractional deposition in any one layer of fibers is small or that there is complete mixing of the aerosol between layers. The first assumption restricts Equation 4 to homogeneous aerosols. For heterogeneous aerosols, however, Equation 4 will still express the performance characteristics for any given particle size if it is recognized that the terms N_t and η in Equation 1 will then represent the performance for that same size. If the fibers are not normal to the direction of flow, an additional orientation factor must be provided in Equation 4.

If means are available for evaluation η_t as a function of particle size, fiber size, and operating conditions, it is apparent that N_t may be calculated by means of Equation 4 and the corresponding values of η or D.F. from Equations 1 and 3, respectively. The subsequent discussion will show how η_t may be evaluated.

Deposition Mechanisms: The deposition of aerosol particles on a body may be due to any one or more of several mechanisms, where, as shown by numerous investigators, (2)(4)(5)(6)(7)(8)(9)(10)(11), the effectiveness of each mechanism is measurable in terms of the physical and operating conditions by a dimensionless group, which will be termed a separation number, N_s . These are listed below:

| <u>Deposition Mechanism</u> | <u>Separation Number</u> |
|------------------------------------|----------------------------------------------------------------------------------|
| Flow-line (or Direct) Interception | $N_{sf} = D_p / D_b$ |
| Inertial Interception | $N_{si} = k_m \rho_p D_p^2 u_o / 18 \mu D_b$ |
| Diffusional Deposition | $N_{sd} = D_v / u_o D_b$ |
| Gravitational Deposition | $N_{sg} = u_t / u_o$ |
| Electrostatic Deposition | |
| By Charges | $N_{sec} = k_m \epsilon_p \epsilon_{bs} / \mu \delta D_p u_o$ |
| By Induction | $N_{sei} = k_m \epsilon_{bs}^2 D_p^2 (\delta_p - \delta) / \mu \delta^2 D_b u_o$ |
| Thermal | $N_{st} = [k / (2k + k_p)] [(T - T_b) / T] [\mu / k_m \rho D_b u_o]$ |

A detailed consideration will show that target efficiency is a function of some two dozen variables. By dimensional analysis, η_t may then be shown to be a function of some 1-1/2 dozen dimensionless groups, which include all of the N_B terms listed above in addition to other groups which measure modifying influences on the flow pattern and force fields.

For simplification, it may be assumed that electrostatic and thermal effects are negligible. The latter will normally be the case if no marked temperature gradients are present. The magnitude of electrostatic effects will be discussed later. With these assumptions it may be shown that

$$\eta_t = \psi(N_{sf}, N_{si}, N_{sd}, N_{sg}, N_{Re}, \epsilon_v) \quad (5)$$

Relative to other deposition mechanisms, gravitational settling will normally be significant only with aerosol particles larger than about 1 micron diameter and with collecting bodies larger than some 100 microns diameter when operated at low face velocities. Gravity settling would be expected to act somewhat independently of the other mechanisms with little interactive effect. Consequently, for most purposes, this may be treated as a separate additive effect on target efficiency, having a magnitude on the order of N_{sg} .

To further simplify Equation 5 we may assume that the modifying influences of N_{Re} and ϵ_v on flow pattern are negligible. Equation 5 then becomes

$$\eta_t = \psi_1(N_{sf}, N_{si}, N_{sd}) \quad (6)$$

or, in alternate forms,

$$\eta_t = \psi_2(N_{sf}, N_{sd}, N_{sc}) \quad (7)$$

$$\eta_t = \psi_3(N_{sf}, N_{si}, N_{sc}) \quad (8)$$

$$\text{where } N_{sc} = N_{sf}^2 / N_{si} N_{sd} = 18 \mu / km \rho_p D_v \quad (9)$$

The term N_{sc} is analogous to the Schmidt number in mass transfer and measures the interactive effect of flow-line and inertial interception and diffusional deposition. It should be noted that N_{sc} involves simply the physical properties of the gas and the aerosol particle.

In order to be able to predict that target efficiency from Equations 6, 7 or 8, it is necessary to know the functional relationship between the variables. Several investigators have attempted to develop this relationship analytically for conditions where one or the other of the separating mechanisms is controlling. To date, however, no general solution has been developed. The nearest approach is that of Davies (2). The purpose of the investigation of Ohio State University was to develop the relationship experimentally.

EXPERIMENTAL PROCEDURE

In the experimental investigation, a test aerosol was passed through individual pads of fiber mats in series. Collection efficiencies were determined over a wide air velocity range (0.02 to 20 ft./sec.) by measuring the amount of aerosol retained in each pad and the amount passing the series of pads.

In order to take advantage of the convenience of colorimetric techniques, a dye was selected for producing the aerosol. The test aerosol was prepared from a volatile dye, du Pont "Oil Orange," in a large-scale version of the La Mer generator (3). Unlike the La Mer generator, however, the aerosol was formed by quenching the hot dye-vapor-laden air with filtered room air and no nucleation was employed. Throughout all the tests, the generator conditions were held constant to give a fixed reproducible aerosol as determined by frequent checks of filtration efficiency on a given filter-pad arrangement. The size of the aerosol particles was determined with jet impactors borrowed from the University of Illinois (8). The aerosol particles were relatively uniform but not homogeneous, having a mass median diameter of 0.4 micron and a standard geometric deviation of 1.4. It is believed that the particles were present in the air stream as spherical supercooled droplets of dye, although it is known that they crystallize into needles on shock or after a period of 10 to 20 minutes. Concentrations were on the order of 1 to 2 mg. of dye per cu.ft. of air.

The filter pads consisted of 0.1-in. thick layers of glass fiber packed between retaining screens. Five such pads were mounted in series in each test. Four types of fibers were used at various packing densities:

| <u>Fiber No.</u> | <u>Trade Name</u> <u>(Owens-Corning Fiberglas Corp.)</u> | <u>Mean Fiber Diameter,</u> <u>Microns</u> |
|------------------|-------------------------------------------------------------|-----------------------------------------------|
| F-1 | Aerocor-PF-Type AA | 1.29 |
| F-2 | Basic 28 | 7.6 |
| F-3 | Fine Wool | 10.7 |
| F-4 | Curly Wool (Type 115K) | 29.4 |

All test fibers were fired at 400°C. to remove any binder or lubricant. The clean-up filters located after the test pads consisted of two standard Aerocor-PF-Type AA mats in series. The amounts of dye collected on each pad and by the clean-up filters were determined by leaching out the dye with benzene and analyzing the solutions colorimetrically.

EXPERIMENTAL RESULTS

Figure 1 shows the experimental results presented in the form of a plot of transfer units vs. superficial air velocity for the various fibers at several packing densities. It will be noted that the same type of curve was obtained with all the fibers and packing densities. The high-velocity end represents the region in which inertial interception is the controlling deposition mechanism. As the velocity is reduced, inertial deposition becomes less effective and collection efficiency (measured in terms of transfer units) decreases. At velocities on the order of 1 to 10 ft./sec., however, diffusional deposition becomes a sig-

nificant factor. At lower velocities, diffusion becomes the controlling deposition mechanism and collection efficiency increases with a further decrease in velocity. It will also be observed that the curves become flatter for the fine fibers. This reflects the superimposed effect of flow-line interception, which is relatively more pronounced with the fine fibers and is independent of gas velocity in the magnitude of its effect.

While the data are presented directly in Figure 1, they are of little general utility in this form. It is necessary to generalize them in terms of fundamental concepts. This may be done by using the data as a means for evaluating the exact nature of the functional relationship implied by Equations 6, 7, and 8.

Since the gas properties and the aerosol particle size were held constant throughout this study, the value of the interaction parameter, N_{sc} , defined by Equation 9, was constant at a value of 2140. Equation 7 and 8 would now indicate, pursuant to the assumptions made in deriving them, that all the collection efficiency data expressed as target efficiencies, should be unique functions of either the inertial interception number, N_{si} , and the flow-line interception number, N_{sf} , or of the diffusional separation number, N_{sd} , and the flow-line interception number, N_{sf} . In other words, if the target efficiencies obtained in this study are plotted against either N_{si} or N_{sd} , unique curves should be obtained for given values of N_{sf} .

In Figure 2, the data are shown in the form of a plot of target efficiency, η_t , vs. N_{si} with N_{sf} as the parameter. Figure 3 represents the same data plotted as target efficiency, η_t , vs. N_{sd} with N_{sf} as the parameter. It should be emphasized that these two figures are not independent; they are merely alternate ways of presenting the same data and it is possible to go from one to the other by direct calculation. Since the interaction parameter N_{sc} is constant, once any two of the three separation numbers, N_{sf} , N_{si} , and N_{sd} , are fixed, the third is determined (Equation 9). The value of the third parameter is shown as a dashed line in each figure. Figures 2 and 3 may be regarded as the graphical manifestation of the functional relationships implied by Equations 8 and 7, respectively, for the specific value for the interaction parameter of 2140.

DISCUSSION OF RESULTS

Validity of Assumptions: In deriving Equations 6, 7, and 8, several assumptions were made. The fact that the resulting indicated method of correlation did result in unique relationships for the data may be taken as evidence, although not proof, that the assumptions were valid within the precision of the data. Individual consideration of the various assumptions will lend further weight to this conclusion.

Since the tests were run under essentially isothermal conditions, no thermal deposition would be expected. Order-of-magnitude estimates also indicated that deposition by gravity settling should be negligible over the range of conditions employed. This was confirmed experimentally by the fact that no significant differences in collection efficiency were obtained when the gas was passed horizontally through the filter pads or vertically up or down through the pads.

It is known that the Reynolds number, N_{R0} , has an influence on the flow pattern around single cylinders and, hence, would be expected to influence deposition efficiency in that case. With proximate cylinders, as in fibrous filter pads, however, the Reynolds number should have no effect provided it is not above a value of on the order of 1. In the current tests the Reynolds number was less

than 10 and usually less than 1. The absence of a Reynolds number effect on the flow pattern is further substantiated by the fact that the pressure drop through the pads was essentially a linear function of air velocity. For Reynolds numbers greater than 10, however, a distinct effect would be expected, although this region is beyond the scope of the present test data.

The data show no distinct effect of packing density on target efficiency although there is an indication that higher densities result in somewhat higher target efficiencies. Since bed densities were not varied widely, however, these indications are not sufficiently beyond the precision of the measurements to be conclusive. Actually it would be expected that higher bed densities would compress the streamlines around the fibers and yield higher target efficiencies. For the range of densities investigated, however, it may be concluded that density has no major effect on target efficiency.

From the fact that a correlation was obtained by neglecting electrostatic effects, one might conclude that electrostatic effects were of no major significance in these tests. If the electrostatic separation number followed the same trend in all the tests as one of the other separation numbers, however, this conclusion would not be valid. An examination of the various separation numbers will show that the group N_{sei} , which is a measure of electrostatic deposition by induction, would be directly proportional to the diffusional separation number, N_{sd} , if any surface charge, ϵ_{ps} , had been the same on all the pads tested. While this would represent a coincidental condition, it is not an unlikely one. The only direct evidence against this possibility is the fact that the target efficiencies obtained are of the order of magnitude that would be expected if diffusion were a controlling factor in the absence of inductive deposition. Consequently, while it cannot be conclusively demonstrated that electrostatic effects were absent, it can be concluded that any such effects that might have been present were not major factors.

Comparison with Other Investigators: There are only two sets of data available in the literature which are sufficiently complete to approach a basis for comparison. The data of Blasewitz et al (1) dealt with an aerosol that was quite heterogeneous and, in addition, involved considerable uncertainty as to the magnitude of the particle size. La Mer et al (3), while complete in other respects, did not measure the properties of the filter pads. Hence, the comparative interpretation of their data involves a possible error of several-fold. When presented on the same basis as Figures 2 and 3, the data of Blasewitz and La Mer indicate qualitative agreement with the present data.

The data in Figures 2 and 3 suggest limiting curves for $N_{sf} = 0$. These have been drawn in as dotted or short-dashed lines. In Figure 2 this limiting curve would represent the target efficiency at low Reynolds numbers if inertial interception alone were involved. Langmuir (4) reports a calculated value of N_{ei} of 0.27 below which no deposition by inertial interception can occur at low Reynolds numbers, although he gives no details as to the method of arriving at this value. This value was used as an asymptote in drawing the limiting curve for $N_{sf} = 0$ in Figure 2. Also shown as a dotted curve in Figure 2 are the calculated values reported by Langmuir and Blodgett (5) for potential flow. These values would correspond to the target efficiencies to be expected for pure inertial interception at very high Reynolds numbers and should be much greater than those for viscous flow.

Davies (2), Langmuir (4), Lewis and Smith (6), Ranz (7), and Stairmand (11) have all developed approximate analytical expressions for target efficiencies under conditions of pure diffusion to single cylinders. While these expressions differ by several-fold factors owing to differences in simplifying assumptions,

that of Langmuir is probably the most accurate. Langmuir's expression falls below the dotted line of Figure 3 by a factor ranging from 0.5- to 3-fold. Lewis and Smith obtain results 70% higher than the dotted line while Stairmand is higher by a factor of 3. Ranz is in approximate agreement with Langmuir. It should be remembered that these analytical expressions are for single cylinders. Higher target efficiencies would be expected for proximate cylinders.

APPLICATION

Figures 2 and 3 give a quantitative representation of deposition in fibrous filter media at low Reynolds numbers (less than 10) in the absence of significant thermal, electrostatic, or gravitational effects. They are specific, however, for an interaction number of 2140. To obtain a generalization of these curves, it would be necessary to obtain similar curves for a range of the interaction number. For higher values of the interaction number, the curves of constant N_{sf} would, in general lie below those of Figures 2 and 3; while, for lower values of N_{sc} , the curves of constant N_{sf} would lie above those of Figures 2 and 3. In either case, however, the curves of constant N_{sf} would approach those of Figures 2 and 3 at high values of N_{sd} or N_{si} (i.e. at the right-hand side of each figure). In other words, for high values of N_{si} and N_{sd} , the curves of Figures 2 and 3 would be sensibly independent of N_{sc} .

To use Figures 2 and 3 for general design estimates in the absence of more extensive similar data at other values of the interaction number, the following procedure is suggested. For the specific values of the separation numbers N_{sf} , N_{si} , and N_{sd} involved in a particular problem, calculate from Figures 2 and 3 the target efficiency corresponding to each of the three combinations of two of the separation numbers. In general, this will yield three values for the estimated target efficiency. For the singular case where the interaction number for the specific problem is 2140, these three values of target efficiency will, of necessity, come out equal. If the interaction number is less than 2140, use the highest of the three target efficiency values obtained. If the interaction number is greater than 2140, use the lowest of the three target efficiencies obtained. This approximation should yield estimates that are correct within a factor of two for the range of conditions likely to be of practical interest.

SUMMARY AND CONCLUSIONS

A method has been presented for generalizing the principles governing deposition of aerosol particles in fibrous packing by the mechanisms of flow-line interception, inertial interception, and diffusional deposition. Experimental data have been obtained which express these principles quantitatively for an interaction number of 2140. In the absence of more extensive data over a range of interaction numbers, a method is suggested for utilizing the present data for general design or performance estimates.

The following is a list of indicated directions for further research to fully develop the fundamentals of aerosol deposition in filters:

1. Confirming Data. In this field, with its many uncertainties regarding basic techniques of measurement, it is especially desirable to obtain comparisons with other data obtained independently and preferably using different techniques. Literature data currently available are not sufficiently complete to enable quantitative comparisons to be made.

2. Effect of Interaction Number. While an approximate method is suggested for employing the data presented herein for general design, it is necessary that further data be obtained over a wide range of the interaction number (say for N_{sc} ranging from 100 to 100,000).

3. Effect of Bed Density. Data are required to establish the quantitative effects of packing density. The present study involved a relatively limited range. Such data should be extended to dense packings such as may be encountered in compressed mats.

4. Effect of Reynolds Number. For practical conditions under which deposition by flow-line interception or diffusion are significant, the Reynolds number should be sufficiently low that it is questionable whether the Reynolds number would have any significant separate influence. For inertial interception, however, high values of the Reynolds number, for which marked effects would be expected, are frequently encountered.

5. Effect of Mean Free Path of Gas Molecules. Insofar as the mean free path effects the flow around fibers, this factor has been essentially ignored by all but Langmuir (4) who provides an approximate allowance. In practice it will be significant with very fine fibers or at reduced pressures. Although not separately allowed for, it was probably beginning to be a significant factor in the case of the finest fiber employed in the present study.

6. Effect of Other Deposition Mechanisms. Considerable work remains to be done to evaluate the principles of deposition by gravity, electrostatic, and thermal mechanisms. Ranz (7) (9), in particular, has made a start in this direction.

7. Effect of Fiber Orientation. There has been essentially no systematic work on the quantitative effect of fiber orientation. The present study dealt exclusively with fibers mounted perpendicular to the gas flow.

8. Deposition in Granular Solids. There has been essentially no fundamental work to evaluate the quantitative principles of deposition in beds of granular solids.

9. Filter Life. The above-indicated needs for further research are aimed primarily at developing the fundamentals of deposition. In practice, a far more important consideration is that of filter life from the standpoint of plugging by the particles deposited in the filter. To date there has been no systematic evaluation of this phase. Actually, before a truly fundamental analysis of filter life can be made, it will probably be necessary to first develop the principles of deposition.

10. Mechanical Stability. In practice, the compressive properties of fibers are an important consideration in design of deep-bed filters. Mechanical stability with time under corrosive or stressed conditions is also very important. These phases have hardly been touched upon in investigations to date.

NOMENCLATURE

A = face area of filter pad normal to direction of gas flow, sq. cm.

D_b = fiber diameter, cm.

D_p = aerosol particle diameter, cm.

D_v = diffusion coefficient for aerosol particle = $k_m R T / 3 \pi \mu N D_p$, sq. cm./sec.

- k = thermal conductivity of gas, (cal.)/(cm.)(°K.)(sec.)
 k_m = Stokes-Cunningham correction factor for mean free path of gas molecules, dimensionless.
 k_p = thermal conductivity of aerosol particle, (cal.)/(cm.)(°K.)(sec.)
 m = mass of filter pad through which gas flows, grams.
 N = Avogadro's number = 6.023×10^{23} molecules/(gram mole).
 N_{Re} = Reynolds number = $D_b u_o \rho / \mu$, dimensionless.
 N_s = separation number, dimensionless.
 N_{Sc} = interaction number = $18 \mu / k_m \rho_p D_v$, dimensionless.
 N_{sd} = diffusional separation number = $D_v / u_o D_b$, dimensionless.
 N_{sec} = electrostatic separation number for effect of charges = $k_m \epsilon_p \epsilon_{bs} / \mu \delta D_p u_o$, dimensionless.
 N_{sei} = electrostatic separation number for effect of induction = $k_m \epsilon_{bs}^2 D_p^2 (\delta_p - \delta) / \mu \delta^2 D_b u_o$, dimensionless.
 N_{sf} = flow-line interception number = D_p / D_b , dimensionless.
 N_{sg} = gravity separation number = u_t' / u_o , dimensionless.
 N_{si} = inertial interception number = $k_m \rho_p D_p^2 u_o / 18 \mu D_b$, dimensionless.
 N_{st} = thermal separation number = $[k / (2k + k_p)] [(T - T_b) / T] [\mu / k_m \rho D_b u_o]$, dimensionless.
 N_t = number of transfer units, dimensionless.
 R = gas constant, 8.31×10^7 (ergs)/(°K.)(gram mole).
 s_v = specific surface of fibers, = $4/D_b$ for cylindrical fibers, sq. cm./cu. cm.
 T = gas temperature, °K or °C abs.
 u_o = superficial gas velocity (based on filter face area), cm./sec.
 u_t = terminal settling velocity of aerosol particle in gravity field, cm./sec.
 δ = permittivity of gas, (statcoulombs)²/(dyne)(sq. cm.).
 δ_p = permittivity of aerosol particle, (statcoulombs)²/(dyne)(sq. cm.).
 ρ_b = fiber density, g./cu. cm.
 ρ_p = aerosol particle density, g./cu. cm.

- μ = gas viscosity, poises.
- ϵ_v = fractional voids in filter pad, dimensionless.
- ϵ_p = electric charge on particle, statcoulombs.
- ϵ_{ds} = electric charge on fiber surface, (statcoulombs)/(sq. cm.).
- η = overall fractional collection efficiency, fraction of particles entering filter that are deposited in the filter pad, dimensionless.
- η_t = ratio of cross-sectional area of the original aerosol stream, from which particles of a given size are removed because the particle trajectories intersect the fiber surface, to the area of the fibers projected normal to the nominal direction of gas flow, dimensionless.
- ψ = "a function of."

REFERENCES

1. Blasewitz, A. G., et al, General Electric Company, Hanford Works, Document H W 20847, April 16, 1951.
2. Davies, C. N., Proc. Instn. Mech. Engrs. (London), 1 B, 185-213 (1952); Ninth International Congress on Industrial Medicine (London), pp. 1-36, Sept. 13-17, 1948.
3. La Mer, V. K., et al, Report N Y O-512, Contract No. A T - (30-1) - 651, 1951.
4. Langmuir, I., O.S.R.D. Report No. 865, Part IV, Sept. 4, 1942.
5. Langmuir, I., Blodgett, K. B., Report No. RL-225, General Electric Research Laboratory, Schenectady, N. Y., 1944-45.
6. Lewis, W. K., Smith, J. M., O.S.R.D. Report No. 1251, Dec. 15, 1942.
7. Ranz, W. E., Univ. of Ill., Eng. Exp. Station, Technical Report No. 3, SO-1004, March 31, 1951.
8. Ranz, W. E., and Wong, J. B., Archiv. Ind. Hyg. and Occupational Medicine, 5, 464-77 (1952); Ind. Eng. Chem., 44, 1371-81 (1952).
9. Saxton, R. L., Ranz, W. E., Univ. of Ill., Eng. Exp. Station, Technical Report No. 6, SO-1007, Dec. 31, 1951; J. Appl. Physics, 23, 917-23 (1952).
10. Sell, W., Forsch. Gebiete Ingenieurw., 2, Forschungsheft No. 347, Aug., 1931.
11. Stairmand, C. J., Trans. Instn. Chem. Engrs. (London), 28, 130-137 (1950).
12. Thomas, D. G., "Deposition of Aerosol Particles in Fibrous Packing," Ph.D. Thesis, Ohio State University, 1953.

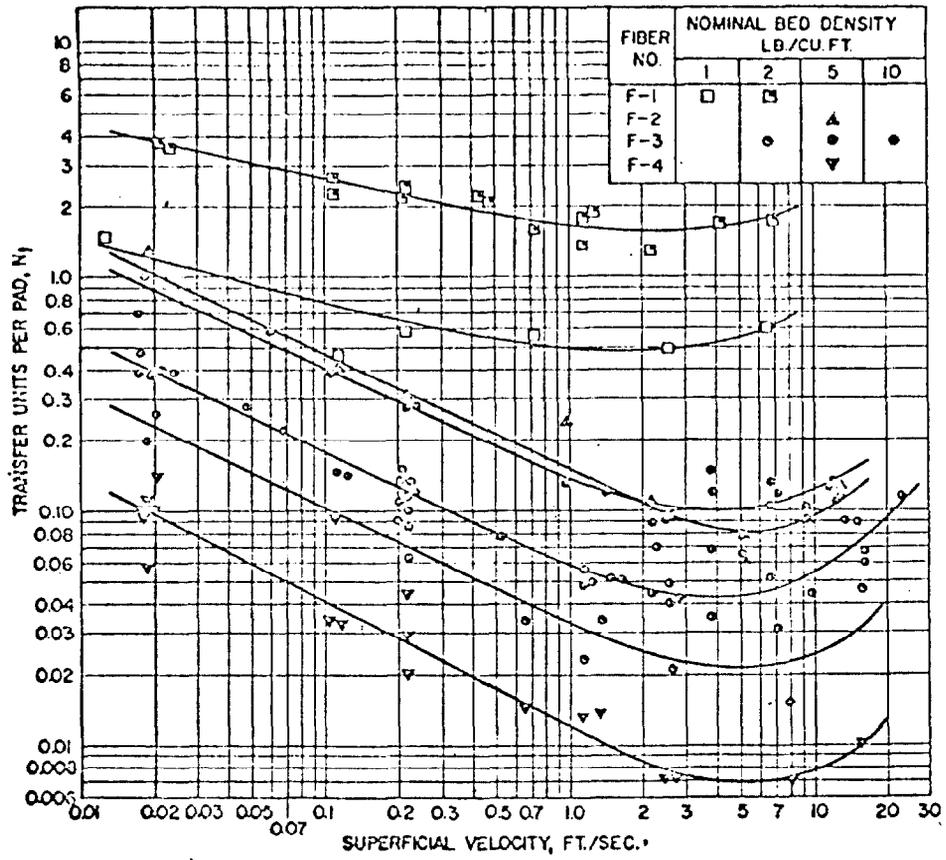


FIG. 1

SUMMARY OF EXPERIMENTAL COLLECTION EFFICIENCY DATA

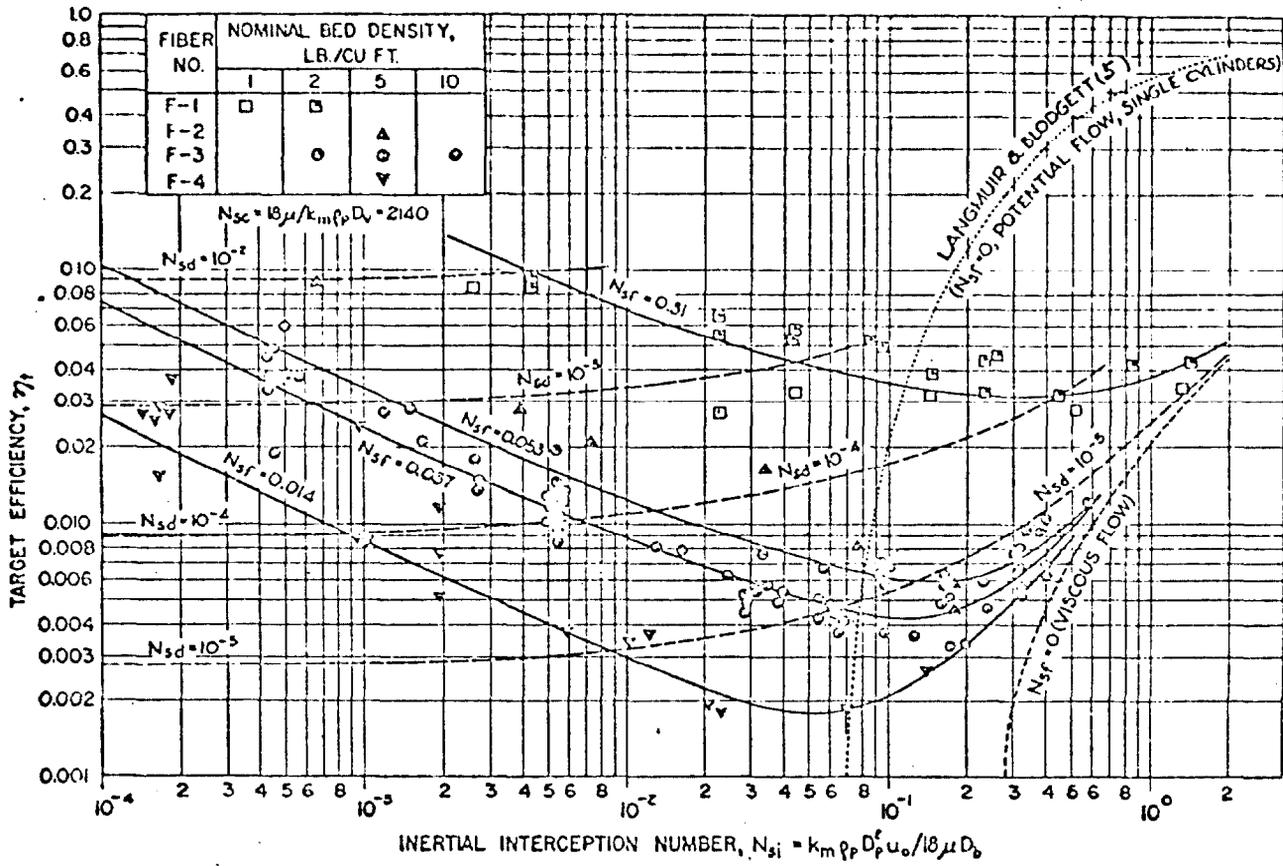


FIG. 2

TARGET EFFICIENCY AS A FUNCTION OF THE INERTIAL INTERCEPTION NUMBER

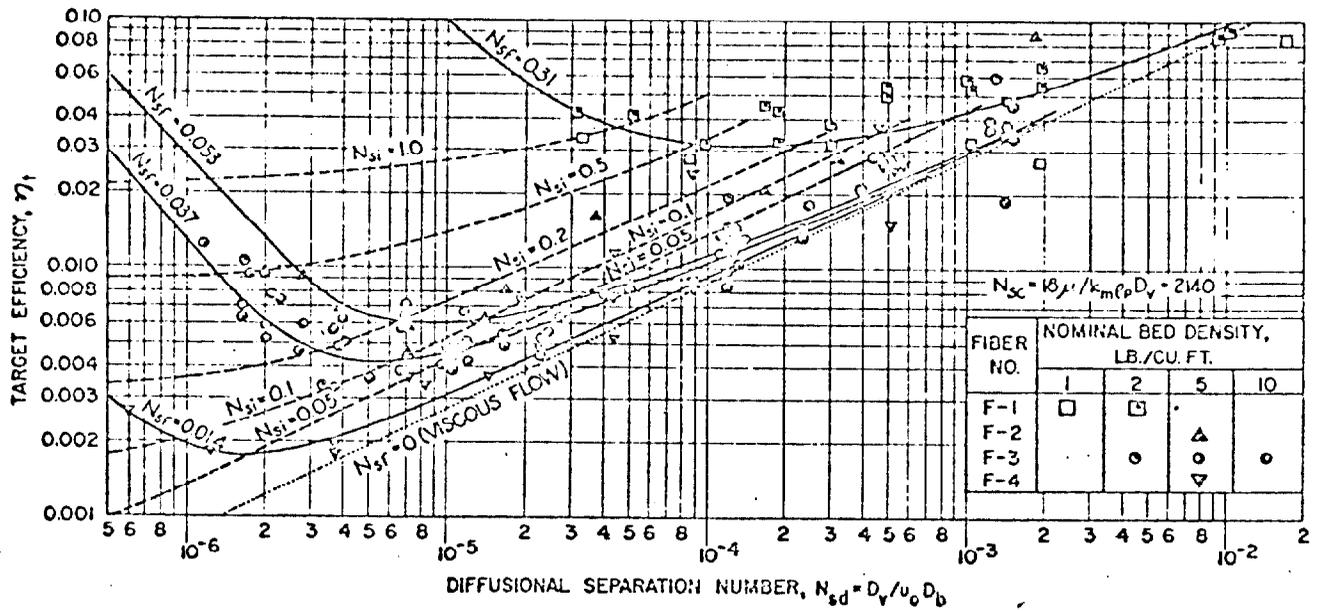


FIG. 3

TARGET EFFICIENCY AS A FUNCTION OF THE DIFFUSIONAL SEPARATION NUMBER

AIR CLEANING
NEW DEVELOPMENTS AT U.C. RADIATION LABORATORY

By M. D. Thaxtor, UCRL

I'd like to touch on two items under the heading of new developments at the Radiation Laboratory, under the topic of air cleaning. The first is a minor item, a scrubber for the entire or partial removal of corrosive vapors. We've been fiddling with this gadget for 2-1/2 years and have found it useful in our box applications as well as in non-radioactive bench chemistry. Its purpose is to protect filters, ducts, blowers and other air cleaning and air handling equipment. At the outset let me give credit to the Harvard air cleaning lab for the stimulus received there in 1951 where their scrubber was demonstrated. We used the saran bed reported by them. The resemblance ends there, however, and our results cannot be compared with theirs. We were seeking a very compact package whereas Harvard's was on an industrial scale.

We may describe our unit as "a small vertical gas scrubber, concurrent flow, single stage, with saran fiber bed, scrubbing liquor circulated by air lift, and containing an integral reservoir." A downstream exhauster is universally used.

The unit may be said to have two major portions, upper and lower. The upper portion contains gas inlet port, liquor discharge, spreader plate, saran bed disengaging space and gas outlet. The lower contains the air lift feed and reservoir of scrubber liquor. The assembly is tubular and has been made in three sizes, our so-called 2", 4" and 6" sizes. The 2" and 4" sizes are self-contained in polyethylene and industrial glass Pyrex pipe sections respectively, whereas the largest is 6" Pyrex pipe housed in a 30 gallon common drum, polyethylene lined.

Some dimensions may be of interest:

| <u>DATA:</u> | <u>Scrubber Size & Dimensions</u> | | |
|----------------------------------|---------------------------------------|-----------|------------|
| | <u>2"</u> | <u>4"</u> | <u>6"</u> |
| Overall height, inches | 17.5 | 34 | 34 |
| Width, inches | 2 | 4 | 21 |
| Bed internal diameter inches | 1.8 | 3-5/16 | 4-3/4 |
| Bed cross sectional area--inches | 2.6 | 8.3 | 17.8 |
| Bed depth--inches | 6 | 10 | 10 |
| Lift height--inches | 17 | 25 | 26 |
| Liquid reservoir height--inches | 8.5 | 12 | 16 |
| volume-- | --- | 2 liters | 17 gallons |
| Liquor cycling rate, cc's/min. | --- | 400 | 600 |
| Thruput gas volume as lift air | --- | 0.23 CFM | 1.7 CFM |
| Total gas thruput @ 3" w.g., CFM | 3-1/4 | 10 | 19.2 |

It was experimentally determined by cut and try methods that the optimum air line tube diameter was 7 mm inside the air lift tube of 16 mm.

Observe in the above data the thruput is directly related to bed diameter. Laboratory efficiency tests have been run only on the 4" size with and without an upstream condenser. Vapors from boiling 12.6 M HCl mixed at the vapor pickup with room air to make up volume was the feed material. Hence the concentration dropped as volume went up. Total acid in each run was 100 ml boiled to dryness. The tests were repeated with 16.2 M HNO₃. Efficiency calculations are based on back titration of scrubber liquor which was 2 N NaOH. Results are expressed as % removal to scrubber liquor from the air stream.

HCL tests

| CFM | 4" scrubber | 4" scrubber with condenser |
|-----|-------------|----------------------------|
| 5 | 66 | 100 |
| 3 | 71 | 91 |
| 1 | 88 | -- |

HNO₃ tests

| | | |
|---|-----|----|
| 5 | 58 | -- |
| 3 | --* | 67 |
| 1 | --* | 98 |

*Not determined; acid reacted with tubing used in assembly.

In one application where beta-gamma radioactive mists were encountered the scrubber also acted as a satisfactory air cleaner. This is, however, an exception; its efficiency for particulates is like all scrubbers, rather poor. Qualitatively these scrubbers have performed well for our major purpose of protecting downstream equipment. They have worked visibly well on HF as expected but not so well on H₂SO₄. The 4" and 6" units are mounted downstream and outside of Berkeley boxes. The 2" under current study is designed to go inside such boxes. Rough sketches are available for those interested.

The second item to be discussed is more important. It might be said that it concerns not air cleaning, but a method of avoiding a probable failure of air cleaning. A few introductory remarks are necessary: At UCRL we encounter our major air cleaning problems in connection with investigations on the transuranics. Substantially, as you know, these are alpha emitters; some of them are beta-gamma and neutron emitters as well. When the specific activity is high a very small percentage loss to room air or to stack gas will result in exceeding the AEC limits for air pollution.

When one manipulates substantial quantities of high specific activity material and the treatments involve heating, cooling, stirring, transferring, gassing, centrifugation, precipitation, dissolving, evaporation to dryness and a host of energetic chemical reactions, the chances for aerosol formation and dispersion are considerably enhanced.

Since in research practice it never occurs that the sequence of processing events, or conditions surrounding each event, is duplicated in successive experi-

"sausage link" prepared by the usual heat-sealing technic. All components of the system are liquid, solid and gaseous waste receivers as such, and will be concrete jacketed and buried at the termination of the operations, with the exception of the accumulator tanks. It is planned to sample the bags in these and assay their contents by three methods: filtration, ESP and vibrating reed electrometer. Attempts to clean the accumulated gases are planned and will be prosecuted if time and the assays permit. In the event of poor success the gases will be compressed in steel cylinders, jacketed in polyethylene and encased in concrete for burial.

We have become truly amazed at the detailing required. The two operating boxes require eleven gloved boxes to serve them, 1200 feet of polyethylene pipe, 500 hose clamps, over 150 valves and much other impedimenta. The cost is of course commensurate. The designed capacity of the system is 615 cubic feet with a two-fold safety factor on volume. It is anticipated the equipment will run continuously for some 60 days. An example of the complexity a closed system requires may be given. Consider the sole factor of environmental temperature variations. We plan to hold the system at all times at about minus 1/2" water gauge with respect to atmospheric pressure. Yet a shift of 11 degrees F would cause a change of pressure in all voids of the apparatus of about 13" w.g. Stated another way, if the volume of one of our accumulators is 240 cubic feet, this would mean a volume change of about 8 cubic feet just because of this small temperature variation. This must be allowed for in the sensing and controlling apparatus and provisions made for tempering the ambient atmosphere.

What I should like to hear at this meeting of course is a description of an air cleaning train with sufficiently ample decontamination ability so all the above headaches could be avoided when we run into this type of problem again.

A CONSTANT VOLUME RADIOCHEMICAL HOOD

By G. T. Saunders, CR&D

DESIGN PHILOSOPHY

In 1951, design criteria were being established for a new chemistry laboratory to be built by the California Research & Development Company, and studies were undertaken at that time to determine the type of radiochemistry hood that was to be used. The first requirement established was that the hood must be an integral part of a constant volume central exhaust system. Secondly, and opposed to a constant volume unit, it was desired to obtain a constant face velocity regardless of door setting. Lastly, it had to be inexpensive.

An examination of commercially available radiochemical hoods and those in current use at A.E.C. sites showed that none could meet our three demands. The problem was resolved by the designing of a hood that was formulated around several features:

1. To meet constant volume and constant face velocity -- which we set at approximately 100 FPM -- it was determined to use the hood door itself as an air regulating valve by incorporating a by-pass port directly above the hood compartment.
2. The exhaust filters were to be installed immediately adjacent to the hood outlet and at floor level to facilitate ease of change.
3. The hood must be readily portable and must pass through a standard 3'0" x 7'0" door.
4. It must be easily disassembled so that in the event of contamination only the affected part need be taken away.
5. It must be inexpensive.

How these features were achieved are to be illustrated by a look at the unit as it was designed and tested. (Refer to Figures I & II (Slides 1, 2, & 3))

GENERAL DESCRIPTION

The overall dimensions of the hood are 9'2" high by 4'3" wide and 2'10-1/2" deep, without front air foil -- with foil it is 3'1-1/2" deep. It is constructed throughout with mild carbon steel. The canopy and coverplates are of sheet metal and the supporting members utilize standard structural shapes. All surfaces that are exposed to either corrosion or contamination are finished with a baked phenolic resin. The hood opening is equipped with a removable air foil to insure smoother air entry.

The hood deck will support a floor loading of 500 pounds per square foot. Standard utility connections are provided, which includes a cup sink.

The hood section and the by-pass section both have a face area of 11 square feet; the hood window is likewise 11 square feet and as it is moved up or down the total air intake area remains at 11 square feet. With an average face velocity of 100 FPM, the volume remains at roughly 1100 CFM.

The air from both the hood and bypass compartments pass through the filter units at the base of the hood. A fiberglass prefilter is provided for each of

two 2' x 2' x 5-7/8" CWS #6 (equiv.) filters connected in parallel. The total air volume in the unit can be adjusted by means of a butterfly damper located downstream from the filters. An indicating manometer shows the pressure drop across the filter bed, and as the filter loading increases the total air volume can be adjusted to a maximum of 3" static pressure drop across the filter bed.

The concrete slab construction of the building precluded any service basement so that a furred-in space is provided at the side of the hood for the utilities and duct run from the floor to the ceiling. Since two or more hoods are normally installed side-by-side, the common usage of the utility space is economically achieved. All valves and controls are mounted on the panel between the hoods.

The hood is quite simple to disassemble. The upper hood and by-pass section rests by gravity on the supporting structure. By disconnecting the utility outlets, the top section can be lifted off and taken from the room. The lower filter box and supporting structure can be removed by disconnecting a coupling to both water drain and to the air ducts.

The filters are changed by removing the cover plates and withdrawing the filters horizontally.

HOOD DEVELOPMENT

In order to ascertain the air currents, pressure drops, and general flow characteristics of the hood, a unit was mocked up to be run for smoke and velometer tests. It was essentially as shown in Figure I and was used to determine optimum baffle, air foil and opening sizes. The unit was also used to determine the effect that each component had on the other.

In the original concept a simple vertical adjusting baffle was used at the back of the hood chamber. This demonstrated a very rapid increase in face velocity for the lower (hood) section as the door was closed. However, the total air volume remained fairly constant since the major pressure drop was concentrated at the narrow exhaust outlet between the hood and filter plenum.

To correct this increase in face velocity of the hood section, the vertically adjusting baffle was replaced by a hinged baffle which could be moved to decrease the air volume (--thus velocity--) in the lower hood section when the hood door was lowered. This mechanism works in this fashion: when the door is closed to 10" or less from the bottom, the operator may move the baffle to a partially closed position by pulling a handle on the control panel. The baffle locks in this position until the door is raised at which time it returns to its original position. If there is no objection to the higher face velocity, the baffle does not have to be closed. Figure III (Slide 4) shows this linkage in schematic fashion. Figure IV (Slide 5) shows the total volume and average face velocity of the hood in operation.

The use of the baffle showed that a more laminar flow of air was achieved with it than without it, and there was a minimum of hood turbulence regardless of door setting. There appeared to be no back-up of air from one compartment to the other, although, as would be anticipated, there was an increase in stagnated air in the bottom (hood) compartment as the door was lowered. Experiments with various sizes of air foils showed that there was little variation in effect due to size. However, the larger one performed better. The final radius was the maximum curvature to fit the physical installation limitations imposed by both building and personnel access. Slotted fairings were found ineffective at the

relatively low velocities involved. It is well to state, however, that the flow patterns with the air foils were many times better than without: the overall air pattern was laminar with, but turbulent without, the foils.

HOOD LIMITATIONS AND COST

There are limitations, of course, to this type of hood. The most obvious one is that the number of hoods to a room is limited unless special air supply devices are used. This is due to the constant volume aspects of the hood.

The installed price by a commercial fabricator of fifteen units was approximately \$1000 each. No attempt was made to determine the cost of a smaller number of units.

As in all initial designs, there are areas of improvement and we feel if additional units were to be built we would at least modify the following items:

1. Add a clamping bar on filter holders to facilitate holding.
2. Simplify baffle linkage.
3. Use counter weights on door instead of sash balances.

CONCLUSIONS

The hood has proven quite satisfactory in operation and we feel that the desirable features were obtained at a minimum of cost.

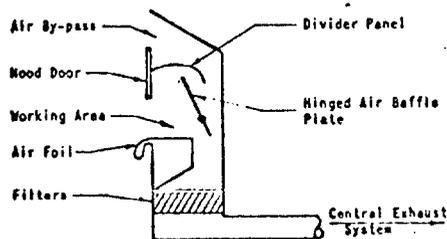
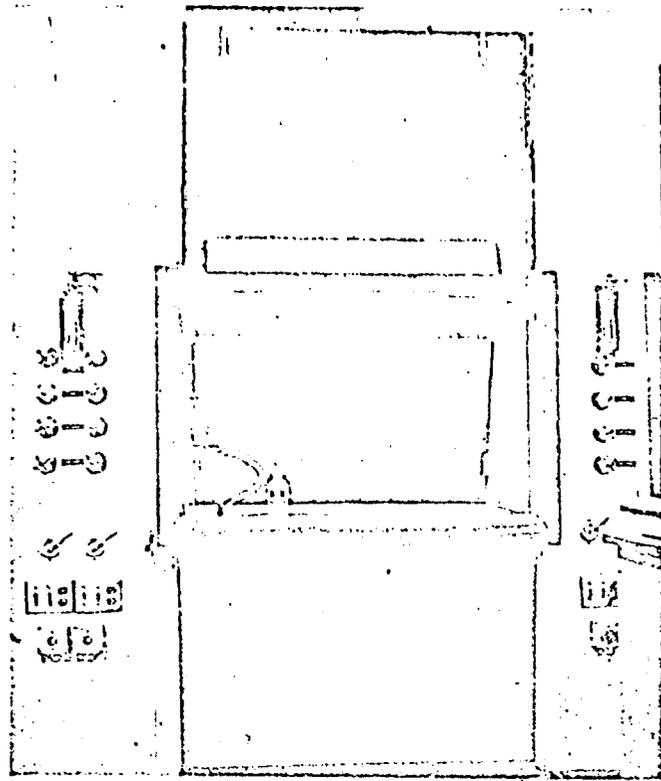
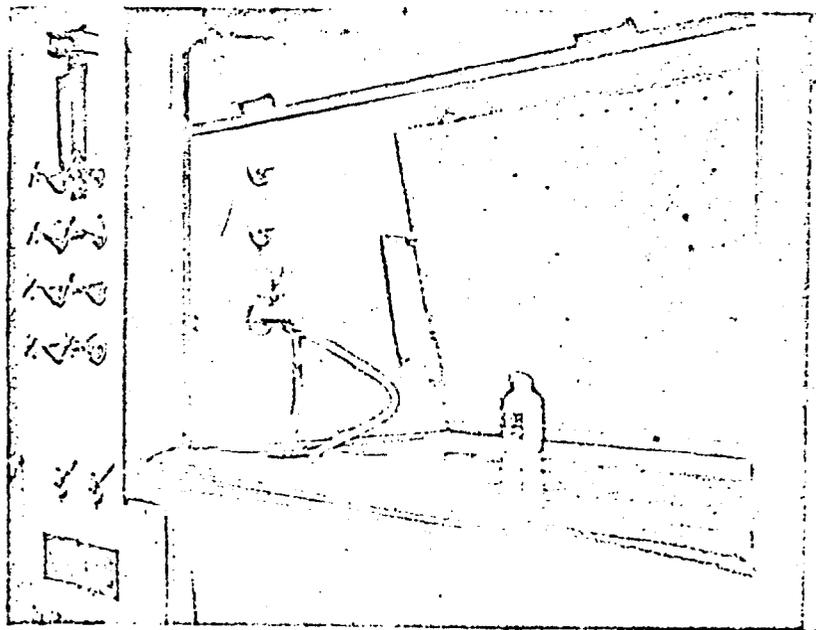


FIGURE I

SCHEMATIC DRAWING OF HOOD ELEVATION



a. Hood Installed



b. Close-up of Hood Installed

FIGURE II

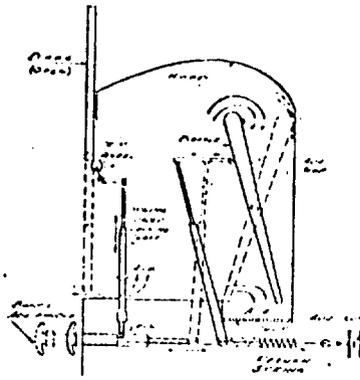


FIGURE III

SCHEMATIC DRAWING OF BAFFLE LINKAGE

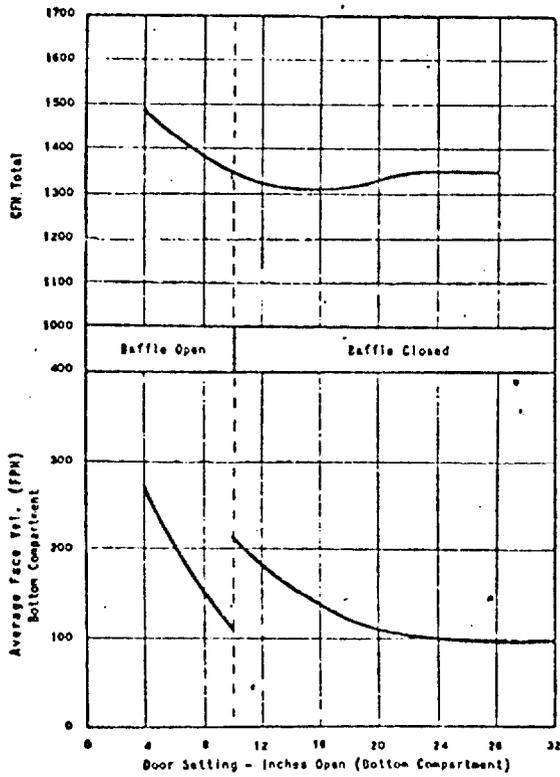


FIGURE IV

PERFORMANCE CURVES OF HOOD

FILTRATION OF MICROORGANISMS FROM AIR BY GLASS FIBER PAPER FILTERS

Herbert M. Decker, J. Bruce Harstad, Frank J. Piper

Chemical Corps, U.S. Army, Washington 25, D.C.

and Myrl E. Wilson, 2nd Lt., USAF

A survey of laboratory acquired infections in the United States reported in 1951 by Sulkin and Pike (1) tabulates a total of 1,334 infections acquired in the laboratory. Filtration of exhaust air from ventilated bacteriological work hoods and from rooms or buildings used in the study of highly infectious diseases will therefore assist in the reduction of laboratory acquired infections.

At the last Air Cleaning Seminar a paper was presented on the "Removal of Bacteria and Bacteriophage from the Air by Glass Fiber Filters." Mention was made at that time that preliminary tests indicated a high filtration efficiency of microorganisms through glass fiber paper filters. Since then, a number of tests have been conducted on this type of filter media. During the past year filter manufacturers have devoted considerable time and effort to the development of ultra microfine glass fiber paper filters for removal of biological and radiological contamination from air supply systems.

The glass fiber filter originally developed jointly by the Department of the Navy and the National Bureau of Standards is now being produced commercially. This filter is as thin as coarse paper (10 mils). The fibers are known commercially as type E Glass Micro Fibers, have a melting point of 1450 F, and an average diameter of 0.5 to 0.75 microns.

A second new type of filter paper is being developed by a research and engineering organization. This second type is composed of a mixture of glass fibers and asbestos fibers. Figures 1, 2, and 3 show the fibers as they appear in the PF 105 spun glass fiber pads and the two newer filter papers. It is evident that the Type E filter material (figure 3) has the most uniform fibers. It was reported at the 1952 meeting that two layers of PF 105 spun glass exhibited an efficiency of 99 per cent in removing Serratia indica from an air stream. Since that time, glass paper filters have been evaluated.

Serratia indica a harmless elongated bacterial organism, about one micron in length and one half micron in thickness was used to evaluate the efficiency of the filter papers. The test equipment is illustrated in figure 4. The organisms were atomized by a Chicago type nebulizer into a cloud chamber where the cloud of bacteria was mixed with air, then passed into the pre-filter sampling chamber, through the filter at face velocities of 10 and 20 feet per minute into a post-filter sampling chamber, and finally exhausted by means of a blower to the outside air. Biological material from this nebulizer is not always unicellular, because agglomeration of organisms may occur during or after release of the aerosol.

The air was sampled in front of the filter by liquid impingers constructed with a critical orifice which permitted air to be drawn through the collecting medium at approximately 0.5 cubic feet per minute. The collecting medium in the impingers consisted of 20 ml nutrient broth and 6 to 8 drops of olive oil. One-tenth ml of the sample was streaked

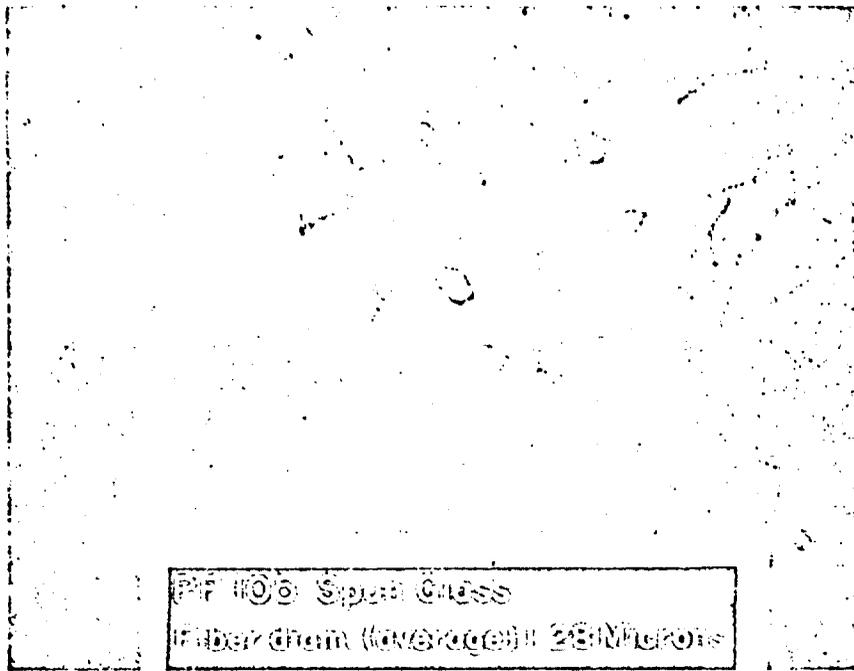


FIGURE 1. PF 105 Spun Glass Filter Media

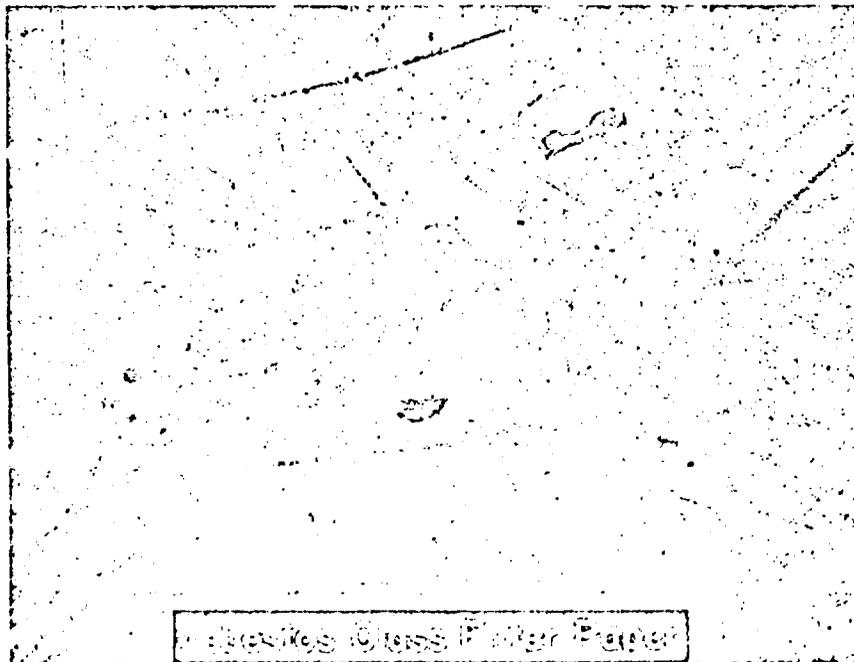


FIGURE 2. Asbestos Glass Filter Paper

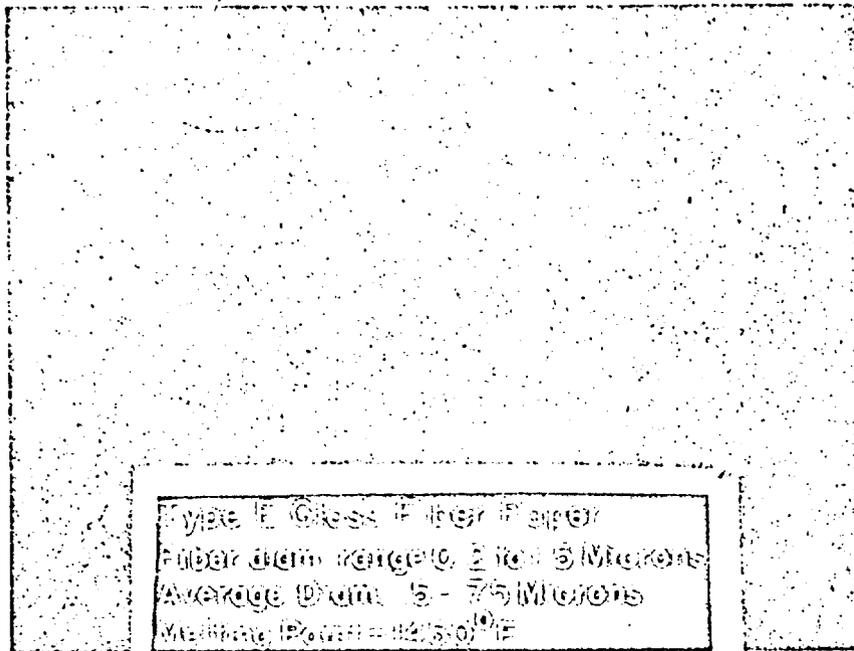


FIGURE 3. Glass Filter Paper

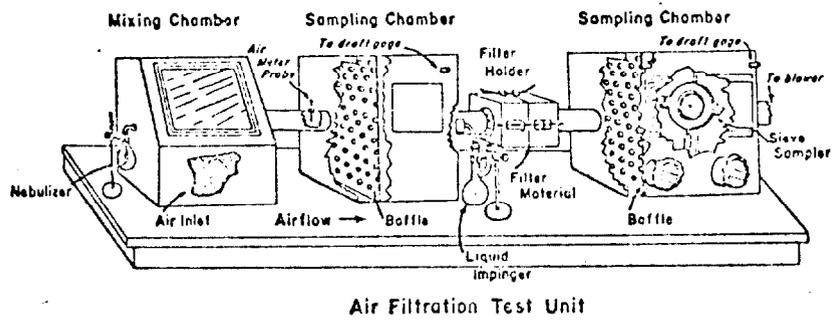


FIGURE 4. Air Filtration Test Unit

on a corn steep agar plate. In addition; one ml samples from the liquid impingers were serially diluted and one-tenth ml samples of the dilutions were streaked on plates for incubation and counting. Sieve samplers containing corn steep agar petri plates were used to sample air after it had passed through the filter.

The efficiency of the filter paper was determined by sampling the cloud concentration before and after the filter. The results of the test are shown in figure 5. At an air flow of 20 linear feet per minute penetration of S indica through the type E glass filter paper was two organisms from each 100 million test organisms recovered in front of the filter. At an air flow of 10 linear feet per minute the penetration was one organism. With the asbestos-glass paper, at an air flow of 20 linear feet per minute, the penetration was 28 organisms per 100 million test organisms. When the air flow through the asbestos glass paper was reduced to 10 linear feet per minute the penetration increased to 140 organisms. The increase in penetration from 28 to 140 probably results from the lesser impingement of the organisms on the fibers at the lower velocities.

Since steam is frequently used in safety cabinets for biological decontamination purposes, tests were conducted to determine whether the passage of steam through the type E glass filter material would have an effect on the filtration efficiency. Free flowing steam was passed through a 100 CFM type E glass pleated filter for a total of three hours. The results of the tests indicated that there was no apparent change in filtration efficiency.

**EFFICIENCY OF GLASS AND GLASS-ASBESTOS FILTERS
IN REMOVAL OF S INDICA FROM AN AIR STREAM**

| FILTER MATERIAL EVALUATED | AIRFLOW (linear feet per minute) | RESISTANCE (inches of water) | NUMBER OF FILTERS* EVALUATED | PENETRATION (per 100 million org. recovered before filter) |
|---------------------------------|-------------------------------------------|------------------------------------|------------------------------------|---------------------------------------------------------------------|
| GLASS PAPER FILTER TYPE E | 20 | 3.2 | 7 | 2 |
| | 10 | 1.5 | 5 | 1 |
| ASBESTOS-GLASS PAPER | 20 | 3.1 | 5 | 28 |
| | 10 | 1.5 | 5 | 140 |

*Each filter was tested a minimum of ten times.

FIGURE 5. Efficiency of Glass and Glass Asbestos Filters in Removal of S indica From an Air Stream

CONCLUSIONS

The data obtained on the filtering efficiency of the filter pads and papers are most promising, and indicate possibilities for wide practical application. Results of our earlier work showed that two $\frac{1}{2}$ inch pads of 1.28 micron size spun glass at a linear air flow of 20 fpm removed an average of 99 per cent of the bacteria and virus organisms. It was felt that this type of air filtration system would be satisfactory for general building exhaust supplies such as in hospitals and in industrial concerns. However, in specialized circumstances such as in the case of some research institutions where organisms may be handled in large numbers or in apparatus in which significantly infectious bacterial aerosols are accidentally or deliberately created, a greater arrestance is necessary.

There is now available a highly efficient mineral filter paper that can be easily used at high temperature; is fire resistant, does not disintegrate when wet, and can be biologically decontaminated by heat.

A non-combustible filter frame for the all-glass fiber filter is being developed commercially (figure 6). The filter made of asbestos fibers and glass fibers is also approaching commercial availability. Industrial installations, hospitals and research laboratories which require removal of biological, radiological or other particulates from an air stream, now have access to a highly effective, fire resistant and chemical (except hydrogen fluoride and alkalies) filter. Frequently, such a filtration system may be used in lieu of a costly incinerator.

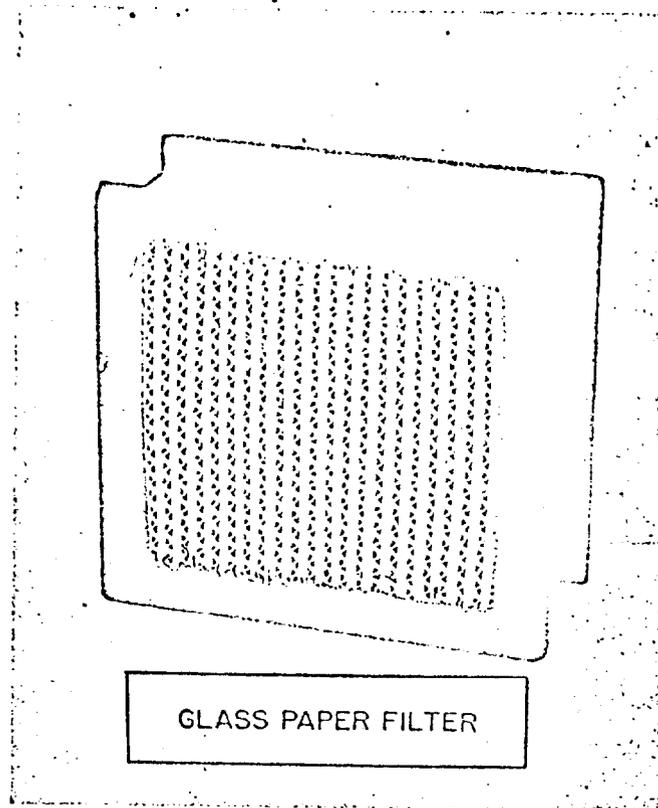


FIGURE 6. GLASS PAPER FILTER.

REFERENCE

- (1) Survey of Laboratory Acquired Infections, Sulkin, E.S. and Pike, R.M.
American Jl. of Pub. Health, 1951, Vol. 41, pp 769-781.

FURTHER STUDIES ON ELECTROSTATIC SEPARATION

by

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I. Introduction

At the last air cleaning seminar we presented a preliminary report of our studies on electrostatically charged aerosol filters. At that time we outlined some basic concepts of electrostatics such as methods for producing static electricity, mechanisms of charge reduction and measurement of charge. In addition, we reviewed existing information on the nature and behavior of the resin-wool filter. In this paper we shall attempt to bring you up to date on the results of our continuing research on the electrostatic effects in fiber filters.

II. Experimental Studies on the Effect of Aerosol Charge on Filter Efficiency

A. Apparatus and Procedure

The electrical mechanism of removal in a dry fibrous filter is related to the electrostatic force between the aerosol and the collecting surface. This force may be either a Coulomb or a polarization force¹. The Coulomb force exerted on an aerosol particle possessing a charge Q_p in an electric field of intensity E surrounding a charged fiber is as follows:**

$$F_c = Q_p E$$

* Senior Sanitary Engineer, U. S. Public Health Service on assignment from the Environmental Health Center, Cincinnati, Ohio

** The units used are in the "unrationalized" cgs or Gaussian system. That is, F is in dynes, E in statvolts/cm, Q in statcoulombs, and r in centimeters.

The field E at a distance r from the axis of a long slender fiber charged uniformly with Q_f units of charge per centimeter of length is as follows;

$$E = \frac{2Q_f}{kr}$$

Since the relative dielectric constant k for air is nearly 1, the Coulomb force experienced by the aerosol particle in air is;

$$F_c = \frac{2Q_p Q_f}{r}$$

Thus, the removal force is a function of the product of the charge on the individual particle and the charge on the fiber.

If F_c is negative, the particles tend to move from the aerosol stream onto the collecting surface, the net effect being an increase in filtering efficiency. Conversely, a positive value would indicate a lowering of efficiency.

In the case where one of the components is charged and the other is a dielectric, the force between the two may be a polarization force². An uncharged particle whose dielectric constant differs from that of the surrounding medium experiences a net force when placed in a non-uniform electric field.

Consider an uncharged particle in the non-uniform field E surrounding a long slender charged fiber in air. The inductive force on a particle of volume V and of dielectric constant k is as follows;

$$F_p = \frac{(k-1)VE}{4\pi} \frac{\partial E}{\partial r}$$

where r is the radial distance from the fiber.

Thus, the collecting force on a dielectric particle is related to the absolute value of the electric field surrounding the charged fiber, as well as the field gradient. The motion of the particle will be in direction of

the greatest field strength, that is, towards the fiber, regardless of the polarity of the fiber. Since $E = \frac{2Qr}{r}$, $F_p = \frac{(k-1)d^3Qr^2}{6r^3}$ where d is the particle diameter.

An evaluation, therefore, of the role of electrostatics in filtration must concern itself with two components - particle charge and fiber charge.

In this study we have divided our investigations into two phases. The first phase is concerned with the effects of particle charge on the filtration efficiency of an initially uncharged fiber filter. The remainder of this paper deals principally with this aspect and will include a description of the test procedure, apparatus and results.

The second phase is concerned with the effect of charged fibers on the efficiency of filtration of uncharged aerosol particles. Some exploratory work on this aspect has been initiated, and brief mention will be made of tests in progress.

a) Aerosol generator

Figure 1 shows the general layout of the entire test assembly. A 15 inch diameter steel drum open at the top houses a constant speed motor driving a horizontal 4 inch diameter brass disc.* From an overhead constant head tank, a solution of 0.1 percent methylene blue in 95 percent ethyl alcohol is fed through a hypodermic needle onto the center of the disc. The resulting thin liquid film is centrifuged off the edge to form a fine liquid spray consisting of droplets of two distinct sizes; the main droplets and the satellites, of approximately 1/3 the size of the main ones. The diameter of the main droplets is a function of the rotational speed, radius of the disc and physical characteristics of the liquid. An induced downward flow of air

* The aerosol was generated by a spinning disc sprayer adapted from the unit developed by Walton & Prowett³.

through the drum intercepts the satellites and conveys them into the inlet of the 5 1/4 inch test duct. Contact with dry room air results in the evaporation of ethanol from these droplets and solid spheres of methylene blue are formed. Particle size distribution, determined by means of a Cascade Impactor having a molecular filter (MF or Millipore Filter)* as the fifth stage, showed the aerosol to have a mass median diameter of 2.0 μ and a geometric standard deviation of 1.3. Loadings could be varied from about 0.1 to 1.7 mgs. per cubic meter with good reproducibility.

A Stairmand disc and diffuser screen are provided in the duct to insure uniform cross-sectional distribution of the aerosol.

b) Aerosol charging device

The aerosol is charged by means of an ionizer section containing a series of electrodes consisting of fine wires and coplanar brass cylinders. A direct current power supply furnishes controlled voltages up to 12,000 volts and ion currents up to 150 microamperes. A unipolar corona discharge is established between the wire and cylinder electrodes. Particles entering the electric field between the wire and cylinder are charged as a result of bombardment of ions having the same polarity as the wire. The emerging aerosol, therefore, possesses a charge having predominantly the same polarity as the discharge electrode. Aerosol charge could be varied from test to test by varying the ionizing voltage and current.

c) Sampling

Sampling probes placed on either side of the test filter permit determination of filtration efficiency. The filter medium in the sampler is a MF (Hydrosol Assay Type) having an efficiency of approximately 100 percent. The sampling rate was 5 liters per minute.

* Lovell Chemical Company, Watertown 72, Massachusetts

Mass concentration of methylene blue aerosol collected by the samplers is determined by dissolving the molecular filter in acetone, adding ethanol to dissolve the methylene blue and analyzing the solution colorimetrically on a Klett colorimeter.

d) Aerosol charge measurement

The filter medium used in these tests was 50 μ diameter glass fibers packed to a density of one pound per cubic foot. The filter was 5 1/4 inches in diameter and 1 inch thick. Aerosol charge measurements were made with a Faraday cage consisting of an 8 inch long brass collar around a Lucite filter holder as shown in Figure 2. A Rawson electrostatic voltmeter of low capacitance and high leakage resistance is connected to the Faraday cylinder. The capacitance of the entire electrical system including the meter is determined by a capacitance meter*. Electrical shielding of the measurement unit eliminates the effects of stray electric fields and capacitance. Critical parts of the test assembly are carefully grounded through conductors using soldered connections.

The product of the capacitance of a body and its potential equals its charge. Therefore, the collection of aerosol particles on the test filter is reflected by a steady change in voltage reading. Thus $dQ/dt = C dv/dt^{**}$, that is, the product of the cylinder voltage change and the capacitance of the system is a measure of the net charge of collected aerosol per unit of time. Appropriate corrections are made for the charge carried by air ions, atmospheric dust and alcohol vapor.

Knowing the aerosol concentration upstream of the filter, as determined by the upstream sampler, it is possible to calculate the weight of methylene blue collected on the filter after correcting for measured filter efficiency.

* General Radio 1612AL R-F Capacitance Meter 0 to 100 μ mf.

** Where Q is in Statcoulombs, C in Statfarads and V in Statvolts.

From these data the ratio of charge to mass in terms of statocoulombs per gram can be calculated. Since the median particle size is known, a reasonably accurate approximation of the average electron charge units per particle can be obtained.

B. Test Results

Two series of runs were made, one with positively charged particles and the other with negatively charged particles. The superficial filtering velocity was 33 feet per minute with a filter resistance of 0.024 inches w.g. Aerosol loading ranged from 0.10 to 0.65 mgs/cubic meter for negative aerosol tests, and 0.19 to 1.7 mgs/cubic meter for positive aerosol tests. Although the filter used for the negative aerosol was a different one from that used with the positive aerosol, the medium, packing density, filtration velocity and resistance were quite similar.

It will be noted that the filter efficiency at zero charge was different for the two filters. This is of little significance since these tests were concerned only with the relative effect of aerosol charge on penetration.

The shape of the Curves in Figures 3 and 4 indicate that the filter efficiency gradually increases with aerosol charge from an initial value at zero charge to a maximum value, remaining constant with increasing aerosol charge. The results are similar in the case of the positive and negative aerosols.

The maximum increase in percent removal due to charge in either case is the same, namely $\left(\frac{72.5-64.5}{64.5}\right) 100 = 12.4\%$ for the negative aerosol, and $\left(\frac{85-75.5}{74.5}\right) 100 = 12.7\%$ for the positive aerosol. Also noteworthy is the fact that, with either polarity, the maximum efficiency is reached at an aerosol charge of about 2×10^5 statcoulombs per gram.

Test results can be explained as follows: The initial or "zero charge"

penetration through the filter is determined by its inherent mechanical filtration efficiency. As filtration time increases, the deposition of charged particles on the filter gradually causes it to become charged. As this filter charge increases, the electric field at the filter surface becomes more intense. Thus, approaching charged particles experience an increasing Coulomb repulsion until the electric field is sufficiently high to retard or repel oncoming particles.

For the purpose of this discussion let us assume that the filter surface represents a uniformly charged infinite plane. This, admittedly is an oversimplification of the field conditions, but nevertheless it is a limiting case⁴. Then; $E = \frac{2\pi\sigma}{k}$ where E = Electric field intensity

σ = electric charge density at filter surface

k = dielectric constant = 1 for air.

Since the repulsive force F_e on an approaching particle with a charge of

Q_p is as follows: $F_e = EQ_p$, then $F_e = \frac{2\pi\sigma Q_p}{k}$ but $\sigma = \frac{\Delta Q \cdot t}{A}$ where ΔQ is the filter charge increment per unit of time. Therefore $F_e = \frac{2\pi\Delta Q \cdot t \cdot Q_p}{Ak}$

This electrical repulsion causes the particles to decelerate. However, as the particles slow down the viscous drag force of the airstream on the particle increases as follows:

$$F_d = 3\pi\eta d \Delta V$$

F_d = drag force.

η = viscosity of air

d = particle diameter

ΔV = velocity of particle relative to the airstream.

Since $F_e = F_d = 3\pi\eta d \Delta V$, $\Delta V(\text{fpm}) = (2.6 \times 10^5) \Delta Q \cdot t \cdot Q_p$

Values of ΔV during filtration of positive aerosols of relatively low and high charge respectively were calculated and plotted in Figure 5. It

will be noted that the repelling effect of the filter, as it gradually becomes charged by virtue of deposited charged particles, is of significant magnitude. This reduction of particle velocity reduces filter penetration since it increases the effectiveness of such removal factors as gravitational, diffusional and electrostatic forces normally operating in mechanical filtration. The repelling effect in the case of the more highly charged aerosol is much more marked.

From a comparison of the slopes of the two curves it may be inferred that at aerosol charge values slightly higher than 2.2×10^5 Statcoulombs per gram the repulsion effect of the filter reaches a maximum. It follows therefore, that beyond this point filter efficiency assumes a constant maximum value. This is in general agreement with experimental results shown in Figure 8 which indicate that percent removal of aerosol reaches a maximum at an aerosol charge of about 2×10^5 Statcoulombs per gram.

The above explanation is based on the assumption that the filter represents a uniformly charged infinite plane. The actual shape and intensity of the electric field at the surface of the test filter is more complex than this. The actual charge density at the filter face is lower than assumed, and therefore the electrostatic effects are less marked. Nevertheless, these figures serve to demonstrate the general character of these effects and how they vary with aerosol charge.

The failure of the filter to attain a removal value closer to 100 percent may be attributed to the fact that the test aerosol was not completely homogeneous in size and not uniformly charged, consequently, there existed particles possessing a charge below the critical value.

III. Effect of Fiber Charge on Filter Penetration

As mentioned previously, the electrostatic mechanism in filtration

involves two components - the particle charge and the fiber charge. The former was discussed above, however, the fiber charge effects may be of equal or greater importance.

The attraction of airborne dust and lint to synthetic fibers and fabrics during textile processing operations suggests the use of these media in aerosol filters. The new synthetic fibers are known to develop and retain high static charges and this aerosol collection ability is related to electrostatic forces.

Before initiating tests to determine the significance of fiber charge on filter performance it was necessary to devise techniques for both producing electrostatically charged fibers and for measuring such charges. The method developed for charge measurement involved the Faraday effect (Figure 6). The Faraday cylinder described previously is connected to a Rawson electrostatic voltmeter in parallel with a calibrated air capacitor as a range extender.

It was observed that by briefly rubbing a sample of certain plastic fibers and dropping it into the Faraday cylinder a substantial deflection on the voltmeter could be obtained. The product of this voltage and the total capacitance of the system is equal to the net charge on the fibers in units of statcoulombs per gram.

Figure 7 shows the results of two tests made with 70 μ Saran fibers. In Test #1 the fibers were hand rubbed, whereas in the second test the charge was generated by rolling the fiber mass in a glass cylinder.

It will be noted that charge decreases exponentially with weight. Plotted on log-log paper, the average slope of these curves is -0.38. Analysis of these data disclosed that these results are in close agreement with the theoretical relationship between mass and the ratio of charge to mass for a sphere having a uniform charge density on its surface. A comparable

plot of this relationship would yield a line with a slope of -0.33 .

These results represent experimental verification of the fact that in charging fibers in this manner, essentially the net charge is distributed on the outer surface of the fiber wad, since tribo-electrification can occur only at the contact surface between the wad and the hand or glass cylinder.

This method of charging therefore was not considered satisfactory as it did not distribute the charge throughout the filter mass. Another technique was devised in which the fibers were electrostatically charged by means of a set of wool hand carders. It was observed that after several strokes of the hand carders Saran fibers became highly charged. The mechanism involved in this method is likewise tribo-electrification. In 2 series of tests, known weights of Saran fibers were hand carded and dropped into the Faraday cage. From the voltage reading and capacitance the fiber charge was calculated. The results are shown in Figure 8. Each point represents an average of 5 measurements.

The significant conclusions to be derived from these results are as follows:

1. The plot of Q/M vs Q is based on 2 series of measurements made on different days. Since the points fall very close to the line it is evident that the procedure is quite reproducible.

2. The values of charge obtained by this method are about 18 times higher than the previous method involving rolling in a glass cylinder, thus demonstrating the greater effectiveness of this technique for charging the fibers.

3. The calculated value of maximum surface charge density on the fibers is 0.8 statcoulombs per cubic meter which compares quite favorably with reported values of about 0.6 encountered in industrial practice, and

2.0 for charging belts of Van de Graaff, electrostatic generators⁵.

In one series of tests the samples were carded with 40 strokes while in the other 20 strokes were used. It was subsequently determined that these high values of fiber charge could be reached after only 3 or 4 strokes of the hand carders. Thus it was concluded that these results represented the limiting charge densities attainable by this technique.

Since this method of charging the fibers is relatively simple, reproducible, and capable of generating satisfactorily high charge levels it was adopted as standard procedure for this phase of our studies.

IV Conclusion

It is planned to construct fiber filters charged in this manner to determine the relationship between charge intensity and aerosol removal efficiency. Also of interest will be the life of such a charge and its variation, if any during operation. From such investigations it is hoped to obtain a better understanding of the electrostatic effects in aerosol filtration.

References

1. Ranz, N. E. and Wong, J. B., "Impaction of Dust and Smoke Particles," Industrial and Engineering Chemistry, Vol. 44, June 1952, p. 1371.
2. Pohl, H. A., "The Motion and Precipitation of Suspensoids in Divergent Electric Fields," Journal of Applied Physics, Vol. 22, July, 1951.
3. Walton, W. H. and Prewett, W. C., "Production of Sprays and Mists of Uniform Drop Size by Means of Spinning Disc Type Sprayers," Proc. Phys. Soc. (London) 62B:341 (1949).

4. Gilbert, N. E., "Electricity and Magnetism", MacMillan Company, New York, 1941.
5. National Bureau of Standards Circular C438, "Static Electricity", Washington, D. C., 1942.

List of Figures

1. Schematic of Test Apparatus
2. Aerosol Charge Measurement Unit
3. Effect of Particle Charge on Filtration - Test Results
4. Effect of Particle Charge on Filtration - Test Results
5. Retardation of Charged Particles during Filtration
6. Apparatus for Measuring Fiber Charge
7. Relation Between Charge/Mass and Mass
8. Relation Between Charge/Mass and Mass

SCHEMATIC OF TEST APPARATUS

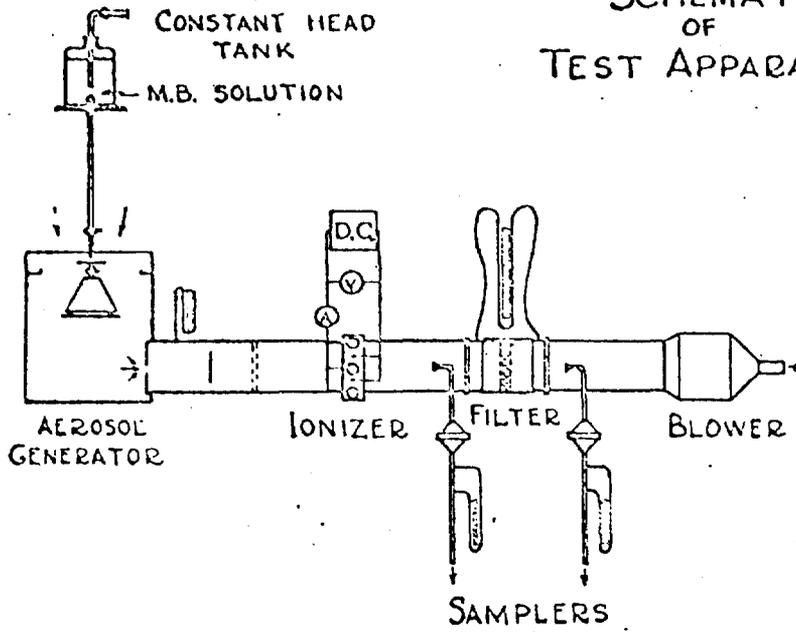
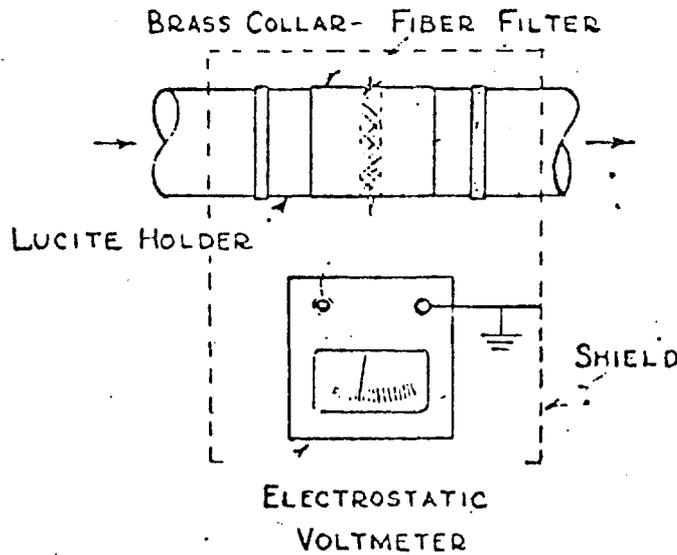


Figure 1. Schematic of Test Apparatus



AEROSOL CHARGE MEASUREMENT UNIT

Figure 2. Aerosol Charge Measurement Unit

EFFECT OF PARTICLE CHARGE ON FILTRATION 50 μ GLASS FIBER FILTER

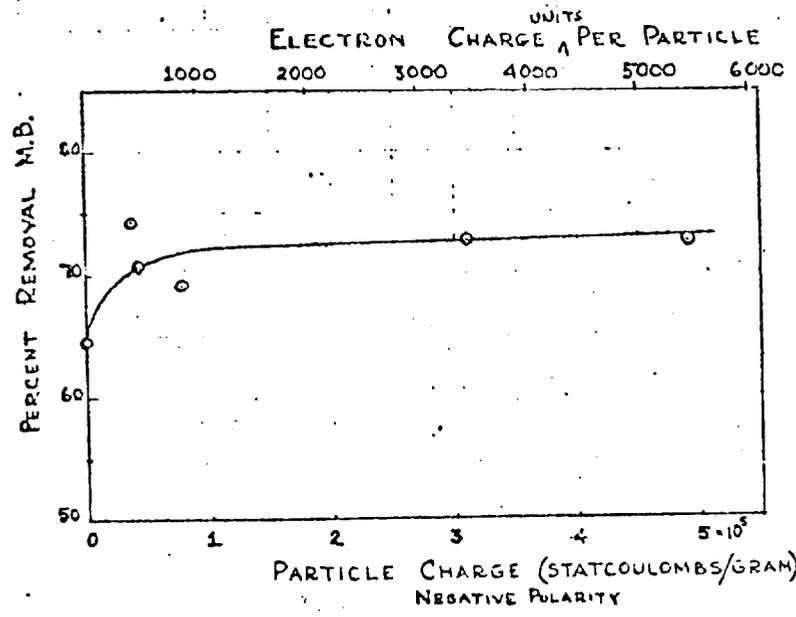
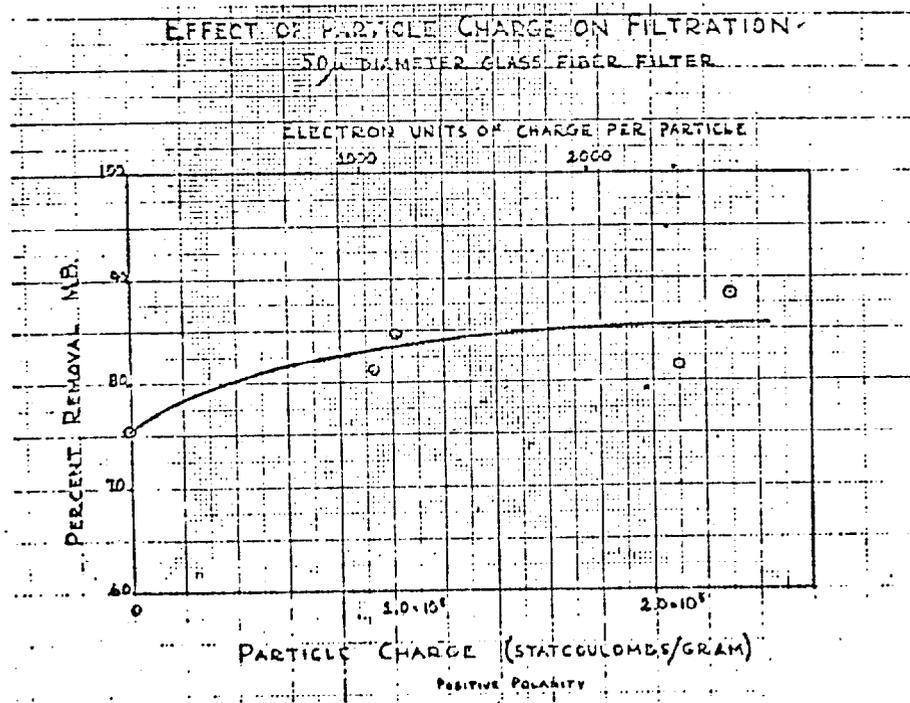


Figure 3. Effect of Particle Charge on Filtration - Test Results



4. Effect of Particle Charge on Filtration - Test Results

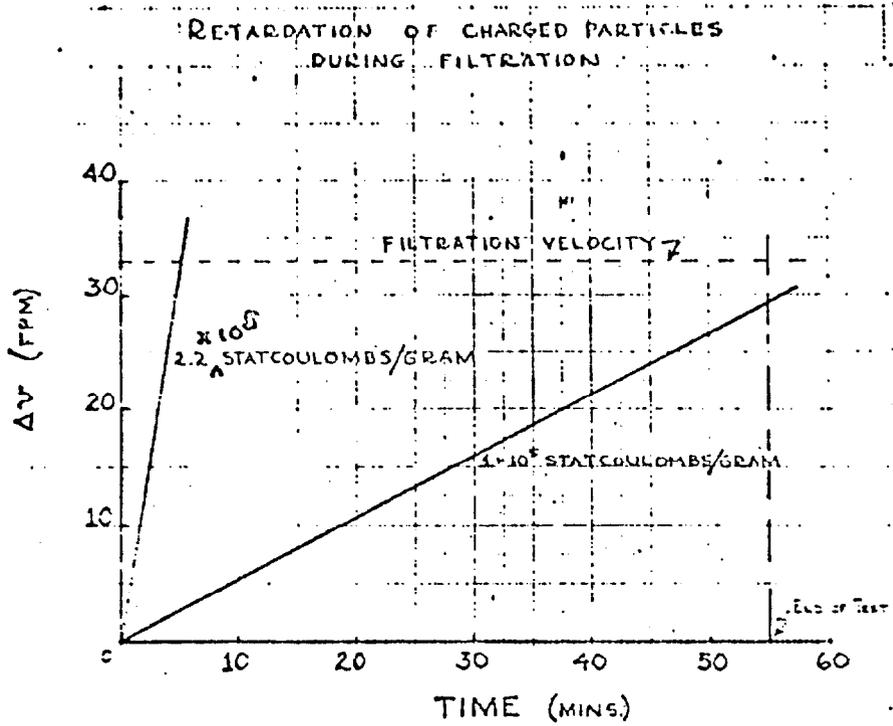


Figure 5. Retardation of Charged Particles during Filtration

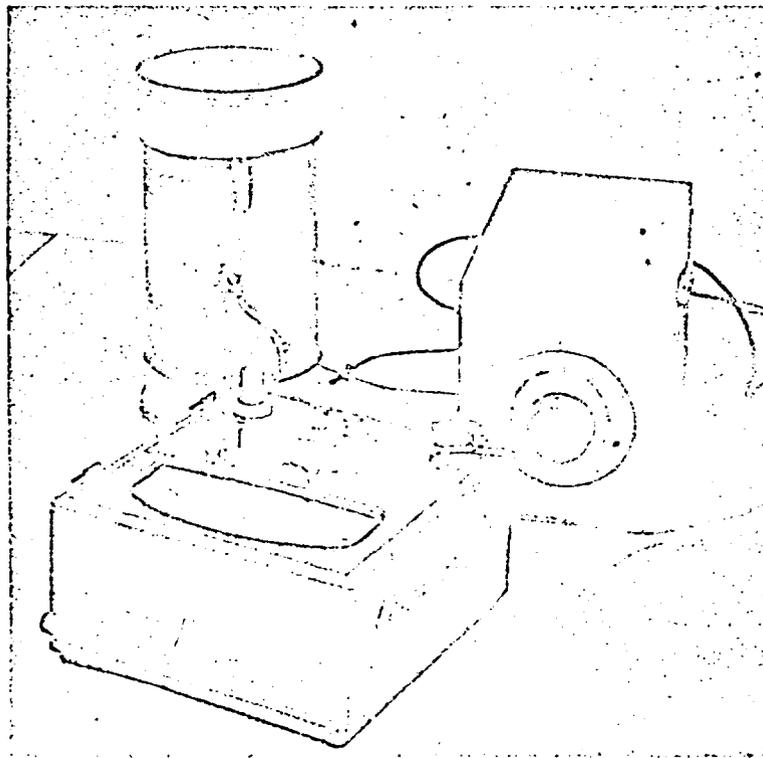


Figure 6. Apparatus for Measuring Fiber Charge

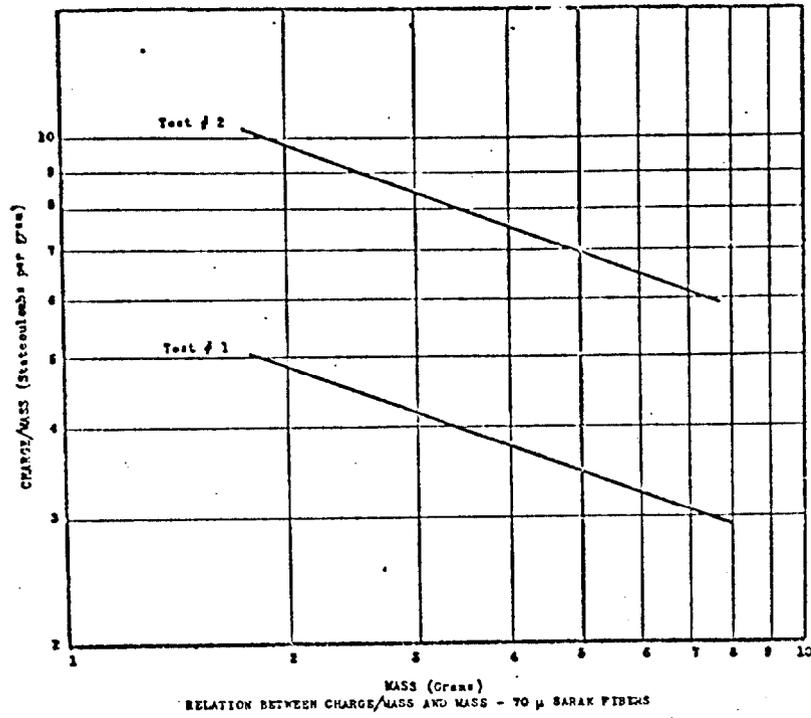


Figure 7. Relation Between Charge/Mass and Mass

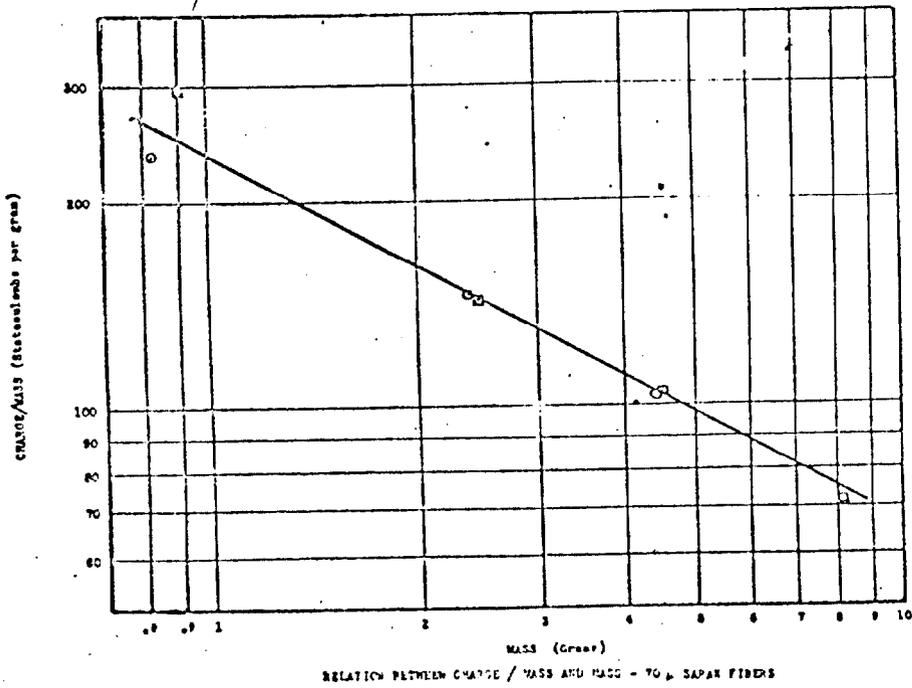


Figure 8. Relation Between Charge/Mass and Mass

FURTHER STUDIES OF FABRIC DUST COLLECTORS

by

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I. Introduction

In conjunction with studies on commercial dust collectors, this laboratory has conducted performance tests on a Simon Suction Filter (Entoleter) furnished by the Safety Car Heating and Lighting Company, Inc., (Entoleter Division). Arrangements for the loan of this device (originally manufactured in Great Britain) were made through the New York Operations Office of the Atomic Energy Commission.

The Entoleter unit is a multicompartiment bag collector employing cyclic automatic rapping (assisted by back-flow air) to keep bag pressure losses within a limited range to insure a nearly constant air handling capacity. The collector was intended primarily for use in the flour milling industry and has a filtration capacity of ten cubic feet per minute per square foot of cloth.

The purpose of tests conducted by this laboratory were to determine performance characteristics of the Entoleter unit on fine aerosols, i.e. talc and fly-ash, 2.5 and 16 microns mass median diameter respectively, when operated at rated capacity (10 cfm/sq.ft.).

Comparison of test data with that obtained from a Hersey reverse-jet

collector operating with similar aerosols and filtration velocities permits better evaluation of the efficiency and pressure loss characteristics of the Entolator unit. No data has been published (except preliminary data in NYO 1586 (3)) on the Entolator collector with dusts whose sizes are in the range 1.0 to 20 microns. The performance of the reverse-jet filter has been discussed in several AEC reports (1,2,3,4) and by Caplan (5,6) and Mason (7).

The results of tests on the Entolator collector do not indicate performance of cyclicly cleaned multicompartment units used industrially at usual low filtration velocities (1 to 3 fpm).

II. Description and Operation

A. Entolator Unit

The Entolator unit tested has four compartments connected on the bottom to a common inlet header and hopper, and on the top by means of individual dampers to a common outlet header. Each compartment contains eight sateen weave cotton bags six feet long and eight inches in diameter (100 sq. ft. of cloth). The bags are attached at the bottom to a manifold plate and at the top to a frame. The manifold and frame are connected rigidly together by rods so that when a section is rapped the bags are lifted and dropped (about 1 1/2 inches) as a unit, thus preventing distortion or collapse of the filter tubes. The dampers at the top of the unit connect to the lifting gear so that when a compartment of bags is rapped, primary air flow to the fan shuts off and the compartment vents to atmosphere permitting a current of back-flow air to assist the rapping in dust removal.

In normal operation dusty air enters the bottom of all tubes, passes up the inside, filters through the cloth, and leaves the compartment

through the damper sections. During its 5.2 minute cycle, each section is simultaneously lifted and dropped in rotation while shut off from the fan and vented to atmosphere. The cleaning operation consists of four such raps with back-flow air. The compartment is replaced in service by shifting the damper automatically to its open position. In the test unit the total air flow to the fan is governed by the number of compartments filtering, and the amount of back-flow air entering when one section is cleaning.

B. Hersey Unit

The reverse-jet air filter consists of a cylinder of wool felt 18 inches in diameter connected to a top inlet plenum and a bottom hopper. Dust deposits on the inside of the cylinder and is blown into the hopper by a reverse-air jet from a slotted ring traversing the outside of the bag. Pressure drop through the bag controls cleaning action by regulating the amount of ring travel. (In many applications the ring runs all of the time). Fabric velocity varied from 10 to 30 cfm/sq.ft. Previous laboratory data reported (3) pressure drops from 1.0 inches water gage to 4.5 inches water gage on 1.0 grain/cu.ft. of fly-ash to 8.7 grains/cu.ft. of talc, respectively. Effluent loadings were in the range 10^{-3} to 10^{-5} grains/cu.ft. It was also reported that the intensity of reverse-jet action and filtration velocity both directly affect the effluent loading.

III. Performance Data

It is possible to compare pressure loss and penetration characteristics of the Entoleter and reverse-jet unit from tests at normal industrial operating conditions (Table I). Loadings range from 0.1 to 1.0 grain/cu.ft. with talc at filtration velocities of 7 and 8 cfm/sq.ft. and from 1.0 to

5.0 grains/cu.ft. with resuspended (Cottrell precipitated) fly-ash at 10 cfm/sq.ft.

A. Pressure Loss

In Table I, several comparisons may be made of pressure loss at constant inlet loading and filtration velocity. For example, in Test 1 the reverse-jet unit has a resistance of 1.6 inches water gage at 0.10 grain/cu.ft. of talc and in Test 2, the Entoleter unit has a resistance of 3.3 inches water gage at the same loading of the same material. The Entoleter resistance is double and the average ratio for all tests is 2.3 (same aerosol at constant loading). Although the reverse-jet unit has a wool felt bag which is higher in clean felt resistance, cleaning by a

TABLE I

Comparisons of Resistance and Effluent Loading
for
Hersey Reverse-Jet and Entoleter Bag Collectors

| Test # | Aerosol | Capacity cfm/sq.ft. | Resistance iwg | Loading - gr./cu.ft. | | Passage % | |
|--------|-----------|------------------------|-------------------|----------------------|--------|------------------------|-------|
| | | | | Inlet | Outlet | | |
| 1 | Hersey* | Talc | 8 | 1.6 | 0.10 | 0.011×10^{-3} | 0.011 |
| 2 | Entoleter | " | 7 | 3.3 | 0.10 | 1.4×10^{-3} | 1.4 |
| 3 | Hersey | " | 8 | 2.5 | 1.00 | 0.27×10^{-3} | 0.027 |
| 4 | Entoleter | " | 7 | 4.7 | 1.00 | 2.1×10^{-3} | 0.21 |
| 5 | Hersey | Fly-ash | 10 | 1.3 | 1.00 | 0.36×10^{-3} | 0.036 |
| 6 | Entoleter | " | 10 | 3.1 | 1.00 | 2.2×10^{-3} | 0.22 |
| 7 | Hersey | " | 10 | 1.6 | 5.00 | 0.80×10^{-3} | 0.016 |
| 8 | Entoleter | " | 10 | 4.6 | 5.00 | 4.2×10^{-3} | 0.084 |

* 100% Blow Ring Operation, Slot Velocity 2000 fpm talc,
4200 fpm fly-ash.

reverse-jet of air results in a lower operating resistance. The cotton sateen used in the Entoleter unit does not get the same degree of cleaning. The reverse flow air in the Entoleter amounts to a maximum of 300 cfm distributed over 100 square feet of cloth, or an average reverse air velocity of 3 fpm. It should be noted that the primary function of the reverse air in this device is to remove the suspended dust dislodged by rapping the bags and to prevent dust leakage to the clean air side of the unit. The reverse-jet operates in the range of 2000 to 4000 fpm over a very small area at any given time, but travels constantly over the whole filter surface.

If the Entoleter collector were operated at 3 cfm/sq.ft. as in usual bag filters, instead of 7 or 10, the resistance would be 2 to 3 times lower. For a given exhaust air volume this would require more collector area, but it would not require cleaning the bags as frequently to maintain a specified resistance.

In evaluating these collectors (both at maximum cleaning capacity) it may be noted that the reverse jet resistances are based on 100 percent blow ring operation. The Entoleter cleaning mechanism, however, operates only .40 minutes per section in 5.2 minutes total cycle and corresponds to 30 percent $\left(\frac{4 \times .40}{5.2} \times 100\right)$ operation. From NYO 1586, p. 26, Fig. 8, it is possible to estimate the additional resistance that would be required to operate the reverse-jet cleaning mechanism at 30 percent. This increase will be 25 percent if the 100 percent blow ring operation resistance is 5.0 inches water gage. With lower resistances as indicated in Tests 1, 3, 5, and 7 the increase is probably higher (up to as much as 50 to 75 percent for low resistances of 1.5 to 2.0 inches water gage). This will not cause the reverse-jet resistance to exceed that of the Entoleter, but will put them much closer together.

All resistances are expressed as averages. Some indications of the range associated with the average are included below. In test number 8 the Entoleter resistance is listed at 4.6 inches water gage. The average resistance or pressure drops across the four sections were respectively 4.2, 4.4, 4.7 and 5.0 inches water gage. Just before shaking Unit IV (highest) the value was 5.3; immediately after shaking the value dropped to 4.8 inches water gage. The average listed is the average of the four units (at equilibrium), each unit at its average operating resistance. In test number 7 the reverse-jet resistance is listed as 1.6 inches water gage. The variation in resistance during one cycle of the blow ring is from 1.6 (downstroke) to 1.7 inches water gage (upstroke).

B. Penetration

The amount of dust leaving the collector per unit air volume is also seen to be lower in the reverse-jet collector. The Entoleter (Test 1) effluent loading at .10 grain/cu. ft. inlet loading of talc is seen to be 1.4 grains/1000 cu. ft. of air, compared to 0.011 grains/1000 cu. ft. for the reverse-jet (Test 2) at the same inlet loading. The effluent loading from the Entoleter is 130 times higher. In tests 7 and 8 (5.0 grains/cu. ft. fly-ash) the Entoleter is only 5 times higher in effluent. On the basis of all the tests shown the Entoleter effluent exceeds the Hersey by a factor of greater than 5 when the inlet loading is less than 5.0 grains/cu. ft. At an average industrial loading of 1.0 grain/cu. ft. the factor is about 7 for both test dusts.

In filtration through porous materials the deposited surface dust cake is the principal filtering mechanism (8). In the reverse-jet unit this cake is dislodged at only a small area and the incoming dust can re-deposit immediately in this more porous area. (Some question exists as to how much

of the deposited cake is removed). With the removal of large amounts of the surface cake in the Entolator unit more time is required to create a layer over the larger cleaned area and penetration is higher. This would be particularly true under light loading conditions when insufficient material enters to "bridge" the spaces between fibers. With larger aerosol particles ($>50 - 60 \mu$) the differences between these collectors may become less marked.

C. Evaluation of Different Bag Materials in the Entolator Unit

As explained above in Section II, the Entolator unit shakes the filter bags without appreciable distortion in conjunction with 100 to 300 cfm of back flow air, so that it is possible to use bags of materials other than cotton sateen with lower tensile strength, higher heat resistance, etc. The following table gives comparative data for cotton sateen, wool felt (light and heavy), Orlon (woven) and glass (woven, lubricated with silicone). These are compared for light loadings of atmospheric dust (0.5μ) and copper sulfate (1μ) without shaking, to get basic performance data. They are then compared with talc and resuspended fly-ash at an average loading of 1.0 grain per cubic foot to get an indication of actual industrial performance while cleaning ^{on} the standard cycle.

The approximate order of these fabrics for light loadings with no shaking, from highest efficiency is: glass, heavy wool, cotton, Orlon, and light wool. It can be seen that the higher efficiencies are associated with higher resistances. The use of heavy loadings changes the order slightly, from lowest penetration: glass, heavy wool, light wool, cotton and Orlon. A consideration of the smoothness of fiber, and weave (or felt) pore size, will tend to confirm the second list above, since the degree of deposited cake filtration depends on the character of the medium upon which the cake

TABLE II

Comparisons of Efficiency of Filter Media

| A. Atmospheric Dust at 10 cfm/sq.ft. | | | |
|--------------------------------------|---------------------------|----------------------------|------------------------|
| Fabric | Average Resistance iwg | Inlet Loading gr/cu.ft. | Weight Efficiency % |
| Light Wool | 0.07 | 0.10×10^{-3} | 75 |
| Orlon | 0.10 | 0.13×10^{-3} | 60 |
| Cotton | 0.29 | 0.15×10^{-3} | 81 |
| Heavy Wool | 0.34 | 0.22×10^{-3} | 85 |
| Glass | 0.56 | 0.058×10^{-3} | 82 |
| B. Copper Sulfate at 10 cfm/sq.ft. | | | |
| Light Wool | | 0.89×10^{-3} | 41 |
| Orlon | | 0.81×10^{-3} | 46 |
| Cotton | | 1.0×10^{-3} | 64 |
| Heavy Wool | | 1.0×10^{-3} | 71 |
| Glass | | 0.90×10^{-3} | 81 |
| C. Tale at 5 cfm/sq.ft. | | | |
| | | | Passage % |
| Light Wool | 5.0 | 1.0 | 0.074 |
| Orlon | 5.5 | " | 0.033 |
| Cotton | 5.5 | " | 0.099 |
| Heavy Wool | 5.6 | " | 0.034 |
| Glass | 5.9 | " | 0.0063 |
| D. Fly-ash at 10 cfm/sq.ft. | | | |
| Light Wool | 2.6 | 1.0 | 0.026 |
| Orlon | 2.4 | " | 0.56 |
| Cotton | 3.0 | " | 0.14 |
| Heavy Wool | 2.7 | " | 0.030 |
| Glass | 4.7 | " | 0.012 |

TABLE III

Fabric Comparisons
with
200 gr./sq.ft. of Asbestos Floats, at 10 cfm/sq.ft.

| Material | Initial Resistance iwg | Final Resistance iwg | Passage % |
|------------|------------------------------|----------------------------|--------------|
| Orlon | 0.16 | 0.95 | 1.4 |
| Cotton | 0.36 | 1.4 | 1.1 |
| Heavy Wool | 0.36 | 0.90 | 0.72 |
| Glass | 0.81 | 2.2 | 0.40 |

is deposited, as indicated above (8) as well as the cake itself.

As stated before (NYO 1586, p. 47) the use of the above fabrics for low loadings (<0.001 gr./cu.ft.) of radioactive particulates would require many hundreds of hours of operation before filter efficiency increased to 90 percent or greater. Therefore, the above bags have been treated with asbestos floats as a filter aid and the efficiency again compared on copper sulfate. These data are given in Table III for a total of 200 grains of asbestos per square foot of filter surface. The bags were not shaken during the testing. The same order of rating of fabric is obtained as was found in Table II for the basic efficiency on copper sulfate. (The final resistance is not a direct measure of performance).

The use of asbestos "floats" and glass or Orlon bags can substantially increase the operating temperature limit for filtration of light aerosol loadings in the Entoleter collector.

IV. Conclusions

A comparison of the Entolator collector with the reverse-jet filter at equal filtration velocities, dust loadings and with maximum cleaning capacity shows (Table I) that Entolator penetration and resistance are on the average of 7.1 and 2.3 times higher, respectively. These data are based upon "standard" fabrics supplied for each unit; cotton for the Entolator and wool felt for the reverse-jet unit.

With wool felt in both collectors, penetrations are found to be about equal for each aerosol tested. Resistances of the Entolator, however, were found to be twice as high with fly-ash and 3.5 times higher with talc, as those of the reverse-jet filter.

The wool felt is concluded to be a better filter fabric than cotton sateen, at the same filtration velocity and the reverse-jet is found to be a superior method of cleaning wool felt.

The Entolator unit offers the possibility of a wide choice of filter fabrics for special applications, chiefly synthetic fibers for corrosive problems, and glass fibers for higher temperature applications, subject to field service life tests not possible to accomplish in the laboratory.

BIBLIOGRAPHY

1. Arthur D. Little, Inc., "Investigation of Stack Gas Filtering Requirements and Development of Suitable Filters. Report #7", Cambridge, Massachusetts, 1949.
2. First, M. W., Silverman, L., et al, "Air Cleaning Studies," U. S. A. E. C. Report No. NYO 1581, Harvard School of Public Health, 1952.
3. First, M. W., Silverman, L., et al, "Air Cleaning Studies," U. S. A. E. C. Report No. NYO 1586, Harvard School of Public Health, 1953.

4. Friedlander, S. F., Silverman, L., Drinkor, P., and First, M. W., "Handbook on Air Cleaning," Washington, D. C., U.S.A.E.C., 1952.
5. Caplan, K. J., "High Efficiency Collection of Radioactive Dust", Heating and Ventilating, 48:79 (1951).
6. Caplan, K. J. and Mason, M., "Second Air Cleaning Seminar for A.E.C. Personnel", Iowa State College, Ames, Iowa, Sept. 15-17, 1952.
7. Mason, M., "Third Air Cleaning Seminar for AEC Personnel", Los Alamos National Laboratory, Los Alamos, New Mexico, Sept. 21-23, 1953.
8. Silverman, L., "Performance of Industrial Aerosol Filters", Chem. Eng. Prog., 47:462, 1951.

PERFORMANCE CHARACTERISTICS OF THE MODEL K ELECTRO-POLAR FILTER

Preliminary Report

by

Richard Dennis, Charles E. Billings and Leslie Silverman, Harvard

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In this paper the results of preliminary performance tests are presented for the "Electro-polar Filter", an experimental dust collector developed by the Western Precipitation Corporation. The objectives of the field and laboratory testing program on commercial dust collectors have been covered in a previous report by our laboratory (1). Those studies are intended to determine collector performance in accordance with applications suggested by the manufacturer and also to investigate new applications by means of minor operating or design changes. The proper evaluation of these data serve as a guide to the Atomic Energy Commission and its contractors in the selection and application of commercially available dust collection apparatus.

The Electro-polar Filter now under test was developed by the manufacturer's research department and would probably be subject to design changes prior to marketing. AEC representatives, contacted by the Western Precipitation Corporation considered it advisable to have the unit tested by the Air Cleaning Laboratory so that its practicability as an air cleaner for low dust load systems could be determined. Since the Electro-polar Filter is an experimental model there is little background data with which to compare its performance. However, the unit employs PF 105 or PF 316 Fiberglas media as the primary filtration elements. These pads have a basic weight collection efficiency of approximately 70 to 80 per cent against atmospheric dust and are suitable only for low dust concentrations.

By placing the filter pads within a strong electric field, electrostatic forces are expected to supplement the usual filtration mechanisms (impaction, interception and diffusion) thus improving the performance of the unit.

Description of Electro-polar Filter - Model K

The Electro-polar Filter consists essentially of a dielectric filter medium of fine glass fibers placed in an electric field. Filter media employed are PF 316 mats or one to two layers of PF 105. The fiber code designation is that of the Fiberglas Corporation. PF 316 is a three micron diameter resin coated glass fiber supplied in 1 inch thick bats at a packing density of 1 lb./ft.³. PF 105 is a one micron diameter resin coated fiber supplied in 1/2 inch bats at a packing density of 0.6 lbs./ft.³. The electric field is furnished by placing the fiberglas mat between two vertically aligned metal screens. The upstream screen is insulated and maintained at a positive potential of 15 kilovolts; the downstream screen, 1 inch removed, is grounded to the unit. Screen construction consists of a stamped diamond shaped grating with a free area of approximately 80 percent. Total filtration area comprises five identical screen sections (20 inch x 60 inch) arranged in a row and all insulated from each other. The entire screen section (total area = 41.5 square feet) is aligned diagonally in a rectangular housing having overall dimensions of 2.5 x 8 x 5.5 feet. This permits a gradual reduction in cross section of the entry plenum so that better air flow distribution may be obtained.

The high voltage supply is furnished by a power pack with a rated output ranging from 11 to 17 kilovolts. Three hundred microamperes are available at 17 Kv. and at currents exceeding 750 μ a (resulting from shorting or arcing) a safety control relay turns off the power.

The power pack is enclosed in a 16 x 16 x 9 inch box which occupies one corner of the collector housing. To reduce excessive dust loadings and prevent screen shorting by gross contaminants "Dustop" roughing filters (in a bank of 3) are located at the inlet to the collector.

Rated Operating Conditions

The Electro-polar Filter is designed to operate at 3500 cfm with a 1 inch layer of PF 316, 2900 cfm with a 1/2 inch layer of PF 105 and 1700 cfm with two, 1/2 inch layers of PF 105. The manufacturer recommends that filters be replaced when pressure losses reach 2 inches of water although fan capacity or exhaust requirements may modify this figure. Recommended screen potential is 15 Kv. Arcing between grounded and high voltage screens may occur as a result of high points or sharp edges on the screen surfaces. The high current accompanying arcing will automatically activate the overload control switch and turn off the power supply. In some instances of arcing a sizable hole may be burnt in the filter which will require patching.

Theory of Operation

It is evident that the glass fiber media employed in the Electro-polar Filter are reasonably good filters for atmospheric dust without superimposed electrostatic effects. Preliminary tests indicate weight collection efficiencies ranging from 70 to 90 percent against atmospheric dust at a filtration velocity of 85 fpm (PF 316 media). Previous tests (1) have also shown that similar fiberglas media (PF 105 and PF 314) operate in the same general efficiency range.

Electrostatic charge measurements upon PF 105 media have indicated potentials of 700 volts resulting from handling alone. High static charges

may be produced through carding as illustrated by the resin-wool filter (2). This information indicates that electrostatic separating forces come into play in fiber collectors regardless of externally applied electrical fields and in addition to usual collecting mechanisms (impaction, interception and diffusion).

By intensifying the electrostatic effects through placing the fiberglass media within an electrical field the manufacturer has sought to improve the overall dust removal characteristics.

The presence of dielectric fibers within an electrical field produces divergencies in field intensity such that the regions of highest field strength are concentrated about the fibers. Dust particles, which become polarized by passing through the electrical field, migrate toward the regions of highest field intensity. It should be noted that the particle motion is always toward the zone of higher field strength regardless of field direction. Higher dust concentrations in the immediate vicinity of the fibers cause increased agglomeration and enhance the probability of capture by inertial mechanisms.

Although mathematical formulas have been presented by Pohl (3) to quantitate the precipitation of solids from liquids in a highly divergent field, no simple relationships can be advanced at the present time to deal with particulate deposition in fiber beds. Pohl describes a system consisting of a single, positively charged central electrode and a concentric cylindrical negative electrode, used to precipitate a graphite-toluene sol. In this case, it is possible to evaluate the field strength at any point as a function of the potential gradient and the electrode dimensions. Equating viscous forces to electrostatic forces permits estimation of particle migration velocities.

In a general equation migration velocity (v) may be expressed as a function of the difference between the dielectric constant of the fluid and particulate components ($k_1 - k_2$), particle radius (a), fluid viscosity (η), absolute value of the field strength (E) and its divergence ($\partial E/\partial r$).

$$v = (k_1 - k_2) a^2 \frac{\partial (E)^2}{\partial r} / 36 \pi \eta \quad (I)$$

Since no data are available to define field divergencies in randomly oriented fiber beds, varying in surface characteristics and having non-uniform resinous coatings, the above equation has only a qualitative significance as far as the Electro-polar Filter is concerned. It should be noted also that in dealing with a dynamic system it would be necessary to combine vectorially the inertial and electrostatic forces. In practical application, Equation I suggests that increased particle size and field potential should improve the collection efficiency of the Electro-polar Filter. For particle diameters > 5 microns, however, electrostatic forces are insignificant in comparison with the inertial effects. Similarly, it appears that variation in filtration velocity would effect collection efficiency only through inertial or diffusional mechanisms.

Test Procedure

Inlet and outlet atmospheric dust loadings were determined gravimetrically with high volume samplers and pleated filters (4). Stain efficiency measurements were made with a film badge densitometer on Whatman No. 41 filter discs and count efficiencies were determined with a Bausch and Lomb dust counter.

Copper sulfate loadings were sampled with AC electrostatic precipitators and the concentrations determined by chemical analysis. The method of

generating copper sulfate microspheres and complete details on all sampling methods have been described in previous NYO reports (1, 5).

Test Results

Preliminary tests on the Electro-polar Filter were designed to determine if the use of an electrical field significantly improved the basic performance of the PF 316 fiber media. As shown in Table I, tests 1 and 3 with atmospheric dust and tests 5, 6, 8 and 9 with copper sulfate indicate average efficiency increases of 15 and 11 percent, respectively, when rated screen voltage (15 Kv) was applied. Filter plugging, however, illustrated by slightly higher pressure losses in tests 2 and 7, indicates a gradual improvement in basic fiber efficiency. Table III compares overall collection efficiency as obtained by simultaneous weight, stain and count methods for operations at no voltage and 15 Kv.

A breakdown of weight collection efficiency appears in Table I since the "Dustop" performance is not governed by the electrical field. Overall unit efficiency, therefore, shows a smaller increase (approximately 8 percent) with application of screen voltage. At lower screen voltages (11 Kv) a very slight decrease in efficiency was observed for copper sulfate (test 10).

Filtration velocities ranging from 36 to 85 fpm and screen voltages varying from 11 to 18 Kv showed no significant efficiency changes with atmospheric dust (Table II) according to stain measurements. However, it is expected that additional tests with a copper sulfate aerosol will permit better correlation of these variables. Changes in concentration and particle size distribution of atmospheric dust were partly responsible for inconsistencies in the data.

Humid air also was observed to reduce collection efficiency although the measurements were qualitative.

In order to eliminate the effect of changing bed characteristics due to retention of copper sulfate, tests 5, 6, 8, 9 and 10 were run with alternate screen sections blocked off. Air flow was reduced proportionately to maintain constant velocity (85 fpm) through the PF 316 media. Since the Dustop filter area was not changed, the velocity through this section of the unit varied with total air flow (Table I). Weight collection efficiencies for Dustop filters were a direct function of velocity indicating that inertial separation was the primary collecting mechanism.

Discussion of Tests

Test data indicate that the use of an electrical field increases the overall weight collection efficiency of the Electro-polar Filter by about 8 percent with atmospheric dust and copper sulfate microspheres. It appears that the overall advantage of the electrical field will decrease with filter usage since the efficiency of fiber beds increases with plugging. Preliminary tests indicate this trend even though pressure losses are still below the rated value of 2 inches of water.

No data has yet been obtained for PF 105 media which, because of its small diameter (1 micron), should be a more effective filter.

Final comment regarding the utility of the Electro-polar Filter as a high efficiency cleaner for low dust concentrations is withheld pending completion of tests.

TABLE I
Effect of Screen Voltage on Collection Efficiency of Electro-Polar Filter
with Rated Velocity (85 fpm) through PF 316 Media

| Test | Inlet Loading Grains/1000 ft. ³ | Screen Voltage Kv | Pressure Loss PF 316 Media Inches water | Filtration Velocity through Dustop fpm | Weight Collection Efficiency % | |
|-----------------------------------------|-----------------------------------------------|-------------------------|-----------------------------------------------|-------------------------------------------------|-----------------------------------|----------------|
| | | | | | Dustop | PF 316 Overall |
| a. Atmospheric Dust* | | | | | | |
| 1 | 0.118 | 0 | 1.07 | 420 | 52 | 91.6 |
| 2 | 0.036 | 0 | 1.16 | 420 | 52 | 94.0 |
| 3 | 0.179 | 15 | 1.07 | 420 | 52 | 98.6 |
| 4 | 0.097 | 15 | 1.13 | 420 | -- | 96.2 |
| b. Copper Sulfate Microspheres** | | | | | | |
| 5 | 0.306 | 0 | 1.24 | 168 | 30.7 | 90.2 |
| 6 | 0.281 | 0 | 1.24 | 168 | 17.0 | 89.5 |
| 7 | 0.206 | 0 | 1.27 | 420 | 46.0 | 94.6 |
| 8 | 0.216 | 15 | 1.22 | 252 | 34.8 | 93.3 |
| 9 | 0.185 | 15 | 1.26 | 252 | 34.8 | 93.4 |
| 10 | 0.187 | 11 | 1.30 | 252 | 34.8 | 97.2 |

* Mass Median = 1.0 microns, Geometric Standard Deviation 1.6.

** Mass Median = 1.2 microns, Geometric Standard Deviation 1.7.

TABLE II

Effect of Voltage and Velocity Variations on Stain Efficiency Tests with Atmospheric Dust

| Test | Inlet Loading Grains/1000 ft. ³ | Screen Voltage Kv | Filtration Velocity fpm | Overall Stain Efficiency % |
|------|-----------------------------------------------|-------------------------|-------------------------------|----------------------------------|
| 11 | 0.087 | 11 | 85 | 98 |
| 4 | 0.098 | 15 | 85 | 95 |
| 12 | 0.125 | 18 | 85 | 98 |
| 11 | 0.087 | 11 | 85 | 98 |
| 13 | 0.123 | 11 | 61 | 98 |
| 14 | 0.208 | 11 | 36 | 98 |

TABLE III

Effect of Screen Voltage on Simultaneous Weight, Stain and Count Efficiencies for Atmospheric Dust at Rated Capacity (3500 cfm)

| Test | Screen Voltage Kv | Overall Collection Efficiency % | | |
|------|----------------------|------------------------------------|-------|-------|
| | | Weight | Stain | Count |
| 1 | 0 | 92 | 80 | 54 |
| 3 | 15 | 98 | 95 | 80 |

SUMMARY

Results of preliminary performance tests are presented for the Electro-polar Filter, a dust collector developed by the Western Precipitation Corporation for high efficiency removal of particulates. Separation is achieved through a combination of the mechanical filtration properties of PF 316 or PF 105 fiberglas and electrostatic effects produced by locating

the fibers within an electrical field (created by two metal screens, one maintained at 15 Kv potential and the other grounded). Theory of operation is based upon migration of polarized dust particles to the regions of high field intensity surrounding the glass fibers.

Test results on clean fibers indicate that application of rated screen voltage (15 Kv) increases overall collection efficiency of atmospheric dust and copper sulfate microspheres by about 8 percent. Filter plugging, however, results in higher base efficiency for the fiber which tends to lessen the advantage of the electrical field.

Current tests include a study of the effect of voltage and velocity variations on collection efficiency. Final evaluation of collector utility is withheld pending analysis of all test data.

LITERATURE CITED

- (1) First, M. W., Silverman, L., et al "Air Cleaning Studies, Progress Report, Feb. 1, 1951 to June 30, 1952". AEC Contract No. AT-30-1-841, USAEC, NYO 1586, Harvard University (Dec. 16, 1952).
- (2) Rodebush, W. H., "Handbook on Aerosols" Chapter 9, Washington, D.C., U. S. Atomic Energy Commission (1950).
- (3) Pohl, H. A., "The Motion and Precipitation of Suspensoids in Divergent Electric Fields", Jour. of App. Phys., 22, 869-871 (1951).
- (4) Silverman, L. and Viles, F. J., Jr., "A High Volume Air Sampling and Filter Weighing Method for Certain Aerosols". Jour. Ind. Hyg. and Tox., 30, 124 (1949).
- (5) Silverman, L., First, M. W., et al "Final Progress Report", AEC Contract No. AT-30-1-841, USAEC, NYO 1527, Harvard University (Feb. 1950).

PRELIMINARY REPORT
on
COTTON AEROSOL FILTER STUDIES

by

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I. Introduction

The discharge of several materials to the atmosphere can create public health problems. Consequently, the further development of satisfactory low cost air cleaning devices may play a part in health protection by encouraging the use and installation of air cleaning facilities. The use of cotton fibers as filter media has prospects for economy because cotton has a relatively low initial cost, has low ash (less than 0.1% (1)) for economical disposal and is readily available.

During the past year, studies have been conducted at the Harvard University Air Cleaning Laboratory on the filtration characteristics of various cotton fibers for atmospheric dusts. Four natural fibers and two ion exchange coatings were investigated.

In conjunction with the basic cotton work a parallel study was conducted on the correlation of weight, stain, and count efficiencies for atmospheric dust. If an empirical relationship can be developed using atmospheric loadings, considerable time can be saved in obtaining an index of count and weight efficiencies from a simple stain technique.

In an attempt to reduce the weight efficiency variation caused by a few large particles a prefilter was used. This introduced a third phase of the

study which had as its goal the evaluation of the profilter as a means of obtaining a relatively consistent aerosol for filter rating.

II. Equipment

Figure 1 is a schematic diagram of the test setup. The profilter had a face area of 0.143 square feet and consisted of 10 layers of Metox mist eliminator screen coated with SAE 30 motor oil.

The napped cloth was used to interlace with the test medium to minimize edge leakage.

Fiber Description

A cotton fiber has been described as an epidermal cell of the seed. It consists of an outer wall, secondary wall and a lumen. With growth, the secondary wall thickness increases until the lumen is nearly closed. With the drying that occurs after picking, the lumen collapses and for mature fibers a kidney or elliptical shape is attained. In immature fibers the secondary wall is thin and upon collapse of the lumen the fiber attains a twisted ribbon or U-shape. Matthews (2) indicates that wall thickness may vary from 0.35 to 15 μ and ribbon widths from 11 to 20 μ .

The fibers tested in this series were sized by Roasano (3). The mean diameters presented in Table I are the geometric means of single transverse measurements of over 200 fibers for each grade.

The Lockett sample contained about 93% mature fibers and the Memphis immature about 38% mature fibers.

The ion exchange treatments which were tested had been applied to S x P fibers by the U. S. Department of Agriculture. The resin treatment was impregnation by Rosiloom HP, an unmethylated methylolmelamine resin which has found use in ion exchange columns. The aminized cotton had been treated with

2-aminoethylsulfuric acid and sodium hydroxide. Aminized cotton has anion exchange properties and the treatment facilitates the use of acid dyes.

Test Procedure

A. Bed Preparation

The fibers tested had been furnished by the U. S. Department of Agriculture, Bureau of Agricultural and Industrial Chemistry, New Orleans, Louisiana. They were received as card slivers and difficulty was experienced in obtaining reproducibility. The fibers were carded again and taken off as card web which was folded into boxes for storage. Compaction in storage made most of the individual layers of the web indistinguishable. The layers were separated by hand as well as possible and cut into six inch squares. The weight necessary to give a packing density of 2 lbs. per cubic foot (porosity 0.98) was computed (cotton specific gravity 1.59). Depending upon the type of fiber and the degree of compaction, five to ten layers were required per inch of final pad. These layers were loosely placed in the plastic box and compressed to the desired bed depth by insertion of the inside section. With this technique packing densities could be satisfactorily reproduced.

B. Operation of Test Apparatus

The combined operation of the upstream and downstream high volume samplers brought room air into the plenum through the prefilter at 50 cfm (face velocity of 350 fpm). One-half of this flow went to the upstream high volume sampler and the other half went through the test section to the downstream high volume sampler.

Stairmand discs were used as orifice meters to determine the respective flow rates. The 25 cfm rate through the test section gave a face velocity at the test pad of 100 fpm. Continuous operation of from 48 to 80 hours on Boston

air was required to produce significant increase in the weight of the downstream sampling filters.

C. Sampling

Samples were taken at three points; 1. Room air (upstream of prefilter), 2. Upstream (downstream of prefilter, upstream of cotton pad), 3. Downstream (downstream of cotton pad).

Weight loading was determined at these three points by determining the net weight increase of type S pleated filters. The room air sample was collected at full flow of the high volume sampler which varied from 70 cfm to 40 cfm. Both upstream and downstream samples were taken at 25 cfm with the entire volume passing through the test pad collected for the downstream sample.

After from 10 to 20 hours of operation, and again 24 to 48 hours later, membrane filter samples were taken at 0.7 cfm for count loading and stain efficiency determinations. The room air membrane filter sample was taken near the prefilter and the upstream and downstream samples were taken through probes in the test section. These samples were taken for 45 to 120 minutes, depending on the rate of stain buildup. At intervals of 15 to 20 minutes the stain density of each membrane filter was determined by use of a Photovolt, Model 200A transmission densitometer.

A blank for zeroing the densitometer on each membrane filter was obtained by backing each filter with Whatman #1 paper to which a 5/8" circle of cellophane tape was attached. With this backing, the stain was deposited in an annular pattern and the center portion of the filter remained clean.

D. Analysis

The stain readings were plotted against time for each filter and the time to reach a constant stain was determined from each curve. The stain efficiencies were then determined from the relationship

$$\% \text{ Efficiency} = \left(1 - \frac{t_1}{t_2} \right) \times 100$$

The membrane filter stains were then counted and sized microscopically under oil immersion (90X objective and 25X eyepiece) to determine the count loading and size distribution at each sampling point. Total efficiency, by count, and size fraction efficiencies were determined from these loadings.

Test Results

Analysis of the data has not been completed, but a summary of weight, stain and count efficiencies is presented in Table I for the various fibers tested. These efficiencies are tabulated in order of decreasing weight efficiency.

The pressure drops listed in Table I are the final drops observed in the respective tests. These values represent no appreciable increase over the drop in the clean beds for the shorter operating periods (48 to 60 hours). For resin treated S X P and Memphis Immature beds there were 7 and 11 percent

TABLE I

Efficiencies of 2" Pads of Various Cotton Fibers on Atmospheric Dust
Packing Density 2#/ft³
Face Velocity 100 fpm

| Cotton | Mean Fiber Diameter μ | Weight Efficiency % | Stain Efficiency % | Count Efficiency % | Pressure Loss Inches of Water |
|---------------------|--------------------------|------------------------|-----------------------|-----------------------|----------------------------------|
| Memphis Immature | 10.0 | 82.5 | 78.8 | 63.5 | 5.8 |
| Aminized S x P | 10.0 | 80.5 | | 57 | 3.0 |
| Untreated S x P | 9.4 | 77 | 72.7 | 58.5 | 4.0 |
| Resin Treated S x P | 10.3 | 74.8 | 72.5 | 61 | 3.6 |
| Lockett 140 | 13.4 | 71.3 | 46 | 39 | 2.1 |
| Iquitos | 15.5 | 67 | 46 | | 1.6 |

To date, the only variables studied have been type of fiber and bed depth. Further studies are planned to test the fiber at different packing densities and face velocities. It is planned to delay further cotton studies until the present data on relationships of weight-stain and count-stain efficiencies are more completely analyzed and the value of the prefilter is established. Using the present techniques, about 5 days are required for each run in order to collect weighable samples and count and size the 6 molecular filters. From a preliminary inspection of the weight-stain relationship it appears that empirical relationships might be derived which will reduce the time from days to hours for each run.

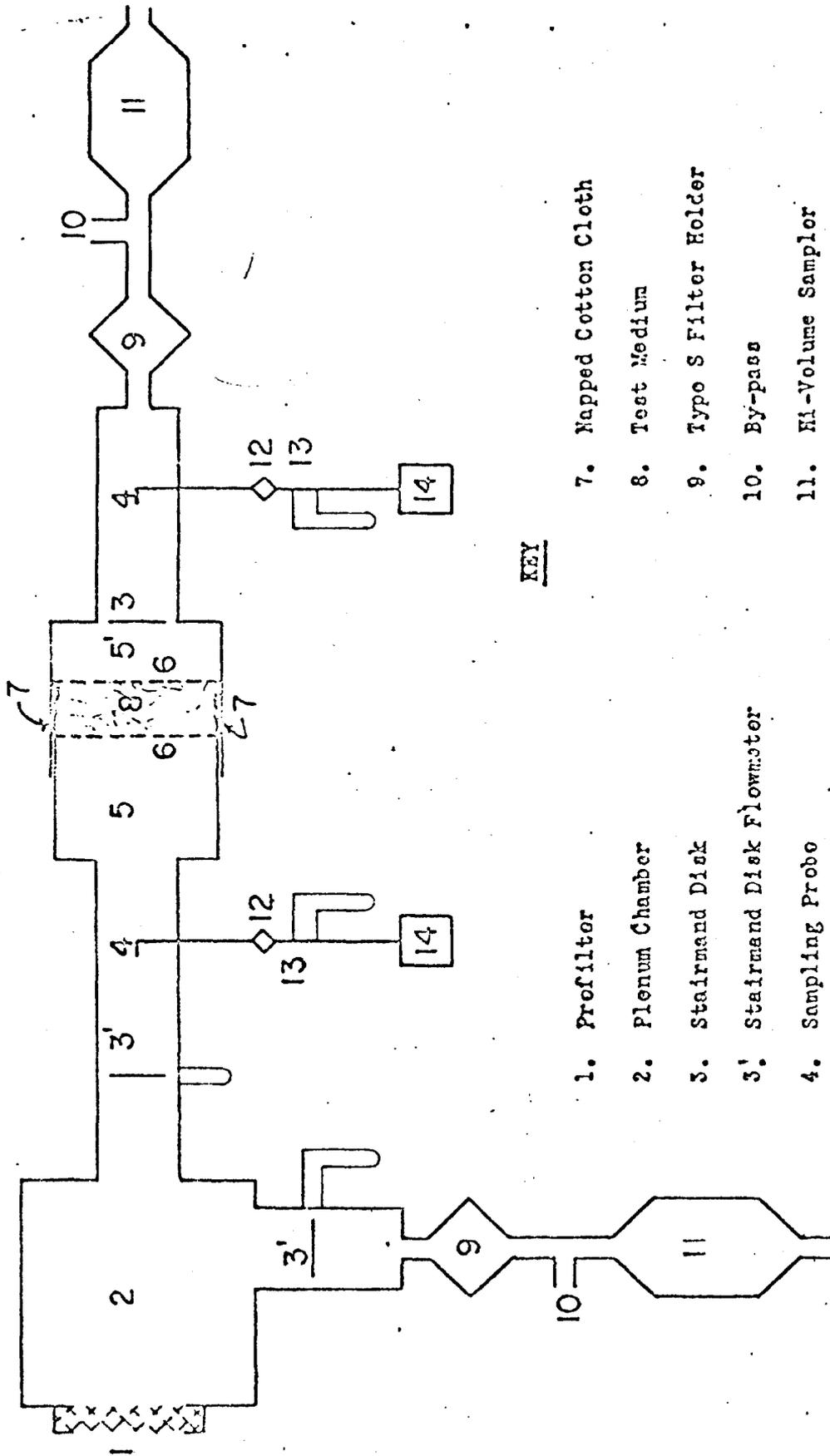
If these relationships do not prove reliable, a synthetic test aerosol will be generated and the cotton tests continued. Future studies will evaluate the effects of various packing densities and various face velocities.

Prefiltration

Partial analysis of the data indicates that the prefilter causes little change in aerosol composition. The average size fraction efficiencies of the prefilter were determined from the data of 28 runs. The average cloud composition for room air was determined from the same data. This average composition was plotted on logarithmic probability paper and, using the average size fraction efficiencies, a second cloud was synthesized which represented a cloud leaving a prefilter of average performance. The line representing this second cloud on logarithmic probability paper was almost superimposed on the initial line. This approach clearly shows that present sizing techniques are insensitive to any changes made in the aerosol composition by this type of prefilter.

It is felt that the major benefit to be derived from the prefilter is in the removal of large particles which may distort any empirically determined relationship between stain and weight efficiencies.

FIGURE 1
COTTON TEST EQUIPMENT



KEY

- | | |
|--------------------------------------|----------------------------|
| 1. Prefilter | 7. Napped Cotton Cloth |
| 2. Plenum Chamber | 8. Test Medium |
| 3. Stairmand Disk | 9. Typo S Filter Holder |
| 3'. Stairmand Disk Flowmeter | 10. By-pass |
| 4. Sampling Probe | 11. Hi-Volume Sampler |
| 5. 6" Plastic box (inside section) | 12. Membrane Filter Holder |
| 5'. 6" Plastic box (outside section) | 13. Flowmeter |
| 6. Wire Screen Support | 14. Leiman Pump |

REFERENCES

1. Silverman, Leslie and Viles, F. J., Jr. Determination of Cotton Textile Dusts in Air. Textile Research Journal, Vol. XX, No. 2, Feb. 1950.
2. Matthews, J. M. Textile Fibers. Wiley & Son, 1948.
3. Rossano, A. T., Jr., U. S. Public Health Service and Harvard School of Public Health - private communication.

INCINERATION OF COMBUSTIBLE WASTES USING TANGENTIAL OVERFIRE AIR

By
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U. S. Bureau of Mines

INTRODUCTION

At the request of the U. S. Atomic Energy Commission, the Bureau of Mines initiated a systematic investigation of incineration. The ultimate purpose of this investigation was to design a packaged incinerator for disposal of radioactive combustible wastes incidental to operations at off-site research laboratories.

The prime requisites of any incinerator are: (1) maximum combustion efficiency, so that smoke, tar, and malodorous constituents are not discharged to the atmosphere; (2) maximum retention of particulate matter within the combustion chamber to obtain the lowest possible dust-loading in the stack gases; (3) maximum reduction of charge volume, so that the least amount of residue must be handled.

Knowledge of the complex heat-and-mass transfer processes which control combustion in solid-fuel-fired furnaces, is meager. Consequently, design of efficient combustion chambers is generally empirical, particularly in the field of incineration. No sound engineering data have yet been published relating such factors as temperature, gas residence or contact time, and turbulence to the burning process of solid fuels.

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ports, 180 degrees apart, located at different levels of the drum. Figure 1 is a schematic diagram of the model incinerator.

The principal objective of the model studies was to establish the relationship of the various process parameters to the burning performance of the incinerator. The variables studied were: (1) air rate, (2) port area, and (3) height of ports above the grate. All tests were made with sawdust whose proximate analysis on the as-fired basis was nominally 8 percent moisture, 74 percent volatile matter, 17.5 percent fixed carbon, and 0.5 percent ash. The gross heating value of the sawdust was approximately 8200 Btu per pound.

The unit was charged at the beginning of each test with 10 pounds of sawdust, ignited, and operated at various predetermined conditions. Each test was considered completed when the last embers were seen to burn out.

The principal observations in each test were: (a) the time required to burn the charge completely; (b) the composition and the temperature of the stack gases, and (c) the relative quantity of smoke and tar in the products of combustion.

Four quantities were used to characterize the performance of the unit: (a) the observed burning rate, that is, the pounds of charge consumed per hour, as denoted by the elapsed time between ignition and complete burn out; (b) the calculated burning rate, derived from the mass air flow rate and the composition of both the charge and the stack gases; (c) the combustion efficiency which is the ratio of the calculated to the observed burning rate; (d) the relative smoke content of the stack gases.

In designing the incinerator for disposal of radioactive wastes several factors, such as handling the residue and the design of the gas-cleaning system had to be considered. However, the most urgent need was to achieve high combustion efficiency and maximum retention of particulate matter, consistent with a reasonable burning capacity.

Generally, incinerators are required to perform satisfactorily over a wide range of operating conditions. For example, the refuse charged generally consists of different kinds and proportions of solids and semi-solid wastes whose heat of combustion and burning characteristics vary widely. Moreover, when charged randomly, as it is normally done, the flow rate and distribution of air through and above the burning charge vary radically. Observations of various types and sizes of incinerators have clearly indicated that unsatisfactory performance is largely the result of inadequate control of the quantity and distribution of undergrate and overfire air.

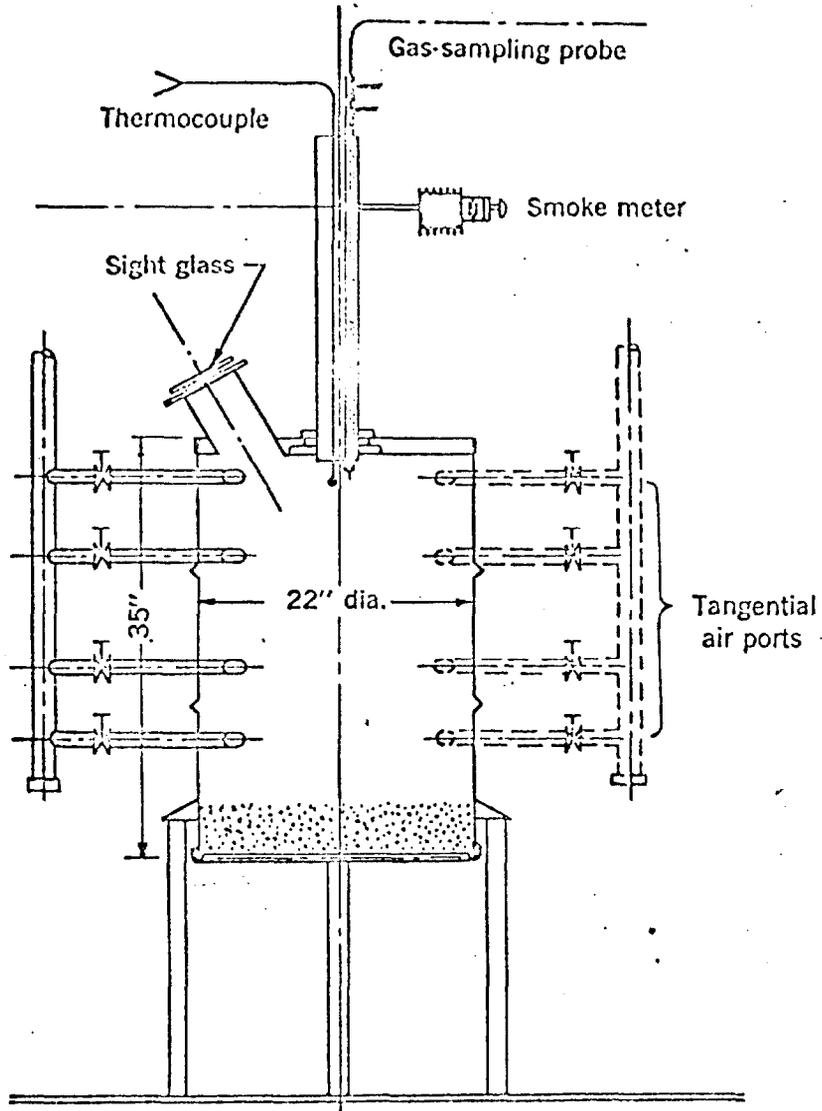
The investigation comprised three phases: (1) Disposal of ash residues by fluxing them in molten Na(OH). This has been completed and reported upon. (2) Evaluation of the process parameters with a model incinerator. (3) Design and evaluation of the performance of a prototype unit, based on the results obtained with the model incinerator.

The objective of this paper is to discuss the operation and performance of the prototype incinerator.

MODEL INCINERATOR STUDIES

Before discussing the results obtained with the prototype unit, it is necessary to review briefly the studies made with the model incinerator.

The model incinerator consisted of a 55-gallon steel drum with a small axial stack at the top of the drum and four pairs of tangential



PL-495
16

Figure 1. Schematic diagram of model incinerator.

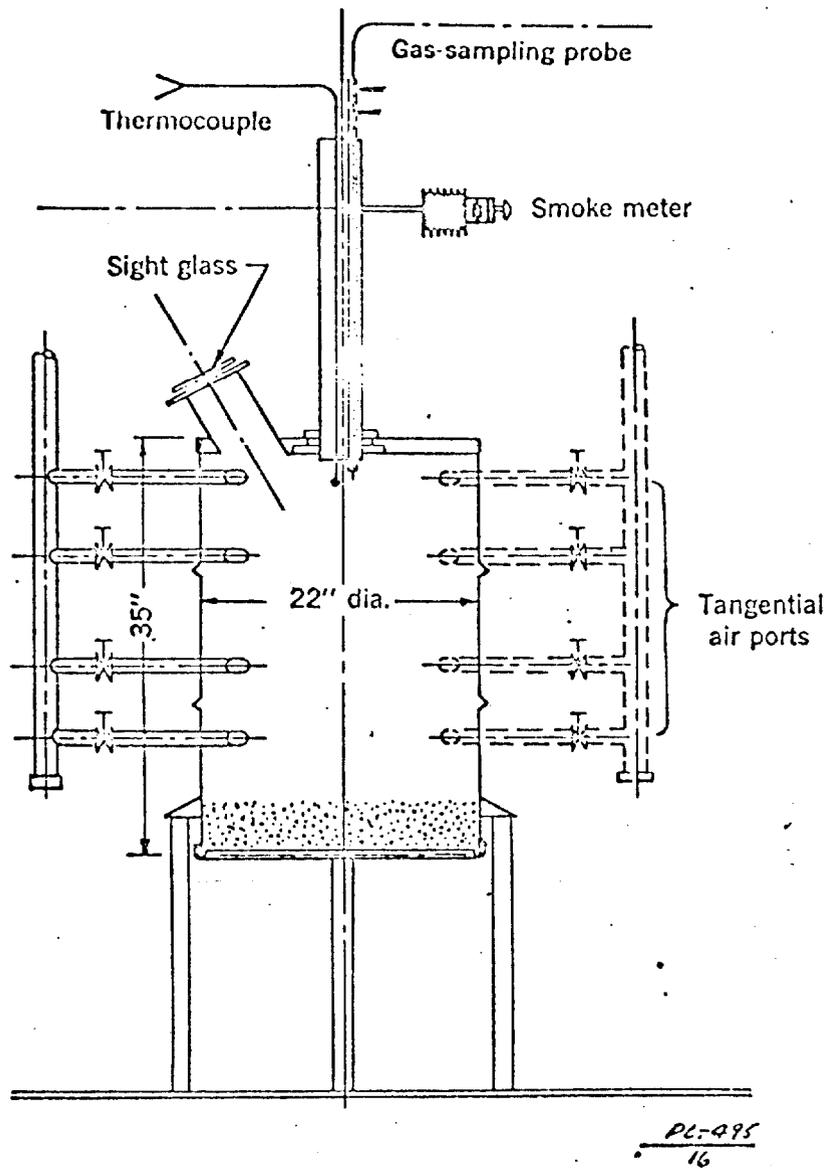


Figure 1. Schematic diagram of model incinerator.

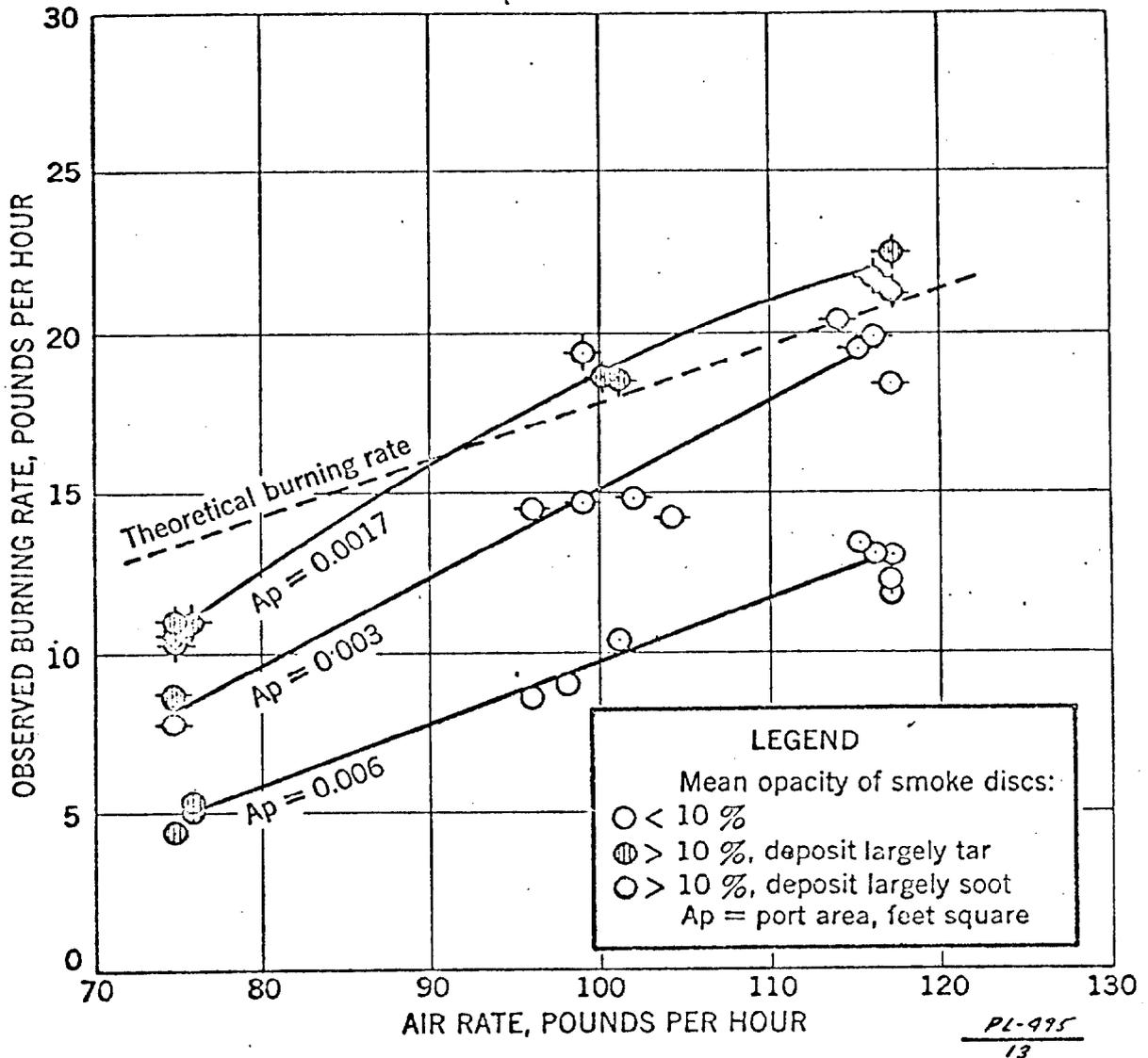
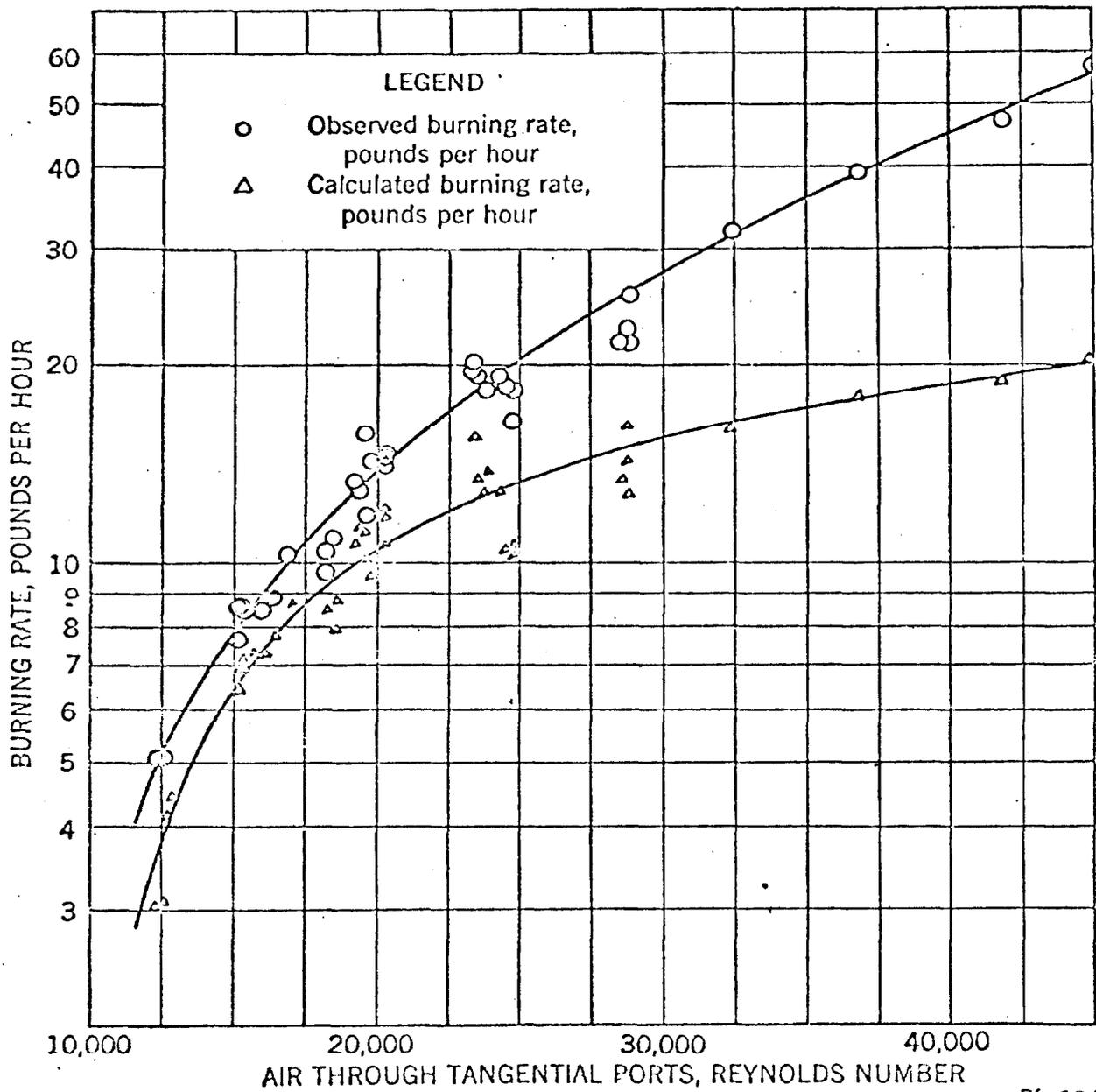


Figure 2. Average observed burning rate as a function of air rate and port area.

PL-495
13



PL-495
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Figure 3. Burning rate as a function of Reynolds number of air in tangential ports.

RESULTS AND DISCUSSION OF RESULTS

Correlation of the results showed that the observed burning rate increased almost linearly with the air rate, and for a given air rate, the burning rate also increased as the port area was decreased. Figure 2 shows the observed burning rate as a function of air rate and port area. Since the observed burning rate is based on the time required to consume the weighed charge, it does not show the amount of combustibles in the stack gases. The theoretical burning rate, shown as a broken line, is the rate at which the sawdust would burn completely to CO_2 and water vapor for a given air rate, if no excess air were necessary, and serves as a guide in comparing the burning rates achieved. When combustion is complete, the burning rates lie on or below this line, and the distance below it is a relative measure of the excess air. It is possible, however, to have unburned combustibles in the presence of excess air. Although the data failed to show a marked effect of the port height, it will be shown later that this variable does have a small effect on the performance of the prototype unit. In general, higher combustion efficiencies were attained when using the uppermost ports.

The results shown in figure 2 suggested that the burning rates could be correlated with a dimensionless parameter characterizing the flow conditions in the tangential ports. Accordingly, the results were plotted as a function of the Reynolds number of the air in the tangential ports. The effect of Reynolds number on both the observed and calculated burning rate is shown in figure 3.

Since the observed burning rate represents all of the fuel that is consumed, and the calculated burning rate only the portion that burns

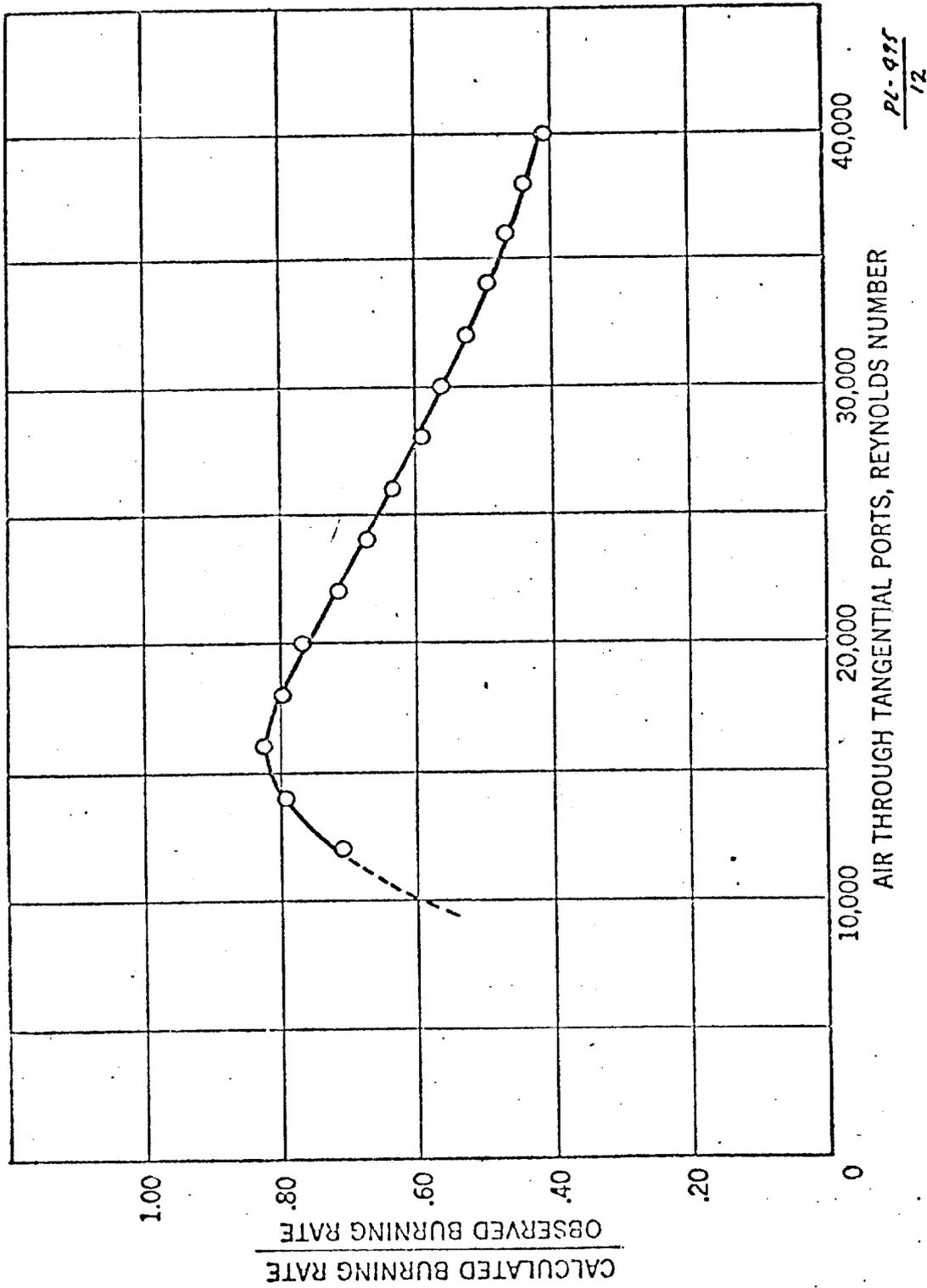
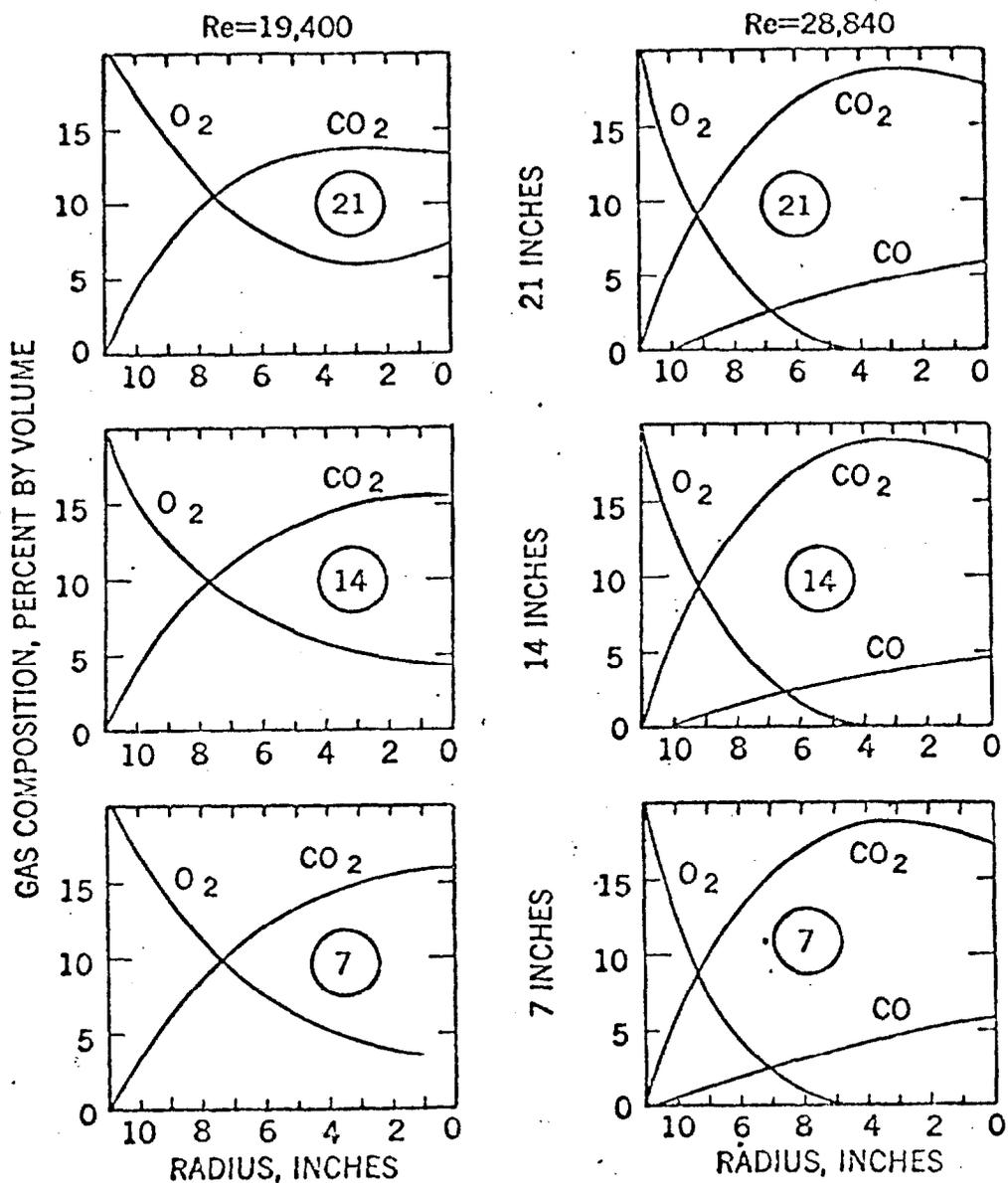


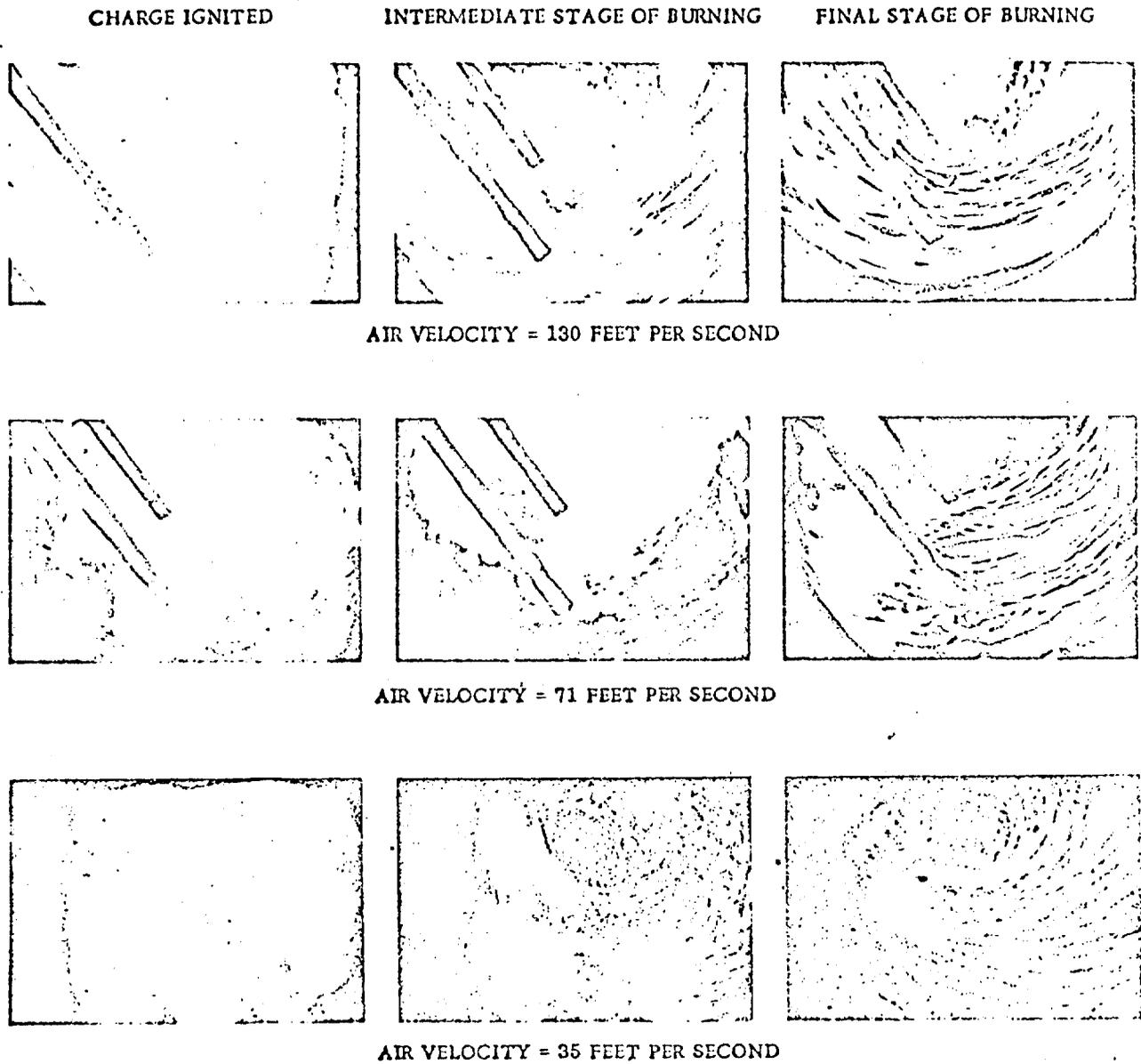
Figure 4. Combustion efficiency as a function of Reynolds number of air in tangential ports.

Note: Zero radius is axis of incinerator, circled numerals are the height of the probe above the fuel bed in inches.



PL-495
11

Figure 5. Composition of gases within incinerator for different Reynolds numbers. Air mass flow rate constant at 117 pounds per hour.



TIME LAPSE PHOTOGRAPHS OF BURNING IN MODEL INCINERATOR TO SHOW EFFECT OF AIR VELOCITY UPON FLOW PATTERN OF GASES AND BURNING PARTICLES. AIR RATE = 115 POUNDS PER HOUR.

Figure 6.

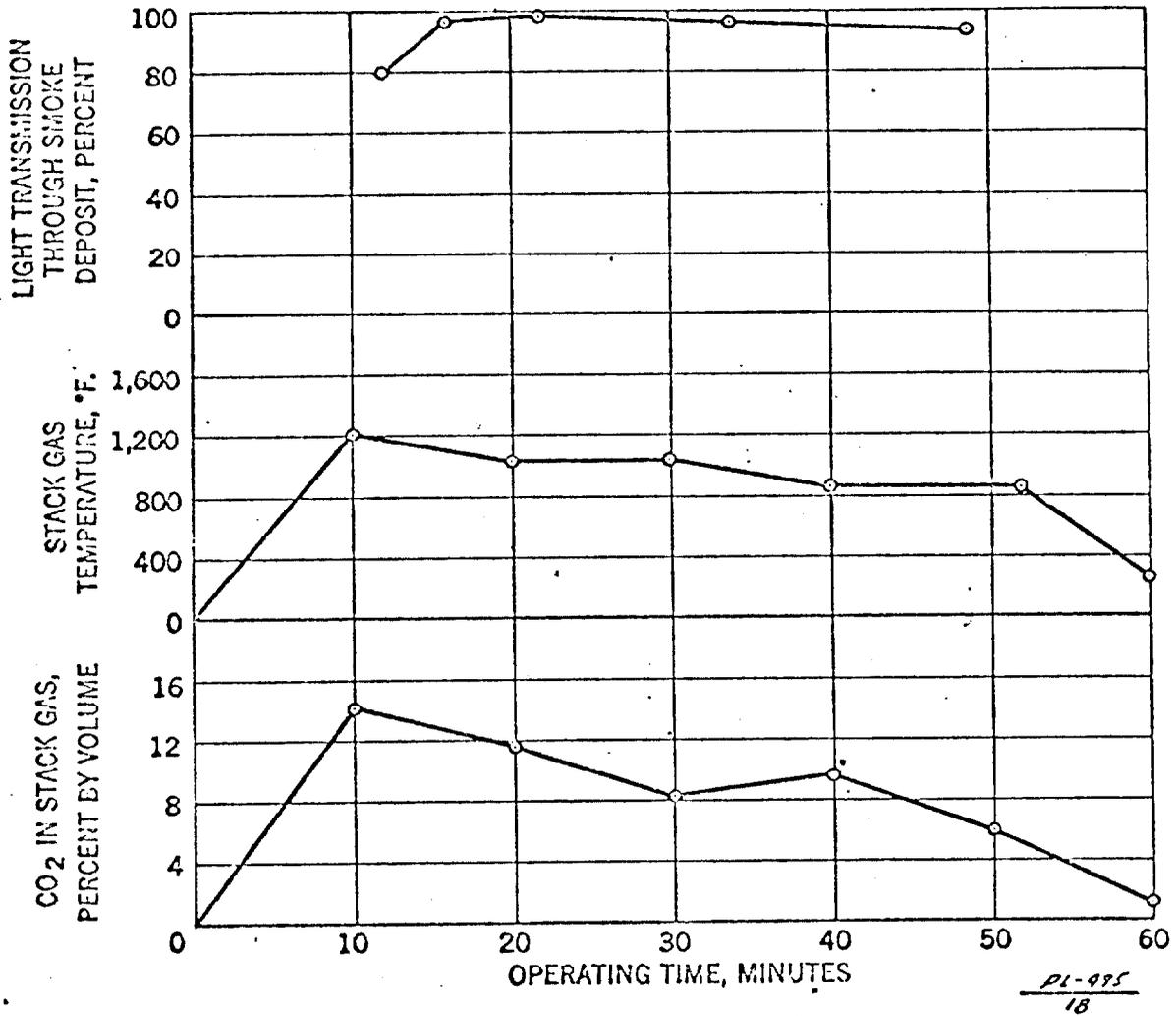


Figure 7. Operating conditions for a Reynolds number of 19,400, air rate = 117 pounds per hour.

to CO_2 and water, the spread between these curves is related to the amount of combustible material in the stack gases. The least spread between the two curves was found at a Reynolds number of approximately 15,000. This is shown more clearly in figure 4.

The burning conditions in the combustion chamber can be characterized by the composition of the hot gases sweeping the surface of the burning charge. Figure 5 shows the composition of the gases at different elevations inside the chamber for a fixed air rate of 117 pounds per hour but for two different Reynolds numbers, 19,400 and 28,840.

It is evident from these data that at the lower Reynolds number excess oxygen was present throughout the chamber, but at the higher Reynolds number the oxygen disappeared at a radius of approximately 4 inches, and CO was formed. Figure 6 shows three stages of the actual burning conditions in the chamber for a fixed mass flow rate of 115 pounds per hour but at three different linear velocities in the ports. These flow conditions correspond to Reynolds numbers of 56,700, 23,500, and 19,400. The angular path of the incandescent particles is clearly evident from these photographs. Comparing the final stage of burning at 35 and 130 feet per second, it will be noted that the average radius of the path of the particles is greater at the higher velocity, which, of course, is to be expected.

In figure 7, the operating conditions for a Reynolds number of 19,400 are given. Special attention is called to the smoke data at the top of the figure. The gray circles are reproductions of the smoke discs, which were taken at the time indicated on the abscissa. Their densities agree quite well with the corresponding photometer results.

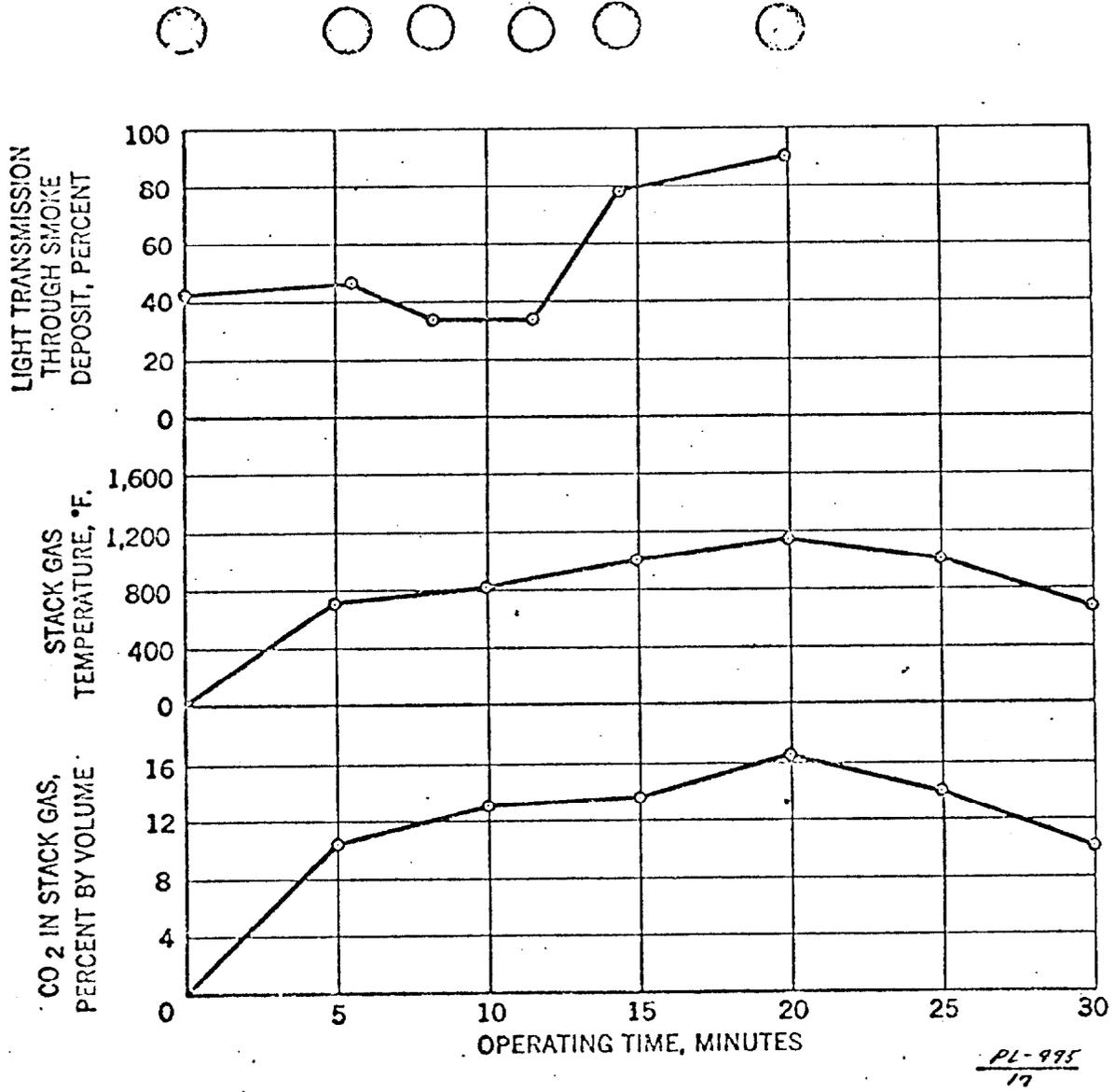


Figure 8. Operating conditions for a Reynolds number of 29,000, air rate = 117 pounds per hour.

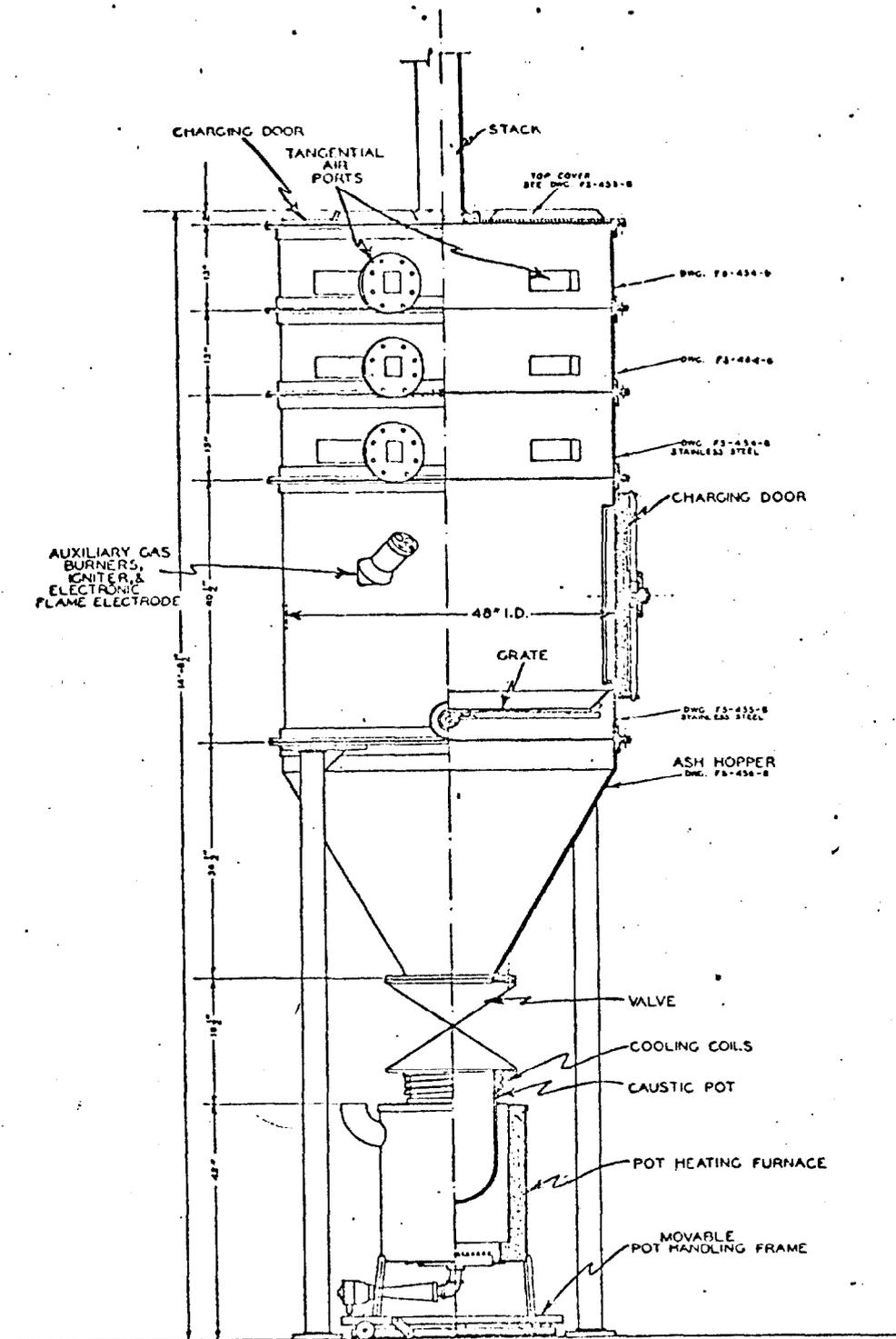


Figure 9. Schematic diagram of prototype incinerator.

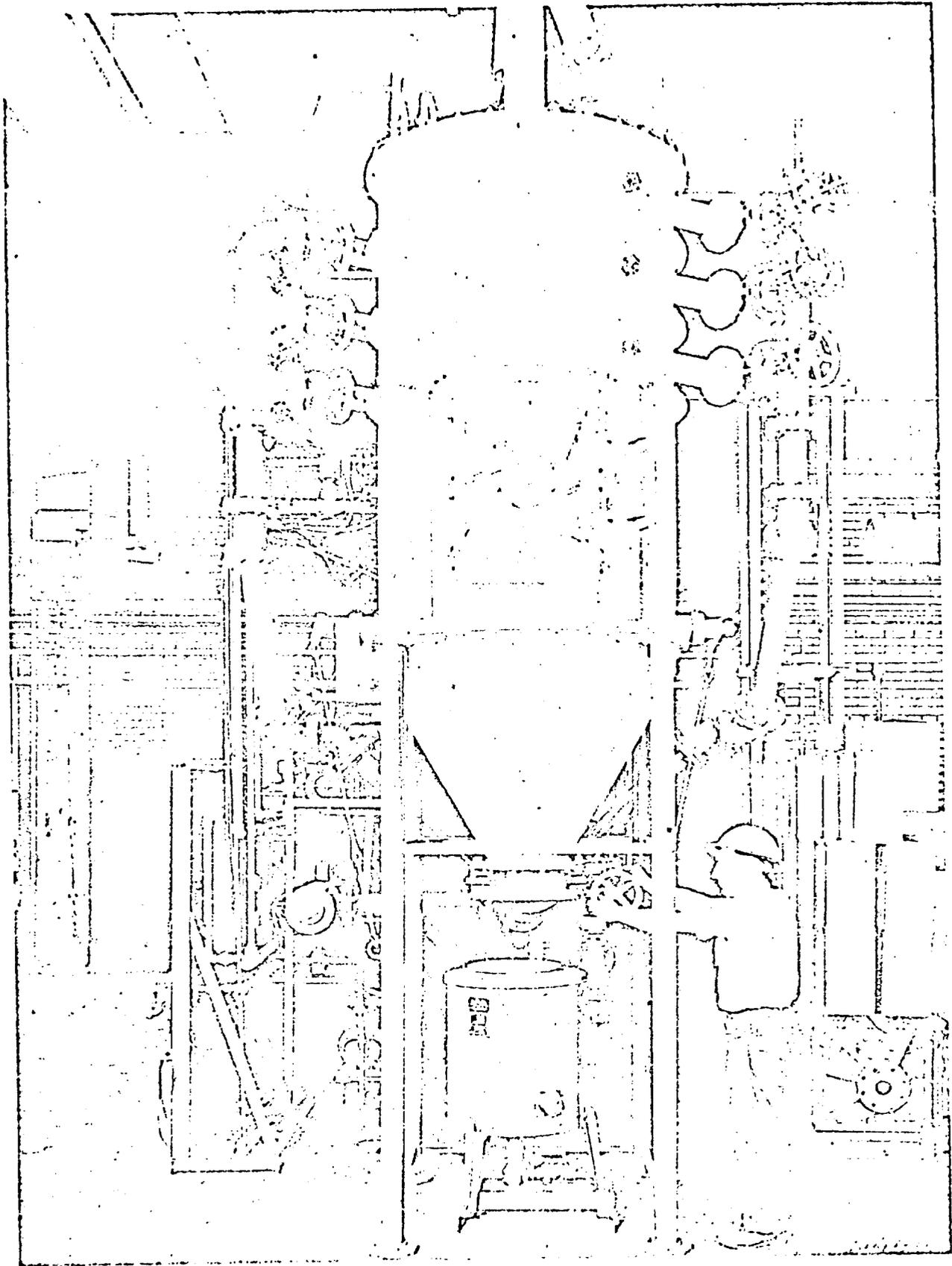


Figure 10. Photograph of prototype incinerator.

In figure 8, the results are given for a Reynolds number of 29,000. The discs for this test were generally darker than for the test at the lower Reynolds number.

PROTOTYPE INCINERATOR

On the basis of those results a prototype unit approximately five times as large as the model was designed. It consists of a cylindrical combustion chamber with an axial stack at the top and a conical ash hopper flanged to the base of the combustion chamber. Figure 9 shows a schematic diagram of the incinerator and the ash-fluxing pot-furnace when assembled for operation. Air to the incinerator is admitted through three pairs of rectangular tangential ports, 180 degrees apart, located at three different levels of the chamber. The ports are valved and connected to a manifold so that any pair or combination of pairs can be used. The area of each port can be varied by means of retractable inserts located in the rectangular section of the ports. The grate consists of two semicircular, cast iron plates hinged in the center, and counter-balanced for ease of manipulation. Two quick-closing doors, one for overhead charging and one for side-charging, were installed for use during the investigation. However, the final unit will be provided with a charge-bin sealed by a guillotine-type door; similar to the Los Alamos unit. Figure 10 is a photograph of the prototype incinerator.

An auxiliary gas burner, with safety interlock devices, is used to ignite the charge.

The total cost of this unit including installation was approximately \$10,000. A commercial model of similar size could be constructed for somewhat less by eliminating auxiliary test equipment, which is not required for satisfactory commercial operation.

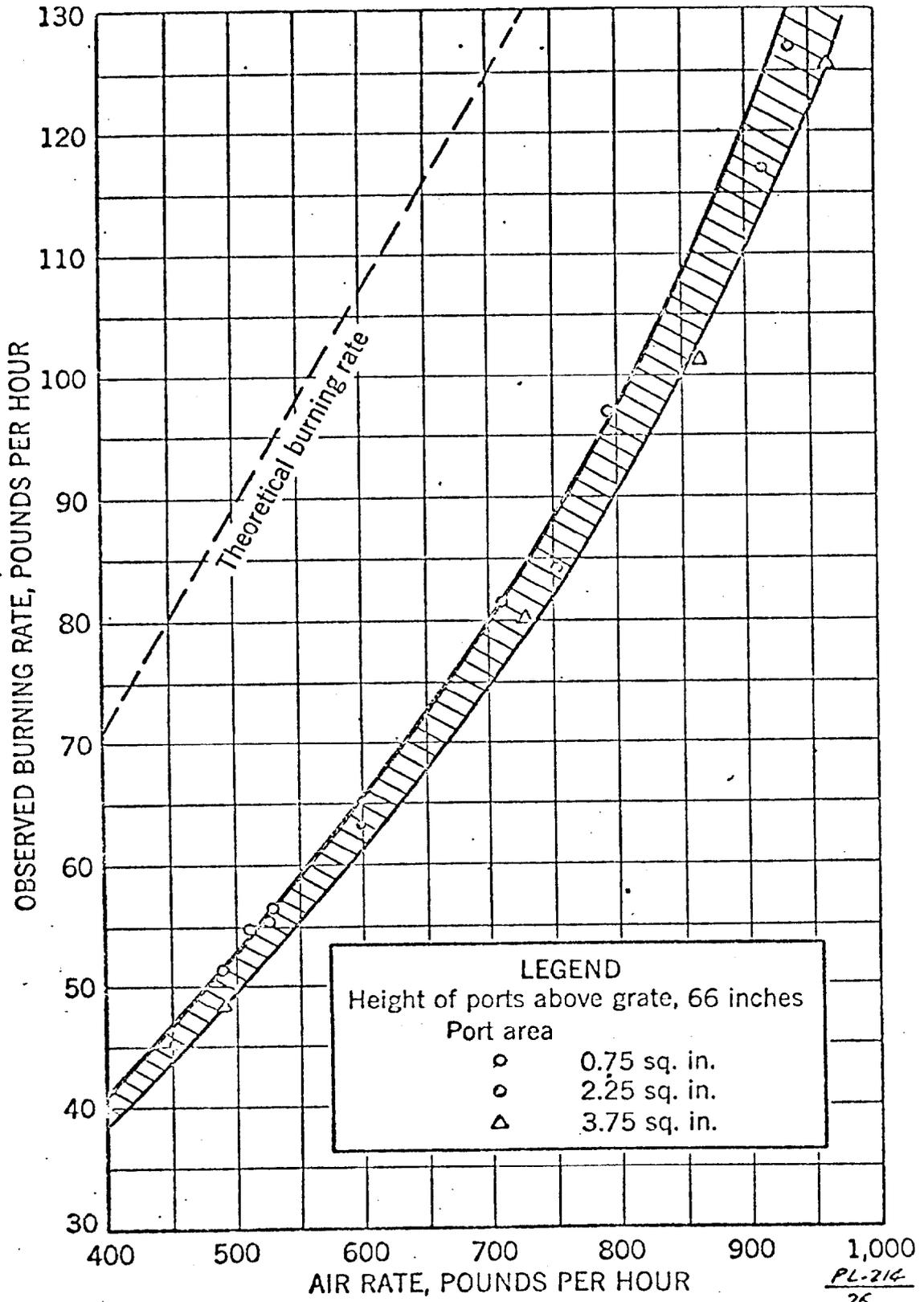


Figure 11. Average observed burning rate as a function of air rate.

EXPERIMENTAL CONDITIONS

The unit is charged batchwise with 100 pounds of sawdust packaged in cylindrical cardboard containers. Fifteen cartons comprise a charge for each test. To ignite the charge the gas burner is turned on for one and one-half minutes and then turned off for the remainder of the test. Each test is considered completed when the last embers are seen to burn out. The burning conditions in the chamber were noted through an observation port located at the top of the chamber.

Several tests were made at air rates ranging from 500 to 1000 pounds per hour, using each pair of ports at the different elevations of the chamber, and various tangential port areas. In addition, some preliminary tests were made with sawdust containing as much as 40 percent moisture.

DISCUSSION OF RESULTS

Since the factors that were varied with the prototype were the same as those for the model incinerator, similar parameters were used to correlate the results. Figure 11 shows the relationship between the observed burning rate and air rate for three different port areas. The ports were located 66 inches above the grate in each case. These data show that the observed burning rate increases with air rate. However, varying the port area at a fixed air rate had little effect. In the model unit the port area had a much more pronounced effect upon the burning rate.

Similar trends were found with ports located at 53 and 40 inches above the grate.

This difference between the model and the prototype suggests that the gas-flow pattern established in the larger unit depends largely on the total quantity of air used, and only to a minor extent on the linear velocity of the air in the ports. These results are in marked contrast with those from the model studies, in which port area had a pronounced effect upon incinerator performance. One possible explanation for this inconsistency may be the differences in geometric relationships between the diameter of both the ports and incinerator, which would affect the transfer of linear momentum of the air in the ports to angular momentum in the chamber. That is, the expansion losses are greater in the prototype unit than they are in the model.

The effect of varying the port height on the burning performance of the prototype incinerator is shown in figure 12. It is significant to note that both the observed and calculated burning rates decreased when the port height was decreased. Moreover, a lower combustion efficiency was achieved when the ports closest to the fuel bed were used. This is better illustrated in figure 13, which is a plot of the ratio of the calculated to the observed burning rate as a function of air rate. It is evident from these results that higher capacities, as well as higher combustion efficiencies, are attainable when all the air is admitted through the uppermost ports.

Since occasionally wet charges are incinerated, some preliminary tests were made using sawdust containing up to 40 percent moisture. No difficulties were encountered in burning the wet charge, except that it was necessary to operate the gas burner somewhat longer

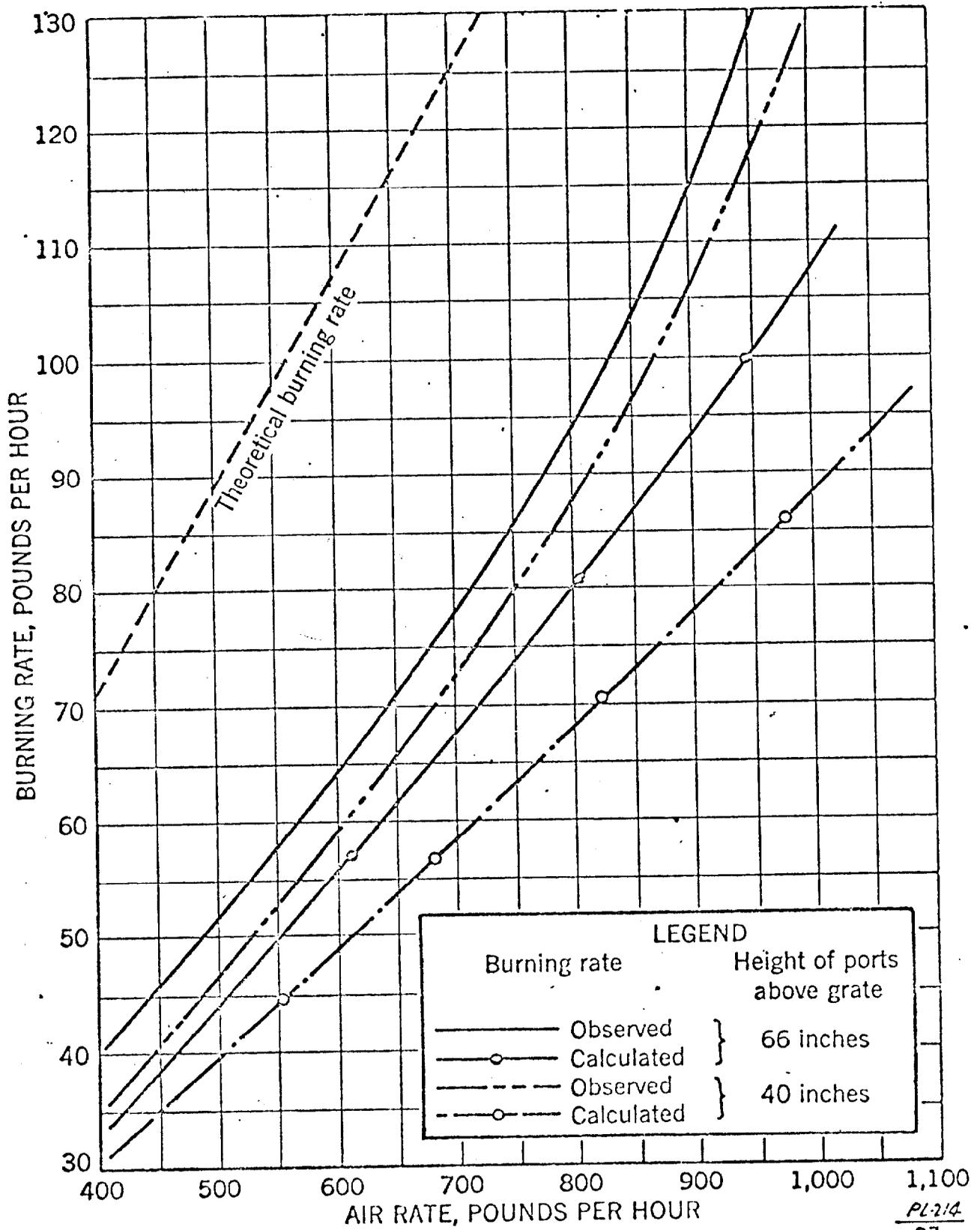


Figure 12. Burning rate as a function of air rate and port height.

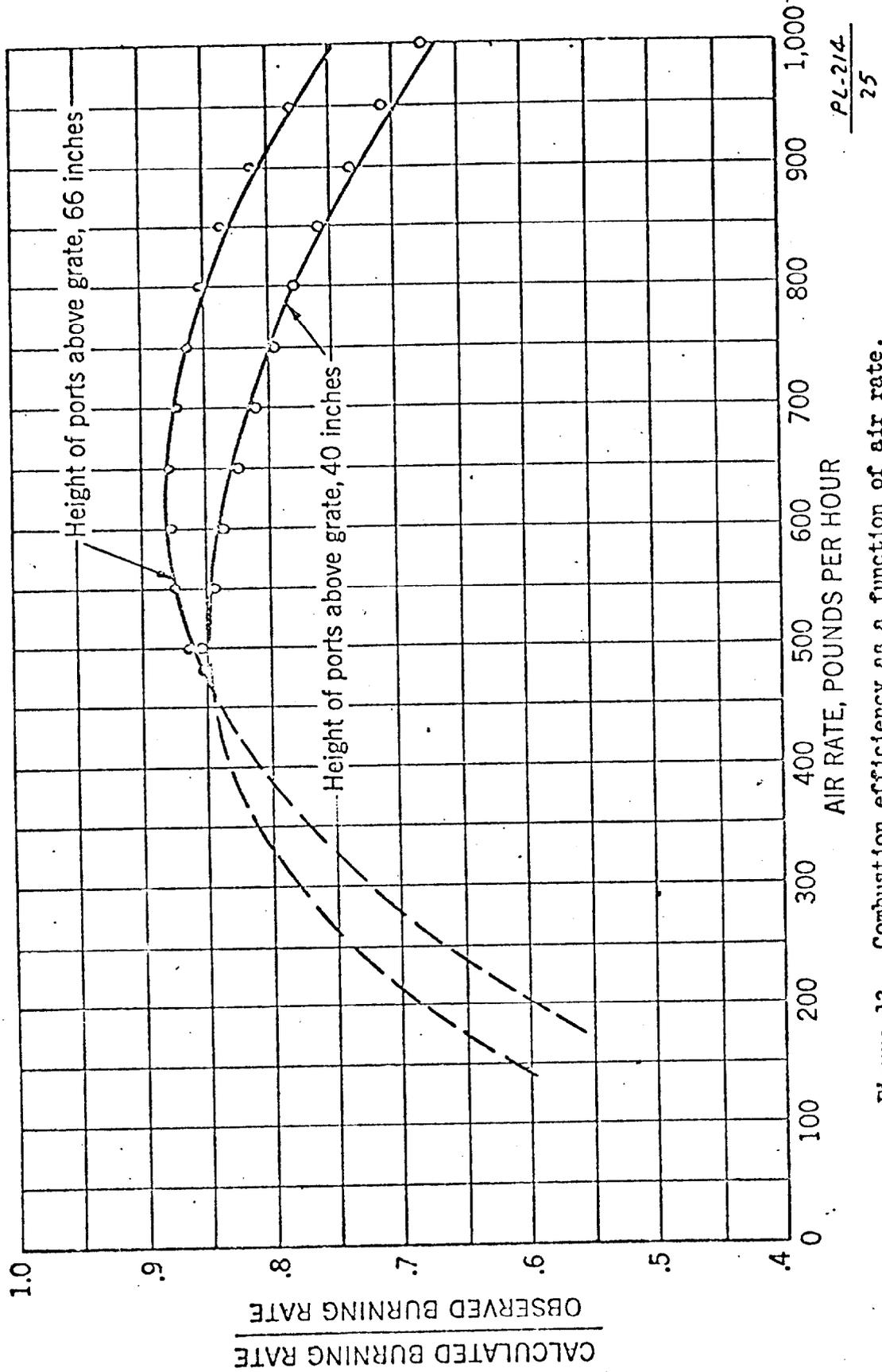


Figure 13. Combustion efficiency as a function of air rate.

PL-214
25

to attain satisfactory ignition. Table 1 shows the results of two tests using sawdust with 7.8 and 40.3 percent moisture. Comparing the data within the heavy boundary lines, it is seen that both the observed and the calculated burning rates do not vary appreciably. However, when the calculated rates are computed on the moisture-and-ash free basis, the charge containing 40.3 percent moisture showed a 25 percent decrease. It is significant to note that no auxiliary burner was used during the tests other than to ignite the charges at the beginning of each test.

CONCLUSIONS

Although a great deal remains yet to be done, the results obtained with the prototype are sufficiently conclusive to draw the following general conclusions:

1. Low ash, high volatile wastes with relatively high moisture content may be burned with high combustion efficiency in a cylindrical combustion chamber using only tangential overfire air. This confirms similar conclusions based upon the model studies. A commercial unit similar in size to the prototype incinerator will burn efficiently approximately 80 cubic feet of waste per day. This based on a bulk density of 10 pounds per cubic foot.
2. Variations of air mass flow rate showed approximately the same effect on the burning rate in the prototype unit as it did in the model unit.
3. The effect of port area and port height on the burning rate in the prototype unit was not consistent with the results obtained in the model studies. In the prototype unit, variations of port height had relatively greater effect than variations of port area, whereas, the opposite was true for the model incinerator.

Table 1.

Comparison Performance Tests of Prototype Incinerator
Using Charges with Different Moisture Content

| | <u>Test No. 2</u> | <u>Test No. 3</u> | |
|--------------------------------------------------------|-------------------|-------------------|--------|
| Composition of charge burned: | | | |
| | <u>Proximate</u> | | |
| Moisture | 7.80 | 40.30 | |
| Volatile matter | 72.30 | 46.80 | |
| Fixed carbon | 19.50 | 12.60 | |
| Ash | 0.40 | 0.30 | |
| | 100.00 | 100.00 | |
| | <u>Ultimate</u> | | |
| H | 6.50 | 8.07 | |
| C | 47.00 | 30.54 | |
| N | 0.10 | 0.02 | |
| O | 45.90 | 61.33 | |
| S | 0.10 | 0.01 | |
| Ash | 0.40 | 0.03 | |
| | 100.00 | 100.00 | |
| Gross heating value, Btu/lb. | 8070 | 5230 | |
| Operating conditions: | | | |
| Weight of charge, | lbs. | 106.50 | 147.00 |
| Approximate density of charge, | lbs/cu.ft. | 10.65 | 14.70 |
| Air rate, | lbs/hr. | 854 | 872 |
| Air temperature at the orifice, | °F | 166.5 | 163.0 |
| Linear air velocity | | | |
| in tangential ports, | ft/sec. | 70.6 | 73.9 |
| Reynolds number, in tangential ports, | | 49,800 | 51,000 |
| Operating time, | minutes | 62.0 | 82.0 |
| Results: | | | |
| Observed burning rate, | lbs/hr. | 103.0 | 107.5 |
| Calculated burning rate (as charged) | lbs/hr. | 87.2 | 99.0 |
| Calculated burning rate (Moisture, Ash, Free basis) | lbs/hr. | 80.0 | 59.0 |
| Maximum stack gas temperature, | °F | 1625 | 1385 |
| Mean stack gas temperature, | °F | 1270 | 1050 |
| Maximum CO ₂ content of stack gas, | percent | 18.9 | 12.8 |
| Mean CO ₂ content of stack gas, | percent | 11.6 | 8.4 |
| Theoretical CO ₂ content of stack gas, | percent | 20.4 | 20.4 |
| Pounds of residue, | lbs. | 0.559 | 0.72 |

4. Both the combustion efficiency and burning capacity of the prototype unit were highest when using the uppermost set of ports. This confirms the results of the model studies with respect to combustion efficiency, but is in contrast with the results in the model with respect to burning capacity.

It should be emphasized that these conclusions are based on a limited investigation of only a few factors. The effect of such variables as the bulk density, chemical composition and moisture content of different waste materials has not been determined. It is evident that these factors must be investigated before a complete evaluation of the unit can be made.

PROPERTIES OF VARIOUS FILTERING MEDIA

FOR ATMOSPHERIC DUST SAMPLING

By W. J. Smith, N. F. Surprenant, A. D. Little, Inc.

INTRODUCTION:

In sampling for atmospheric dust and for testing atmospheric dust conditions, a number of methods are in use which depend upon filtration to arrest the dust particles. The effectiveness of any such method or even its success can depend, to an important degree, on the filter medium that is selected. Because they may be so important, the properties of any filter medium should be well understood before its use is recommended for any test method. It is our present purpose to compare and discuss properties of several filter media with respect to various air sampling requirements. All of the media to be considered are now available, and most of them are being used for air assay work.

There are various reasons for collecting a sample of atmospheric dust, and the purpose to be served will influence selection of the filtering medium. To mention some of the reasons or purposes of sampling, we have measurement of mass concentration of dust in the air, particle size distribution, chemical analysis of the particulates, toxicity assay, radioactivity measurements, study of organisms, and evaluation of soiling characteristics.

Conditions under which the sampling must be done may also influence selection of a medium. For example, glass fibers would not be used in an atmosphere known to contain an appreciable amount of hydrofluoric acid vapor.

In some cases a particular filter medium is used in a certain application only because of long standing practice which, for consistency, is kept unchanged. However when the need arises to select a filter for some new or

special purpose, an understanding of the general filtering properties of available media should be useful in making an intelligent choice. It is our purpose to contribute to the fund of such information.

The problems associated with selection and use of air sampling filter media were discussed at the Air Cleaning Seminar, sponsored by the Atomic Energy Commission and held at Ames, Iowa, Sept. 14-17, 1952. As a result of that meeting a study of filter media and sampling practices was undertaken by Arthur D. Little, Inc. A questionnaire survey of some 40 laboratories, most of them within the Atomic Energy Commission operating areas but including also a number of outside laboratories, provided a list of air sampling media that are in current use at these laboratories.

We assembled a group of samples representing nearly all of the media that were mentioned in the survey. This paper describes and discusses air filtration test results obtained for these media and for a few others¹ that were included because of their special interest. Our test methods have included di-octyl phthalate smoke penetration, atmospheric dust penetration, and plugging rate on atmospheric dust. A range of performance characteristics is provided which may aid one in selecting a filter material for any dust sampling purpose.

Di-Octyl Phthalate Smoke Penetration Test:

The di-octyl phthalate smoke penetration meter or "DOP tester" as it is called more commonly, was developed by the armed services during the war and has become a well known and highly respected device for evaluating high efficiency filters. Instrumental parts of the tester and theories of their

¹AEC mineral papers were added to the group.

operation have been presented well in the literature (1,2,3). For our needs here a very brief description will serve. There is a smoke generator for producing a controlled, mono-dispersed liquid aerosol of di-octyl phthalate. This is accomplished by condensation from the vapor state and the droplets so formed are held very close to 0.3 micron diam. Particle loading is about 50 micrograms per cu. decimeter. Also a light scattering chamber is provided with sensitive photoelectric pickup means for accurate measurement of smoke particle concentration. The tester is adjusted against full aerosol concentration (unfiltered smoke) and against absolutely clean air. Penetration through a test specimen of filter medium is then read off directly in per cent.

Since the aerosol particles at 0.3 micron diam. are in the approximate size range for the most numerous microscopically visible atmospheric dust particles, the DOP test gives efficiency values that parallel those obtained by atmospheric dust counts.

Under the somewhat standardized conditions of normal laboratory test procedure, DOP smoke penetration measurements are made at 28 lin. feet per min. through a 4.5 in. diam. circular area of the medium. In the work to be described, this area size was used for flow rates up to 28 feet per min. To reach the higher flow velocities (up to 200 lin. feet per min.) a test area of 1.75 in. diam. was used.

Table I shows DOP smoke penetration efficiencies over a range of air flow velocities for our whole group of air sampling media. It is evident immediately that there is a very great difference in efficiencies as measured by this test. Perhaps this is the point at which we should stress that DOP smoke penetration alone must not be taken as a general measure of usefulness for all filters. It is a very severe test and is now used primarily to rate absolute-type filters.

When we are dealing with media intended to collect bulk dust or to analyze for atmospheric dust on a weight basis, very fine particles contribute to a minor degree and become unimportant; the DOP test then has much less significance. However, if our interest extends to the sub-micron size dust particles of the atmosphere (and these are by far the most numerous) then the DOP tester can tell us a great deal about what we can expect a filtering material to do.

An interesting feature of the data shown in Table I is the relation of DOP filtering efficiency to flow velocity for the different types of filter materials. We have plotted sets of data selected from Table I to show some characteristic curves.

Fig. 1 is for CWS #6 paper. At a low air flow rate, it is very efficient. This is a fortunate circumstance because this type of material is used principally for making large volume high efficiency space filters in which face velocity through the medium is only five lin. feet per minute. With increase of flow rate, smoke penetration increases to a maximum at about 30 feet per min. As the flow rate is further increased, penetration again falls off, and progressively. This behavior has been studied by Ramskill and Anderson of the Naval Research Laboratories (4). They attribute the low velocity positive slope to the influence of diffusional collection while the higher velocity negative slope is explained by influence of inertial effects. In addition to flow velocity, these authors show how the character of the curves is controlled by aerosol particle size, particle density, diameter of the filter fiber, and inter-fiber spacing.

Pressure drop, plotted separately in Fig. 1, is nearly linear with flow rate indicating viscous flow through the medium.

All of the high efficiency papers, AEC #1, AEC mineral fiber papers, and HV 70 (18 mil) show curves similar to that for CWS #6.

Fig. 2 shows the plotted data for a still more highly efficient medium. This is a sample of glass fiber paper made by the Hurlbut Paper Co. and containing a resin binder. The fibers in the sheet have a diameter of about 1/2 micron. The resulting curve also shows the peak typical of high efficiency media.

Chemical filter papers as illustrated by the Whatman papers are made in several types, and they give a variety of curves. Fig. 3 shows a plot for paper No. 41 which is typical of many of the cellulose papers.

Paper No. 42 (Table I) is remarkably efficient for an all-cellulose sheet. This efficiency is attained at low flow velocity, but pressure drop is high.

MSA type "S" filter which is used successfully for high volume air sampling (5) shows an unusually uniform DOP efficiency level over a broad range of flow rates (Fig. 4). While all of the other filter specimens come in flat sheets, type "S" is different. It has a molded shape of concentric convolutions designed to provide a large filtering area. A piece was cut from a reasonably flat area and used as the test specimen.

Membrane filters have been described as molecular sieves. Collection appears to be almost entirely at the surface. It is perhaps for this reason that they fill up rapidly on an oil smoke (like DOP) and so may not show up to best advantage in this test.

All fiber filter materials "fatigue" in the DOP tester. After running on DOP for several minutes, the smoke penetration increases. One explanation

offered is that electrostatic effects in the filter body are lost due to accumulation of liquid. It is known that filters depending on electrostatic effects fail quickly when used on oily smokes, so there is some basis for the suggested explanation. For the present, it is only important to mention that a DOP test should be made over a short period of time.

Efficiency by Atmospheric Dust Counts:

It was stated earlier that DOP test results are comparable with efficiency as measured by counts on atmospheric dust particles. This is shown by the data in Table II. Here the DOP filtering efficiencies of the various media are given, calculated from Table I. Atmospheric dust count efficiencies are shown for comparison.

To measure these efficiencies on atmospheric dust, a high-speed impactor (9) (6) was used for collection. Particle concentrations were measured before and after the filter. In most cases, four tests were made on each filter and 200 counts were made each time. Efficiencies were calculated from counts on the sonic velocity stage of the impactor; particles were one micron and smaller in diameter. No counts were obtained on the clean side of the very efficient media even after running the impactor for six hours. It should be borne in mind that the great numbers of atmospheric dust particles are less than a micron in diameter. Rating of a filter by counts on such dust is the same as rating that filter for performance in those small particles.

Even those who have been aware of the relation of DOP efficiency to particle count efficiency may be surprised by the close correlation of these separate methods. The results strongly indicate that the DOP tester can be relied upon to evaluate all filter media with respect to efficiency against sub-micron

size atmospheric dust particles.

Efficiency by Particle Size:

In the methods just described we dealt only with sub-micron size particles. When we include consideration of larger particles, our attention becomes limited to the cellulose fiber filters on our list. Larger particles do not penetrate the other media of the group.

Table III shows the particle size analysis for unfiltered laboratory air and for the same air after passing through each of several cellulose fiber filters. In every case, the count peak is shifted in the direction of the smaller particles as would be expected. No particles larger than two microns were observed to have passed any of the filters. Time did not permit us to include all of the cellulose fiber filters; we did try to select a representative group.

Efficiency of filtration by particle size is shown in Table IV. Here again efficiency was measured by particle count on high-speed impactor plates. No particles were found above the size of two microns, and all of the filters showed good to excellent efficiency on particles in the one- to two-micron range. When the primary interest is in weight of dust collected, these filters are generally adequate since large dust particles contribute most. The weight contribution of a particle is measured by the cube of its diameter.

All of the results reported have been on fresh samples of media. Allowance should be made for the fact that all filters improve in efficiency as they fill. As a practical matter, all of the media tested here will perform much better in use than our figures indicate.

Life Tests:

In many air sampling applications, plugging rate of a filter medium is not

a problem. But in those cases where it is desired to sample over a long period of time or to accumulate a sizeable quantity of particulate matter, the rate at which plugging occurs may become important. At times flow resistance or the development of flow resistance may even determine the feasibility of taking the sample.

A life test or plugging rate test consists in operating a filter sample at some selected flow rate and observing the increase in pressure drop with time. The kind of equipment we have used for this is shown in Fig. 5. It consists of separate test stations in which samples of filter materials may be mounted and operated over long periods of time. Each station has a sample holder that takes a 3 1/2 in. diam. disc of the medium and exposes a test area 3 in. in diam. A calibrated orifice meter and control valve allows each sample to be run at a selected rate. Our testers are arranged in two banks of twelve units each, all twelve stations in a bank exhaust into a single manifold line which is connected to the intake port of a three-stage Spencer Turbine Blower.

The flow rate tends to fall off, of course, as the filter fills with its accumulated dust load. This necessitates periodic adjustment of the valve to restore the proper rate. Pressure drop across each test sample is measured with a "U" tube water manometer.

It seemed best to life test all of the media at the same time so that any question of varying dust conditions in the air would not enter in. This brought up the matter of flow rate at which to run; for direct comparisons, all should be run at the same rate. The very low rate of five lin. feet per min. was selected as a start with the intention of increasing the rate after the rapidly plugging samples had been removed. When pressure drop became too high for any manometer, that test was stopped. After 480 hours of running, the flow rate

was stepped up to 28 lin. feet per min. for all surviving specimens except the membrane filters. Only seven specimen filters were remaining 120 hours later. Atmospheric dust loading over the time period of the run was measured by weighing the total dust load on a membrane filter.

Table V includes life tests for the entire group of samples. With one exception, the test specimens were flat discs. The exception, MSA type "S", as mentioned before is a molded filter with concentric convolutions. We used a whole filter and adjusted air flow to allow for the greater area which we estimated to be 75 sq. in.

It is interesting that the media which plug most rapidly are not necessarily the most efficient nor those with highest initial pressure drop. As a class the chemical filter papers tend to plug most readily. High efficiency papers show much better life. The membrane filters are very interesting; pressure drop is high initially but increases only a little as dust load accumulates.

In our experience and to the best of our knowledge, the rate at which a filter becomes loaded does not determine its life, regardless of time the pressure drop through a sampling filter is fixed by the amount of accumulated dust. Operating at low flow rate merely extends the time; dust loading in the air (assuming a constant dust composition) and the total amount of air passed are the controlling variables. In our life tests we used very low flow rates. For this reason Table V gives a slow motion picture of plugging rates. Life for any other flow or dust loading can be estimated from the data given.

Discussion of Filter Properties:

For convenience of reference, Table VI contains some general information on the various filter media we have been discussing. We do not consider this Table to be complete in any way. It contains some of the more obvious qualities

along with a few measurements of our own. Values for ash content of the chemical papers were given by the manufacturers. Values for other media, we determined. Very often some special property will determine the suitability of a given material. Such properties are important and must be considered along with filtering performance when a sampling medium is being selected.

Chemical filter papers appear to be used more widely than any other type of air assay medium. This may be because they are nearly always at hand in a laboratory. For those purposes where the filter must be destroyed to isolate or concentrate the dust, the low ash chemical filter papers are particularly useful.

High surface reflectance of light from chemical papers have made them popular for those test methods which are based on discoloration of the collecting surface.

Although chemical filter papers probably were never intended for air sampling work, they have proved to be most popular. Many kinds are available and data in the Tables of this report show the range of performance characteristics that can be expected. There are some properties inherent in paper and other fibrous media which are disadvantageous in some cases. These will be mentioned at the end of this discussion.

Chemical papers in particular often are found to contain pinholes. When this occurs, it is likely that even some very large dust particles will penetrate.

Unless an air filter medium is manufactured especially for the purpose, its performance characteristics are likely to vary from lot to lot. Chemical filter papers are manufactured for chemical laboratory work. They are made and used primarily for wet filtrations. Therefore it is not surprising that wide variation in air filtration is often found for chemical filter paper. Table VII

lists some experimental results that illustrate this point.

The membrane filter is relatively new, but it holds great promise as an all-round assay medium (7,8). It is highly efficient, may be obtained in white or black, particles accumulate only on the surface, refractive index is such that the filter structure itself becomes invisible for oil immersion microscope viewing, and the filter can be dissolved if need be or it may be destroyed in other ways. Because they are very delicate, the membranes must be handled carefully and supported during use. To generalize, there appear to be more useful properties associated with membrane filters than with any other one medium.

The felt-like papers CWS #6, AEC #1, and the AEC mineral fiber papers were designed for efficient air cleaning and serve that purpose effectively. They are not so well suited for most assay work. Dust particles penetrate the structure so that they are buried and lost for some types of radioactivity measurements (α counts). These papers are so high in ash that they are not at all useable where the filter must be destroyed to perform analysis of the dust. If suitable precautions are taken they may be used for gravimetric sampling on even the finest of dusts and fumes.

HV 70 is a closely formed paper and has found use particularly in radioactivity monitoring.

All-glass papers, like those developed by Naval Research Laboratories (10) and made to a limited extent by several paper companies, are to be recommended for high temperatures or in the presence of corrosive fumes or gases. In our series the Hurlbut glass paper is an example. These papers are made of very fine glass fibers and are the most efficient of fibrous filters. Some have resin or other binders, and this should be burned out before using the sheet in most kinds of test work. In gravimetric work care must be taken that loose

fibers are not lost from the sheet.

All fibrous filters, cellulose or glass, have water associated or adsorbed in their structures. The amount depends upon atmospheric humidity and will vary. In weighing the amount of dust load collected by such filters, it is very important to condition the filter at a known humidity level before every weighing and to weigh the filter in a closed container.

Dust collected on a fibrous filter will penetrate the filter body to some extent. For this reason it is very difficult, if not impossible, to make dust studies under the microscope on most paper filters.

SUMMARY:

A group of atmospheric dust sample media has been studied for performance characteristics. The media were selected to represent those in use in a number of laboratories. Test methods used were di-octyl phthalate smoke penetration, atmospheric dust penetration, efficiency by particle size, and plugging rate on atmospheric dust. A wide range of properties were shown.

The filtering properties have been discussed and the suitability of the media for various applications have been indicated.

It has been demonstrated that efficiency measurements by the DOP smoke test follow very closely the results given by atmospheric dust counts. This suggests that the fast DOP method can be used to rate any filter medium on percent of atmospheric dust penetration by particle count.

ACKNOWLEDGMENT:

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REFERENCES

1. David Sinclair, "Physical Properties of Aerosols," Air Pollution, Louis C. McCabe, McGraw Hill, Ch. 18, p. 169 (1952)
2. Victor K. LaMer, "Preparation, Collection, and Measurement of Aerosols," Air Pollution, Louis C. McCabe, McGraw Hill, Ch. 74, p. 607 (1952)
3. Frank T. Gucker, Jr., "Instrumental Methods of Measuring Mass Concentration and Particulate Concentration in Aerosols," Air Pollution, Louis C. McCabe, McGraw Hill, Ch. 75, p. 617 (1952)
4. Eugene A. Ramskill and Wendell L. Anderson, "The Inertial Mechanism in the Mechanical Filtration of Aerosols," Jl. Colloid Science, Vol. 6, No. 5, pp. 416-428 (Oct. 1951)
5. Leslie Silverman and Frederick J. Viles, Jr., "A High Volume Air Sampling and Filter Weighing Method for Certain Aerosols," Jl. Ind. Hygiene and Toxicology, Vol. 30, No. 2 (1948)
6. Sonkin, Jl. Ind. Hygiene and Toxicology, Vol. 28, No. 6, pp. 269-272, (1946)
7. Melvin H. First and Leslie Silverman, "Air Sampling With Membrane Filters," A.M.A. Archives of Indust. Hygiene and Occ. Medicine, Vol. 7, pp. 1-11 (Jan. 1953)
8. A. Goetz, "Aerosol Filtration with Molecular Filter Membranes," Chem. and Eng. News, 29, 193 (1951)
9. Earl Stafford and Walter J. Smith, "Dry Fibrous Filters for High Efficiency Air Cleaning," Air Pollution, Louis C. McCabe, McGraw Hill, p. 264 (1952)
10. Thomas D. Callinan and Robert T. Lucas, "The Manufacture and Properties of Paper Made From Ceramic Fibers", Naval Research Laboratory, Washington, D.C., (October 20, 1952) NRL Report 4044

TABLE I
Effect of Flow Rate on Pressure Drop^a and DOP Smoke Penetration^b for Various Air Sampling Media

| Flow Rate Linear Feet Per Minute | ABC / 1 | CNS # 6 | HV 70 2 mil 18 mil | Huribud Glass Paper | Whatman Chemical Filter Papers | | | | | | | | | | S&S #60 | Membrane Filters "HA" "AA" | AEC Mineral Filters Class-Abb. All-Class | YSA Type #3 |
|----------------------------------------|---------------|---------------|-----------------------|------------------------|-----------------------------------------------------------|-----------------------------------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------|-------------------------------------------------------------------|-------------------------------------------------------------------|-------------------------------------------------------------------|-------------------------------------------------------------------|--------------------------------------------------------------------|------------------------------------------------------------|---------------|-------------------------------|---------------------------------------------|-------------|
| | | | | | 1 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 | 73 - 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 | | | | |
| 5 | 0.022 1.45 | 0.015 0.57 | 5.0 1.1 | 0.47 1.2 | 0.001 1.05 | 73 - 81 1.9 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 3.7 7.2 | 89 2.5 | 93 0.45 | 93 8.7 | 93 7.7 | 93 9.5 | 93 30. | 0.002 5.4 | 0.002 4.3 | 0.009 0.7 | 0.008 0.75 | 45. 0.3 |
| 10 | 0.026 1.45 | 0.023 1.45 | 5.0 2.2 | 0.53 2.45 | 0.001 2.2 | 68 - 81 3.75 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 3.0 14.6 | 26 5.1 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 0.9 | 89 17. | 89 15.3 | 89 17.7 | 89 13. | 0.002 10.9 | 0.002 8.5 | 0.052 1.45 | 0.050 1.45 | 50. 0.6 |
| 20 | 0.045 2.9 | 0.04 2.9 | 3.5 4.6 | 0.65 4.9 | 0.003 4.4 | 43 - 77 7.7 | 45 - 16 27.3 | 16 10.7 | 77 - 81 1.35 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 1.9 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 1.4 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 3.0 | 81 - / 4 - / 32 - / 10 - / 41 - / 41H - / 42 - / 44 - / 50 35.2 | 0.01 21.6 | 0.01 11.8 | 0.071 3.0 | 0.038 3.05 | 52. 1.6 |
| 28 | 0.055 4.2 | 0.057 4.05 | 2.0 6.3 | 0.59 5.9 | 0.005 6.1 | 27 - 73 10.6 | 0.35 38. | 8 15. | 73 - 76 2.0 | 76 - 81 2.7 | 76 - 81 0.5 | 76 - 81 48.5 | 76 - 81 0.9 | 0.015 31. | 0.015 24.5 | 0.073 4.25 | 0.05 4.25 | 52. 1.6 |
| 50 | 0.045 6.7 | 0.045 7.5 | 2.7 9.4 | 0.45 13. | 0.005 10.8 | 11 - 62 19.6 | 0.3 69.4 | 2.8 25.3 | 62 - 65 3.8 | 65 - 81 5.5 | 65 - 81 0.2 | 65 - 81 86.0 | 65 - 81 0.15 | 0.015 59.5 | 0.02 39. | 0.08 7.8 | 0.051 7.7 | 51. 3.0 |
| 100 | 0.031 13.3 | 0.037 17.0 | 0.2 21.8 | 0.1 27. | 0.005 19.8 | 1.2 40.5 | 25 - 54 11.5 | 0.23 54. | 44 - 54 8.1 | 44 - 54 11.5 | 44 - 54 - | 44 - 54 - | 44 - 54 - | - | - | 0.04 16.0 | 0.025 15.2 | 45. 6.5 |
| 150 | 0.021 22.5 | 0.018 25.5 | 0.1 34.5 | 0.085 38.2 | 0.003 32.5 | 0.3 60. | 12 - 18.1 - | - | 29 - 32.5 12.5 | 29 - 32.5 17.0 | 29 - 32.5 - | 29 - 32.5 - | 29 - 32.5 - | - | - | 0.018 26.7 | 0.013 25. | 34. 10.8 |
| 200 | 0.011 29.5 | 0.01 35. | - | - | - | - | - | - | 15 - 17.8 24.0 | 15 - 17.8 24.0 | 15 - 17.8 - | 15 - 17.8 - | 15 - 17.8 - | - | - | - | - | 28. 16.3 |

^aPressure Drop in inches of water.

^bDOP Smoke Penetration in per cent. (Di-Octyl Phthalate particles 0.3 micron diameter, 50 micrograms/liter of air.)

317

TABLE II

Impactor Count Efficiency on Sub-micron Atmospheric Dust Particles
Compared with DOP Efficiency for Various Air Sampling Media

FLOW RATE 20 LINEAR FEET PER MINUTE

| <u>Filter Medium</u> | <u>Atmospheric Dust Count Efficiency Per Cent^a.</u> | <u>DOP Efficiency Per Cent^b.</u> |
|------------------------------------|------------------------------------------------------------------------|-------------------------------------------------|
| Whatman Chemical Filter Paper Nos: | | |
| 1 | 50. | 57. |
| 4 | 15. | 23. |
| 32 | 99.1 | 99.5 |
| 40 | 85.1 | 84. |
| 41 | 26.5 | 23. |
| 41H | 24. | 19. |
| 42 | 98.8 | 99.2 |
| 44 | 97. | 98.6 |
| 50 | 92. | 97. |
| 540 | 67. | 65. |
| S & S #604 | 13. | 15. |
| HV 70 9 mil | 96.5 | 96.5 |
| HV 70 18 mil | 99.5 | 99.3 |
| MSA Type "S" | 46. | 48. |
| Millipore Type "HA" | | 99.9+ |
| Millipore Type "AA" | | 99.9+ |
| S & S Ultra Filter | | - |
| Hurlbut Glass Paper | (No particles found after 6 hours running.) | 99.99+ |
| CWS #6 | | 99.9+ |
| AEC #1 | | 99.9+ |
| AEC Glass-Asbestos | | 99.9+ |
| AEC All-Glass | | 99.9+ |

^a. Average of 4 tests.

^b. Calculated from Table I.

318

TABLE III

Particle Size Distribution in Atmospheric Dust
Before and After Filtration Through Different Media

COUNT ANALYSIS OF AIR BORNE PARTICLES - PER CENT OF EACH SIZE

| Particle Diameter - Microns - | Unfiltered Air | F i l t e r e d A i r | | | | |
|----------------------------------|-------------------|-----------------------|------------|-------------|-------------|----------|
| | | Whatman #1 | Whatman #4 | Whatman #41 | Whatman #42 | EISA "S" |
| below 0.4 | 31.8 | 52.8 | 45.2 | 47.4 | 51.0 | 50.0 |
| .4 - 0.6 | 42.6 | 35.3 | 38.1 | 40.3 | 39.3 | 41.8 |
| .6 - 0.8 | 16.2 | 10.6 | 14.2 | 9.1 | 8.5 | 7.0 |
| 0.8 - 1.0 | 6.8 | 1.1 | 1.9 | 2.4 | 1.1 | 1.0 |
| 1.0 - 2.0 | 1.6 | 0.2 | 0.6 | 0.8 | 0.1 | 0.2 |
| over 2.0 | 1.0 | - | - | - | - | - |

Notes: Flow Rate: 20 linear feet per minute
through the medium.

Each value based on counts for two filters with no fewer than 40 counts each point each filter.

Particles collected sonic velocity im-
pactor. Counts and measure-
ments by oil immersion micro-
scope 1350X.

319

TABLE IV

Filtering Efficiency^a. by Particle Size for Each of Several Air Sampling Media

FLOW RATE 20 FEET PER MINUTE

| Particle Diameter - Microns - | Whatman #1 | Whatman #4 | Whatman #41 | Whatman #42 | MSA Type "S" |
|-------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| below 0.4 | 57 ^b . | 23 ^b . | 23 ^b . | 99 ^b . | 48 ^b . |
| 0.4 - 0.6 | 58. | 32. | 28. | 97. | 47. |
| 0.6 - 0.8 | 69. | 38. | 64. | 98. | 77. |
| 0.8 - 1.0 | 92. | 79. | 74. | 99.3 | 92. |
| 1.0 - 2.0 | 95. | 74. | 70. | 99.8 | 94. |
| above 2.0 | 100. | 100. | 100. | 100. | 100. |

a. Efficiency for particle retention in per cent by count. Particles above 0.4 micron diameter collected by high-speed cascade impactor.

b. DOP smoke value used for particles below 0.4 micron diameter.

TABLE V

Life Tests - Change of Pressure Drop Across Air Sampling Media with Operating Time

| Flow Rate Linear Feet Per Minute | ASZ CW3 | | HV 70 | | Hurlbut Glass Paper | Whatman Chemical Filter Papers | | | | S & S F504 | Membrane Filters | | ABC Mineral Filters | | Approx. Fust Load | | | | | |
|----------------------------------------|---------|------|-------|--------|------------------------|--------------------------------|------|------|------|---------------|------------------|-----|---------------------|------|----------------------|------|------------|-----------|---------------|------|
| | #1 | #6 | 9 mil | 16 mil | | #1 | #4 | #32 | #40 | | #41 | #44 | #50 | "HA" | | "1A" | Class-13b. | All-Glass | PSA Type - 3" | |
| 0 | 0.72 | 0.72 | 0.95 | 1.05 | 0.95 | 1.9 | 0.48 | 7.0 | 2.45 | 0.35 | 0.5 | 6.5 | 6.0 | 9.5 | 0.35 | 5.4 | 2.3 | 0.7 | 0.7 | 0.17 |
| 24 | 0.75 | 0.75 | 1.15 | 1.2 | 1.0 | 5.2 | 0.80 | 9.45 | 5.7 | 1.2 | 0.85 | 28. | 16.5 | 27. | 0.65 | 5.45 | 2.5 | 0.75 | 0.7 | 0.17 |
| 48 | 0.75 | 0.75 | 1.2 | 1.25 | 1.0 | 6.2 | 1.15 | 11.0 | 6.85 | 1.5 | 1.55 | - | - | - | 0.8 | 5.5 | 2.6 | 0.75 | 0.7 | 0.2 |
| 120 | 0.85 | 0.8 | 1.4 | 1.4 | 1.1 | 7.3 | 2.3 | 12.8 | 8.2 | 2.15 | 3.3 | - | - | - | 1.8 | 5.7 | 2.6 | 0.8 | 0.7 | 0.2 |
| 192 | 0.85 | 0.9 | 1.55 | 1.7 | 1.1 | 8.0 | 3.2 | - | 9.0 | 2.7 | 4.5 | - | - | - | 2.6 | 5.9 | 2.8 | 0.9 | 0.75 | 0.22 |
| 268 | 0.95 | 1.0 | 1.8 | 1.95 | 1.2 | 8.5 | 3.9 | - | - | 3.35 | 6.8 | - | - | - | 3.15 | 6.4 | 3.0 | 1.0 | 0.85 | 0.25 |
| 336 | 1.00 | 1.05 | 1.9 | 2.0 | 1.2 | - | 4.15 | - | - | 3.9 | - | - | - | - | 3.45 | 6.7 | 3.1 | 1.2 | 0.85 | 0.25 |
| 384 | 1.05 | 1.05 | 1.9 | 2.0 | 1.25 | - | 4.15 | - | - | 4.0 | - | - | - | - | 3.5 | 7.1 | 3.15 | 1.25 | 0.85 | 0.25 |
| 480 | 1.05 | 1.1 | 1.95 | 2.1 | 1.25 | - | 4.25 | - | - | 4.3 | - | - | - | - | 3.55 | 8.1 | 3.2 | 1.35 | 0.85 | 0.25 |

| Flow Rate Linear Feet Per Minute | ASZ CW3 | | HV 70 | | Hurlbut Glass Paper | Whatman Chemical Filter Papers | | | | S & S F504 | Membrane Filters | | ABC Mineral Filters | | Approx. Fust Load | | | | | | | |
|----------------------------------------|---------|------|-------|--------|------------------------|--------------------------------|----|-----|-----|---------------|------------------|-----|---------------------|------|----------------------|------|------------|-----------|---------------|---|---|---|
| | #1 | #6 | 9 mil | 16 mil | | #1 | #4 | #32 | #40 | | #41 | #44 | #50 | "HA" | | "1A" | Class-13b. | All-Glass | PSA Type - 3" | | | |
| 0 | 5.6 | 6.15 | 11.0 | 11.7 | 7.0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | |
| 24 | 5.8 | 6.35 | 11.5 | 12.1 | 7.15 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 48 | 6.1 | 6.6 | 12.6 | 14.2 | 7.4 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 72 | 6.6 | 6.85 | - | - | 7.6 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 120 | 7.0 | 7.4 | - | - | 8.4 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

Test Continued at 28 FPM

Continued at 28 FPM

Cont'd at 5 FPM

28 FPM
Except
where
otherwise
noted.

Figures show pressure drop in inches of water.

TABLE VI

Some General Properties of Air Sampling Media

| Material | Type or No. | Manufacturer or Source | Thickness Inches | Ash Content | | Description | Present Application in Air Sampling |
|-----------------------------------------|-------------------------------|----------------------------------|---------------------|----------------------------------|---------------------------------------------------------------|------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| | | | | Grams per 9cm Diameter Circle | (unless other. stated) | | |
| Chemical Filter Papers | # 1 | W. & R. Balston Ltd., England | .008 | .00039 | | White cellulose papers of various grades. | Tests depending on discoloration or change in light transmission. |
| | 4 | | .005 | | | | |
| | 32 | | .010 | | | | |
| | 40 | | .010 | | | | |
| | 41 | | .010 | | | | |
| | 41H | | .007 | | | | |
| | 42 | | .010 | | | | |
| | 44 | | .008 | | | | |
| | 50 | | .005 | | | | |
| | 540 | | .006 | low ash | | | |
| | S&S 604 | Schleicher & Schuell Co. | .008 | .0002 | | | |
| Membrane Filters | "HA" | Lovell Chemical Co. | .005 | 1.5% | Porous cellulose ester films. | Particulate counts, identification by microscope. "Final stage" for impactor & counting. | |
| | "AA" | | .005 | 1.5% | | | |
| | Ultra Filter membrane type | S & S Co. | .005 | | | | |
| HV - 70 | 9 mil | Hollingsworth & Vose | .009 | 14% | Asbestos bearing cel- lulose base paper. | General air assay & radio activity moni- toring. | |
| | 18 mil | | .018 | 14% | | | |
| M S A | "S" | Mine Safety Appliances Co. | .040 | 1.3% | Molded cellulose - concentric convolutions | High volume air sampling. | |
| | | | .010 | 95% | | | |
| Glass Paper | | Hurlbut Paper Co. | .010 | | Fine glass paper - resin binder. | High efficiency par- ticulate removal. | |
| C W S A E C | #6 | Hollingsworth & Vose | .030 | 11% | Felt-like paper as- bestos & cellulose | High efficiency par- ticulate removal. | |
| | #1 | | .050 | 13% | | | |
| AEC Mineral Asbestos Filter Glass | | Arthur D. Little, Inc. | .030 | 95.0% | Glass & asbestos. All-Glass Both with resin binders. | High efficiency par- ticulate removal. | |
| | | | .030 | 95.0% | | | |

TABLE VII

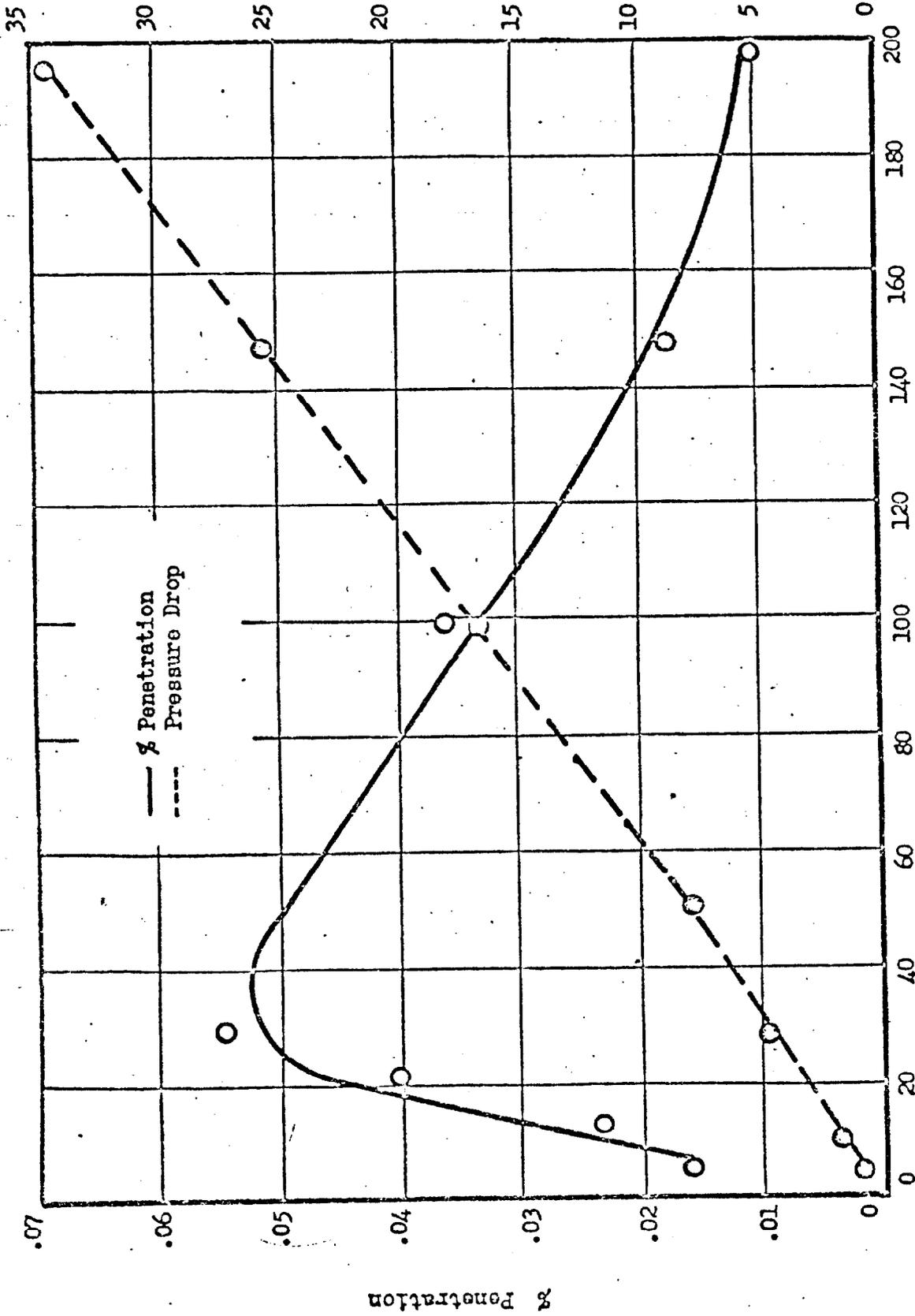
Variations in DOP Smoke Penetration and Pressure Drop at 28 FPM
for Various Samples of Chemical Filter Papers

| Whatman Filter Paper No. | Reported Results (Table I) | | Range | | No. Boxes Tested ¹ |
|-----------------------------|------------------------------------|------|------------------------------------|-------------|----------------------------------|
| | ΔP In. of Water - % Penet. | | ΔP In. of Water - % Penet. | | |
| 1 | 10.6 | 27. | 9.5 - 12.8 | 12. - 28. | 5 |
| 4 | 2.8 | 73. | 2.2 - 2.8 | 72. - 75. | 2 |
| 32 | 38. | 0.35 | 38. - 45. | .008 - 0.35 | 1 |
| 40 | 15. | 8. | 13. - 15. | 8. - 13. | 2 |
| 41 | 2.0 | 75. | 2.0 - 4.2 | 49. - 75. | 4 |
| 41H | 2.7 | 76. | 2.7 | 76. - 82. | 1 |
| 42 | 45.5 | 0.22 | 44. - 55. | .05 - .9 | 4 |
| 44 | 40. | 0.5 | 40. - 48. | 0.25 - 0.5 | 1 |
| 50 | 48.5 | 0.9 | 48. - 61. | 0.3 - 1.2 | 2 |

¹Three samples tested in each box.

223

Pressure Drop-Inches of Water



Velocity-Linear Feet Per Minute

— % Penetration
- - - - Pressure Drop

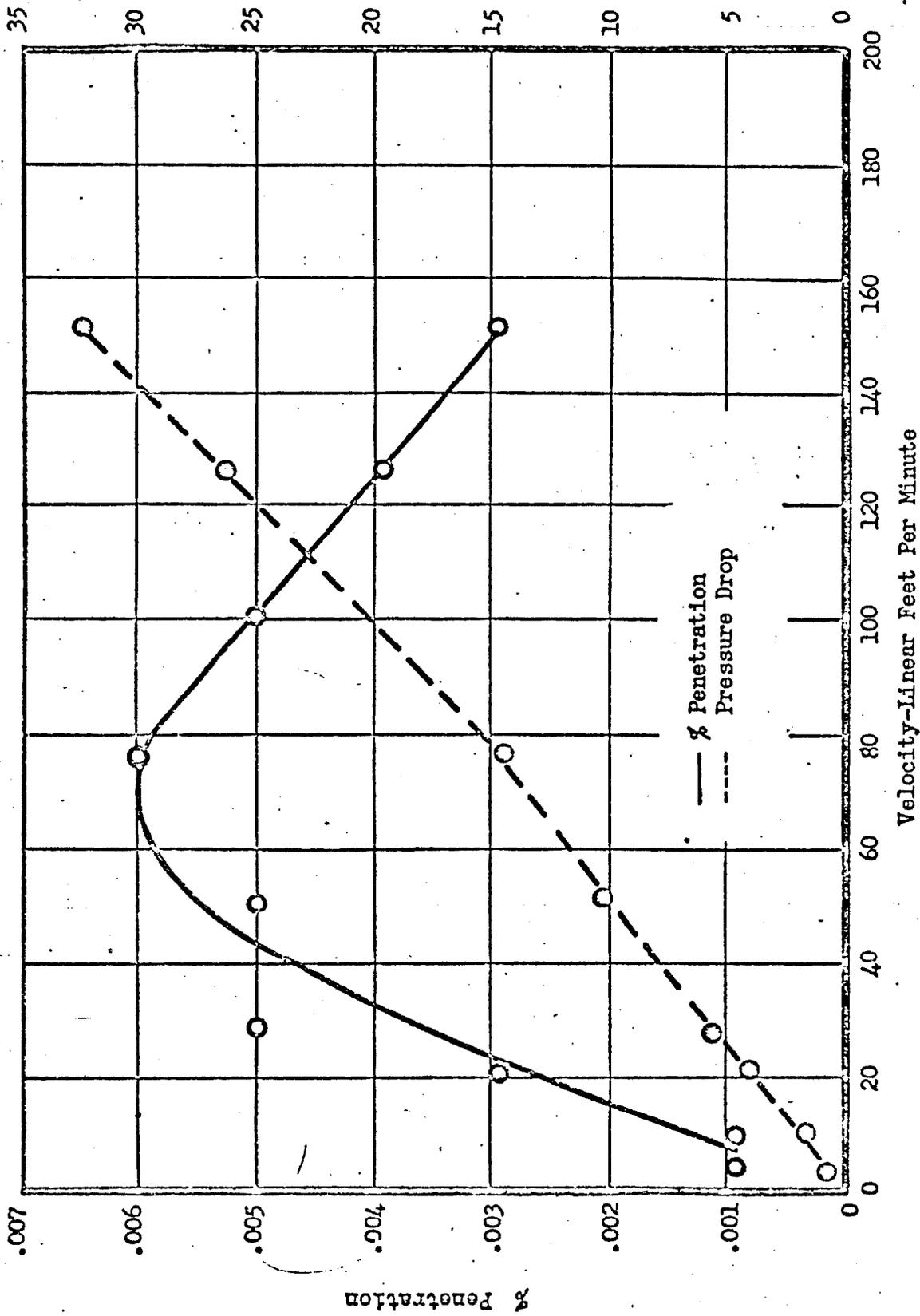
FIGURE 1

DOP SMOKE PENETRATION AND PRESSURE DROP VERSUS VELOCITY FOR C.W.S. NO. 6 PAPER

% Penetration

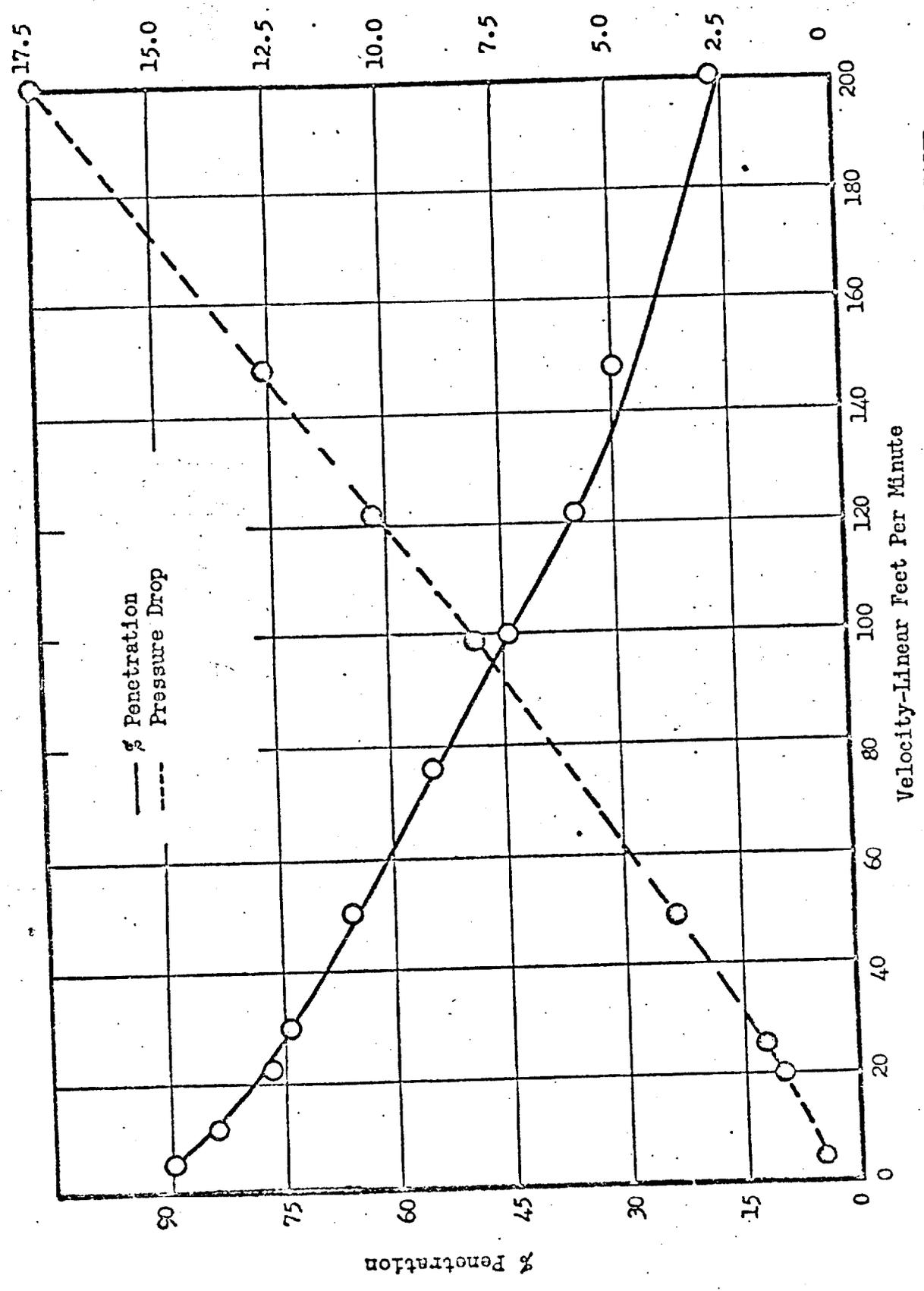
324

FIGURE 2



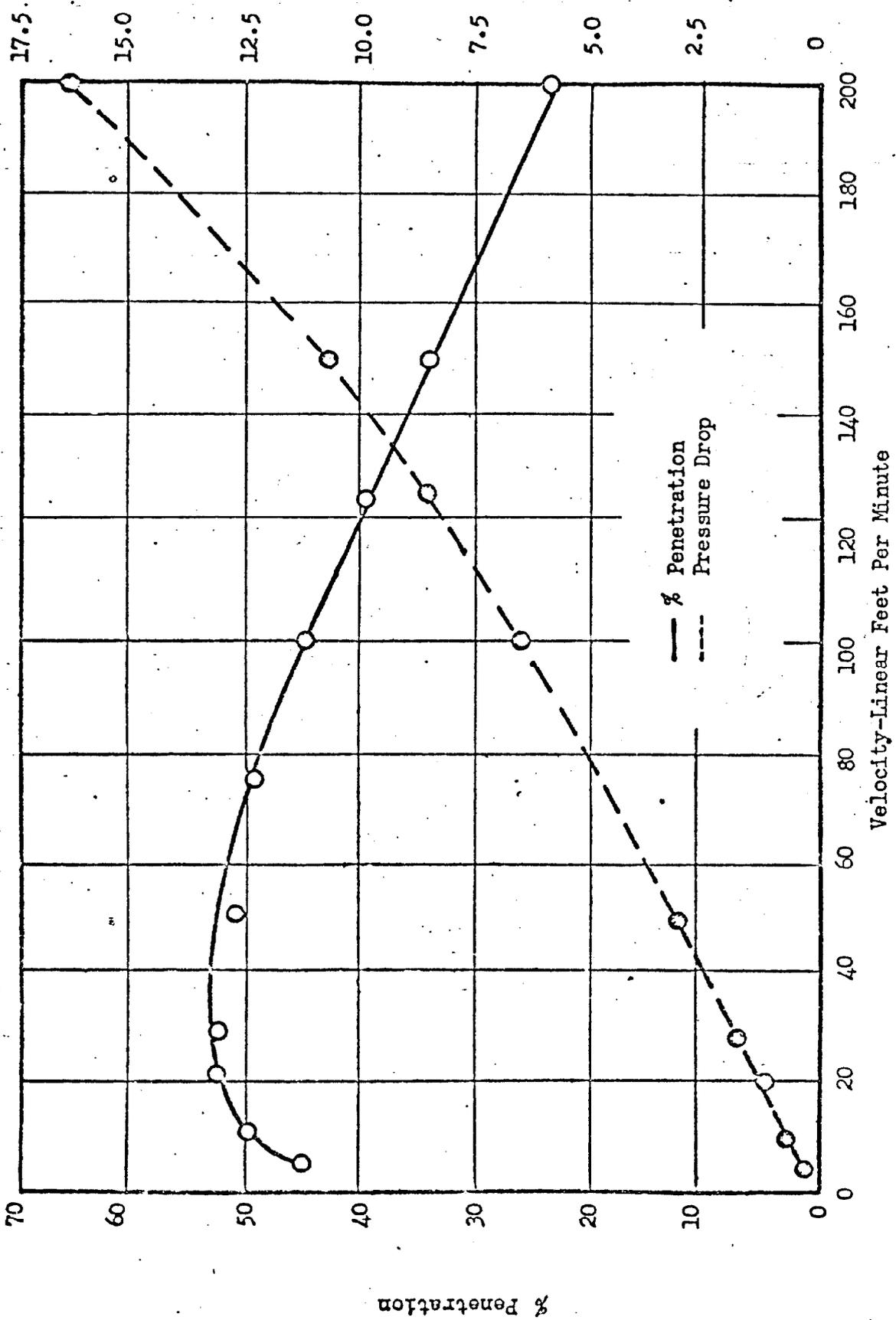
DOP SMOKE PENETRATION AND PRESSURE DROP VERSUS VELOCITY FOR HULBUT GLASS FIBER PAPER

FIGURE 3



DOP SMOKE PENETRATION AND PRESSURE DROP VERSUS VELOCITY FOR WHATMAN NO. 41 PAPER

FIGURE 4



DOP SMOKE PENETRATION AND PRESSURE DROP VERSUS VELOCITY FOR M.S.A. TYPE "S" FILTER

127

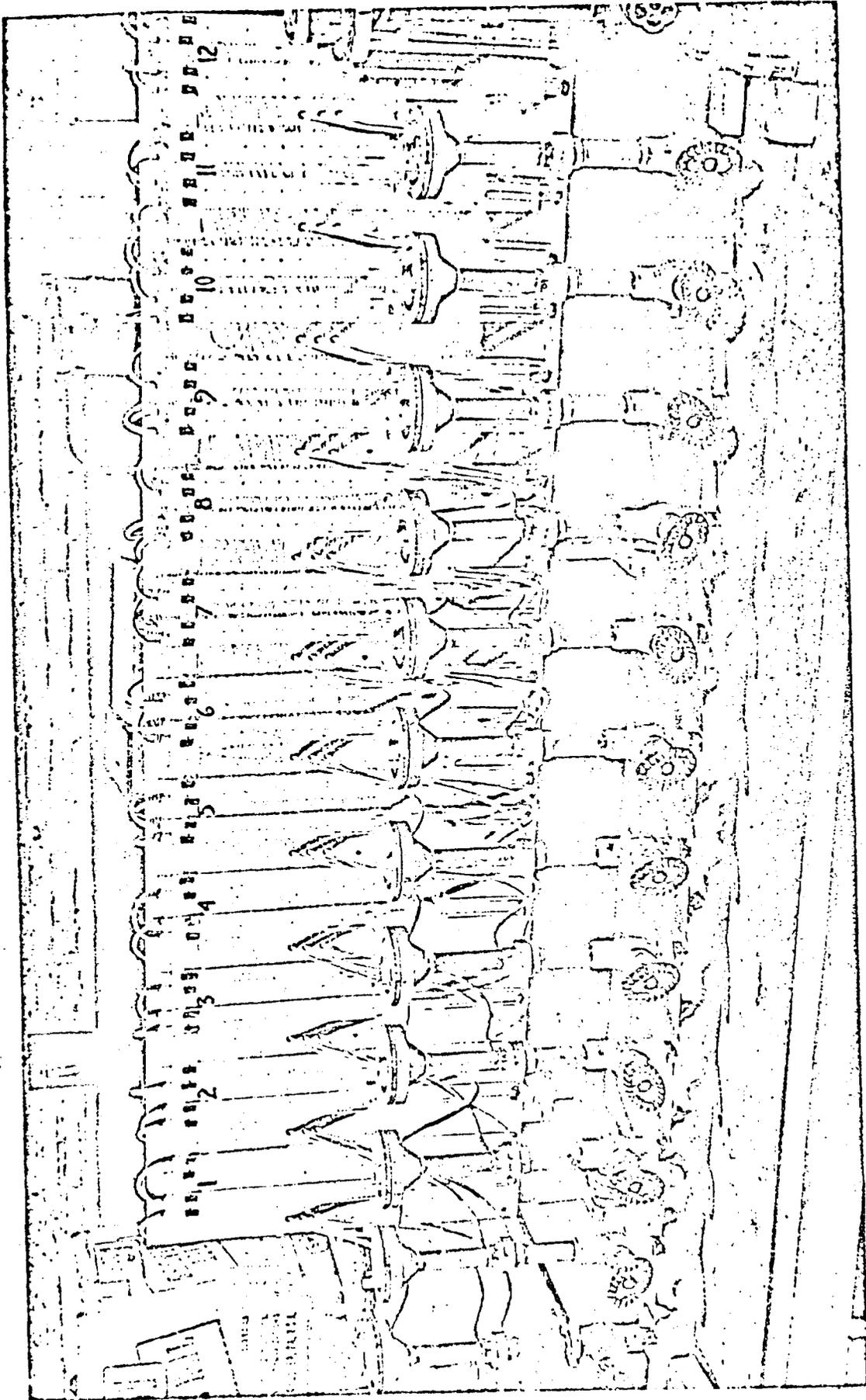


FIGURE 5. LIFE TESTERS FOR AIR FILTER MEDIA

82

SURVEY OF AIR SAMPLING MEDIA AND SAMPLING METHODS

USED AT A.E.C. AREAS AND BY OTHERS

By W. J. Smith, A. D. Little, Inc.

At the A.E.C. Air Cleaning Conference held at Ames, Iowa, September 15-17, 1952, it was agreed that a survey should be made to assemble and summarize information on air sampling media and sampling methods used by groups doing air assay work. This survey was to include both A.E.C. areas and others.

The survey was conducted by questionnaire, and an excellent and highly cooperative response was received. A fund of information has resulted which should be of real value to all engaged in air cleaning and in the study of airborne particulate matter.

An effort has been made to show in a single chart all of the essential information supplied by the survey. A copy of the chart is inserted at end of report. For the most part it is self-explanatory.

Across the top of the sheet are given the laboratories and installations along with the media favored at each site. In some cases several media are used to meet different needs, and this fact is shown.

The side headings represent the various questions that were asked in the survey. Many of these required only a "yes" or "no" reply; others needed more detail. Where an essential piece of information was too lengthy to fit into the chart body, it is shown as a footnote.

QUESTIONNAIRES RECEIVED

| <u>Organization or AEC Area</u> | <u>Location</u> | <u>Individual</u> |
|-----------------------------------------------------------------------------------------------------------------------------------|-------------------------|----------------------|
| Air Sampling Equipment Company | Cleveland, Ohio | William L. Wilson |
| American Cyanamid Company Idaho Reactor Testing Sta. Chemical Processing Plant | Idaho | R. E. Hayden |
| Ames Area Office, AEC Iowa State College | Ames, Iowa | Allan P. Skoog (Dr.) |
| Argonne National Laboratory Radiological Physics Div. | Illinois | J. E. Rose |
| Battelle Memorial Institute | Columbus, Ohio | S. Chapman |
| Brookhaven National Laboratory Health Physics Division Depts. of Physics, Chemistry, Nuclear Engineering and Medecine | New York | Lee Gemmell |
| Brush Beryllium Co. Cleveland Plant | Cleveland, Ohio | F. R. Wolowicz |
| Luckey Plant | Luckey, Ohio | F. R. Wolowicz |
| Harshaw Chemical Company | Cleveland, Ohio | A. J. Stefanec |
| Vitro Manufacturing Co. Health and Safety Div. | - | E. A. McCabe |
| California, University of AEC Project Contract AT-04-1-GEN-12 | Los Angeles, California | Robert J. Buettner |
| Radiation Laboratory | Los Angeles, California | M. D. Thaxter |
| California Research & De- velopment Company Livermore Research Lab. | California | R. C. Thorburn |
| Carbide and Carbon Chemicals Co. Paducah Plant | Paducah | R. C. Baker |
| Y-12 Area | - | Edward G. Struxness |
| K-25 Area, C & CCC | - | J. C. Bailey |

DECLASSIFIED

| <u>Organization or AEC Area</u> | <u>Location</u> | <u>Individual</u> |
|--------------------------------------------------------------------------------------------------------------|------------------------------------------------------|------------------------------------------------|
| Chaney, Albert L. Laboratory | Los Angeles, California | Stanley R. Hall (Dr.) |
| Columbia University Central Aerosol Lab. | New York, New York | Prof. V. K. LeMer |
| Dept. of Chemical Eng. | New York, New York | Arthur Humphrey |
| Connecticut State Dept. of Health Bureau of Industrial Hygiene Industrial Hygiene Lab. | Connecticut | Allan L. Coleman |
| Dow Chemical Company Rocky Flats Plant | - | - |
| General Electric, ANP, Evendale | Evendale | J. A. Martin |
| Industrial Hygiene Foundation for America, Inc. Mellon Institute | Pittsburgh, Pennsylvania | W. C. L. Hemeon |
| Johns-Manville Research Center CWS Contract (not connected with AEC) | Manville, New Jersey | David Sinclair |
| Knolls Atomic Power Lab. Health and Safety Unit | - | L. J. Cherubin R. Z. Bouton |
| Los Alamos Scientific Lab. H-1 Radiological Monitoring Section of H Div. Santa Fe Operations Office | Los Alamos, New Mexico Los Alamos, New Mexico | Dean D. Meyer H. F. Schulte Ed Hyatt |
| Massachusetts, Commonwealth of Mass. Dept. of Labor & Industries Division of Occupational Hygiene | Massachusetts | Hervey B. Elkins |
| Monsanto Chemical Co. Mound Laboratory | Miamisburg, Ohio | J. E. Bradley |
| National Bureau of Standards U.S. Dept. of Commerce Heating and Air Conditioning Section | Washington, D. C. | R. S. Dill |
| National Lead Company of Ohio Fernald Area | Ohio | R. C. Heatherton |

037201030

| <u>Organization or AEC Area</u> | <u>Location</u> | <u>Individual</u> |
|---------------------------------------------------------------------------------------------------------|--------------------------------------|-------------------------------------|
| National Reactor Testing Station U.S.A.E.C. Health Physics Division U.S. Weather Bureau Office | - | P. Griffiths C. W. Sill |
| North American Aviation, Inc. Atomic Energy Research Dept. | - | Paul A. Humphrey Alan A. Jarrett |
| Oak Ridge National Laboratory Health Physics Division | - | D.M. Davis |
| Phillips Petroleum Co. Materials Testing Reaction | Idaho Falls, Idaho | J.W. McCaslin |
| National Reactor Testing Station | - | - |
| Rochester, University of Atomic Energy Project | New York | Robert H. Wilson |
| Savannah River Plant duPont Health Physics Dept. | - | C.M. Patterson |
| Stanford Research Institute | Stanford, California | Konrad Semrau |
| Sylvania Electric Products, Inc. | Bayside & Hicksville, Long Island | Robert P. Gleason |
| Westinghouse Electric Corp. Atomic Power Division Industrial Hygiene | - | Paul R. Bolton |

DECLASSIFIED

EVALUATION OF THE KAPL SEPARATIONS PROCESS STACK EFFLUENT

By J. J. Fitzgerald, GE, KAPL

ABSTRACT

The KAPL Separations Process stack effluent is evaluated. The adequacy and the efficiency of all the sampling instruments are determined. The size of the particles entrained in the stack are studied under both the light and the electron microscope. The mean particle size is less than 0.05 microns. Autoradiographs of the particulate material indicate that the majority of the activity is deposited on these sub-micron particles.

Chemical separations of the material deposited on the Hollingsworth and Vose, H-70 filter papers and the caustic scrubber are made. The rare earths comprise the largest portion of the particulate activity while Ru-106 is given off in relatively large quantities during the Head End Operation.

The relative percentages of the activities given off during the most important phases of the Separations Process are tabulated. The KAPL stack effluent is then evaluated on the basis of the MPC recommended in the Bureau of Standards Handbook 52.

EVALUATION OF THE KAPL SEPARATIONS PROCESS STACK EFFLUENT

An evaluation of the KAPL stack effluent from the operation of the separations process was conducted; to determine the environmental and biological effects of the Pilot Plant operations, to establish maximum permissible limits for discharge of the effluent to the atmosphere, and to determine whether more stringent control of the discharge of activity would be required at higher (gm Pu/ton U) operating levels.

The air monitoring and air cleaning system for the separations process operations is schematically illustrated in Figure KH-9A2403. This stack is approximately 100 feet high and 3 feet in diameter. The gaseous and particulate material emanating from the separations process is passed through a caustic scrubber which takes out some of the volatile components while the CWS-6 filters are over 99 per cent efficient in the collection of most particles. The stack effluent is sampled at the top of the stack after it has been diluted by a factor of approximately 10^3 by the room air. At distances from the stack, constant air monitors are located in selected sites to check the radioactive concentrations at various points near ground level. Vegetation samples are collected and analyzed on a regular schedule to evaluate the accumulation of radioactivity on the vegetation.

The evaluation of the stack effluent required the knowledge of; the total activity discharged, the particle size distribution of the activity discharged from the stack, the isotopic composition of this activity, and the dispersal of the radioactive material from the stack. Each of these requisites will be discussed briefly.

TOTAL ACTIVITY

The determination of the total activity discharged from the stack involved the investigation of; the adequacy of the sampling units, the efficiency of each of the sampling units, representative sampling, and the absorption of alpha and beta activity in the filter media.

As illustrated in Figure KH-9A2403, the sampling system consists of a filter unit to collect efficiently the entrained particulate material followed by a caustic scrubber to collect such radioactive components as ruthenium and iodine which may be readily volatilized. This sampling system was considered adequate since it collects or detects a portion of the radioactivity discharged from the stack with a known efficiency. The efficiencies of the Hollingsworth and Vose, H-70 filter paper were determined for a particle density of 2.7 gm/cm^3 over a wide range of particle sizes and linear face velocities. At an operating face velocity of approximately 5 cm/sec the H-70 filter paper was 97.7 per cent for 0.2 micron particles. The efficiency of the caustic scrubber shown in Figure KH-1104414 was determined for a variety of flow rates, quantities of berl saddles and of caustic solutions. In the range of operating flow rates the efficiency was 95 per cent for the collection of volatile iodine.

Isokinetic sampling was considered since it is not only necessary that the monitoring system be adequate but that the sample taken be representative. Although the system was designed for isokinetic sampling, particle size analyses

made the need for the balancing of the sampling and stack linear flow rates less stringent.

Absorption studies of the alpha and beta fission product activity of the entrained particulate material collected in the H-70 filter papers revealed average absorptions of 55 and 25 per cent for the alpha and beta activities, respectively.

PARTICLE SIZE DISTRIBUTION OF STACK EFFLUENT

Since the stack effluent due to separations operations is composed of a heterogeneous mixture of entrained radioactive and non-radioactive particles, the particle size distribution was studied in relation to the physical size of the heterogeneous mixture of the particles, and in relation to the radioactive distribution.

The molecular filter paper was used as a filtering medium to collect a representative sample of the stack effluent. This type of filter paper was chosen for its efficiency in the collection of submicronic particles and ease in detecting particles in the same medium under the microscope. The particle size distribution during various chemical operations of the Separations Process are illustrated in Figure KH-9A2354. The data reveal the abundance of submicronic particles and the similarity of distributions during various phases of the chemical process. A geometric mean of 0.2 micron in each case is readily observed when the data are plotted on log-probit paper as shown in Figure KH-9A2354. An average of 10 analyses during all phases of the process as shown in Table 1, indicated a geometric mean of 0.2 micron and a standard deviation of 2.7. Since the limit of detection with the light microscope is 0.1 micron, it was felt at the time that the true geometric mean was less than 0.2 micron. This feeling was later substantiated by electron microscopic analyses of the filter samples and by autoradiographic studies of the radioactive particle size distribution.

TABLE 1

SIZE DISTRIBUTIONS OF PARTICULATE MATERIAL

| <u>Repetitive Run</u> | <u>Separations Operation</u> | <u>Geometric Mean, microns</u> | <u>Standard Deviation</u> |
|-----------------------|------------------------------|--------------------------------|---------------------------|
| 1 | Dissolving | 0.2 | 2.5 |
| 1 | Dissolving | .2 | 3.1 |
| 2 | Dissolving | .2 | 2.9 |
| 2 | Dissolving | .2 | 2.7 |
| 3 | Dissolving | .2 | 2.6 |
| 3 | Dissolving | .2 | 2.6 |
| 4 | Head-End | .2 | 2.5 |
| 4 | Head-End | .2 | 2.3 |
| 4 | Extraction | .2 | 2.9 |
| 5 | Extraction | .2 | 2.4 |

The modified cascade impactor with a molecular filter paper in the fifth stage was used to determine a relationship between particle size and activity.

Even with flow rates of 34 l/min through the impactor, nearly all of the activity was deposited on the molecular filter paper, indicating that most of the activity was composed of or deposited on sub-micronic particles.

Autoradiographic techniques were investigated to determine further the relationship between particle size and radioactivity. A stripping film technique similar to the methods employed by La Riviere* and Boyd** indicated the presence of many sub-microscopic particles and the need for electron microscope studies.

Samples were analyzed under the electron microscope at the General Electric Research Laboratory. Silicon dioxide was evaporated on a small section of the Millipore filter, under a vacuum of 0.1 micron of mercury. This section of the filter paper was then dissolved in acetone. Upon hardening, the silicon retained an impression of the surface structure of the filter and served to hold the sample particles in position. The electron micro-graph of an unexposed filter paper used for control purposes is shown in Figure 1121212. The surface of the Millipore filter paper under a magnification of 15000 is seen in this electron micrograph. The electron micrograph of a portion of an exposed filter paper which had a geometric mean and standard deviation under light microscope studies similar to those previously indicated, is illustrated in Figure 1121213. The number of particles in the range of 0.01 to 0.05 micron are far in excess of those greater than 0.05 micron. The true geometric mean, then, is closer to 0.05 micron than 0.2 micron as determined under the light microscope.

ISOTOPIIC DETERMINATION OF FISSION PRODUCTS DISCHARGED FROM PILOT PLANT STACK

Knowledge of the isotopes contributing to the discharged radioactivity was an important requisite in this investigation. The biological effects and consequently the maximum permissible concentrations depend not only on the level or radioactivity, but also upon the body metabolism of the elements that comprise the activity. To determine the maximum permissible concentration that may be discharged from the Pilot Plant stack, the activity was isotopically analyzed during all phases of the separations process for several repetitive runs.

ISOTOPIIC DETERMINATION OF FISSION PRODUCTS COLLECTED IN THE PARTICULATE FORM

The isotopic composition of the radioactive particulate components present in the effluent was determined by radiochemical analyses of the Hollingsworth and Vose, type H-70, filter papers. These filter papers are used as the particle collecting media in the health physics stack monitoring system.

Radiochemical analyses of the filter paper samples collected during all phases of the separation process revealed that the radioactivity emitted from the Pilot Plant stack in the particulate form was composed of the rare earths, ruthenium, zirconium, niobium, barium, strontium, and iodine.

*USNRDL-342, "An Autoradiographic Method of Detecting and Identifying Beta-Active Particles in a Heterogeneous Mixture," by Philip D. LaRiviere and Stephen K. Ichiki, April 1952.

**UR-209, "Stripping Film Techniques for Histological Autoradiographs," by George A. Boyd and Agnes Williams, May 1948.

During the initial analyses of the stack effluent, separations process operations without variation in procedures were repeated. These processes were called repetitive runs. The relative proportions of beta-gamma emitting radioisotopes discharged in the particulate form during each of the chemical operations for seven repetitive runs and several non-repetitive runs were analyzed. An analysis of the third repetitive run is shown in Figure MH-9A8127. The rare earths predominated throughout nearly all of the operations, representing from approximately 50 to 80 per cent of the particulate activity during the dissolving and extraction phases. Ruthenium-106 contributed the greatest portion of the particulate activity during the head-end operations and, in most instances, exceeded the rare earths* during the first part of the dissolving and latter part of the cake dissolution operations (the third repetitive run shown here was an exception). The cake dissolution operation usually takes place following the extraction cycle but it is physically a part of the head-end. Niobium was emitted in varying amounts during all operations, representing from less than 1 per cent to approximately 50 per cent of the particulate activity. Zirconium represented less than 10 per cent of the activity during all operations except the cake dissolution. During the cake dissolution zirconium reached a maximum of 20 to 25 per cent of the particulate activity. Strontium contributed from approximately 5 to 20 per cent of the activity during nearly all of the dissolving, extraction, and cake dissolution operations of the third and fourth repetitive runs. The strontium component was as high as 40 per cent during the extraction cycle of the fifth repetitive run.

The relative proportions of the particulate fission products discharged during 5 repetitive and 2 non-repetitive runs are listed in Table 2.

The rare earths and Ru-106 composed the largest portions of the total particulate activity during repetitive and non-repetitive runs. The per cent rare earth particulate activity in the stack effluent appears to be reduced significantly when the cooling time of the slugs are reduced from 95 to 85 days. Some variations in the isotopic percentage of activity discharged, however, are attributable to the variation in the decontamination factors obtained during different runs. During the dissolving, head-end and extraction operations, on the average, 5, 85 and 10 per cent, respectively, of the total particulate activity was discharged.

ISOTOPIC IDENTIFICATION OF VOLATILE MATERIALS IN STACK EFFLUENT

The total volatile activity, excluding the radioactive noble gases, collected in the caustic scrubber comprised less than 1 per cent of the total activity discharged from the stack during all repetitive and non-repetitive runs. Analyses of the contaminated caustic solution revealed varying percentages of I-131 and Ru-106 collected in the scrubber during operating phases. The volatile components Kr-85, Xe-133 and Xe-135 detected by the constant air monitor comprised the majority of the activity discharged from the stack. Detail analyses of the percentage composition of these volatile materials during phases of the separations process are given in KAPL-814 and KAPL-863.

*KAPL-814, Semi-Annual Progress Report of Radiological Development Activities in the Health and Safety Unit, Jan.-June 1952.

TABLE 4

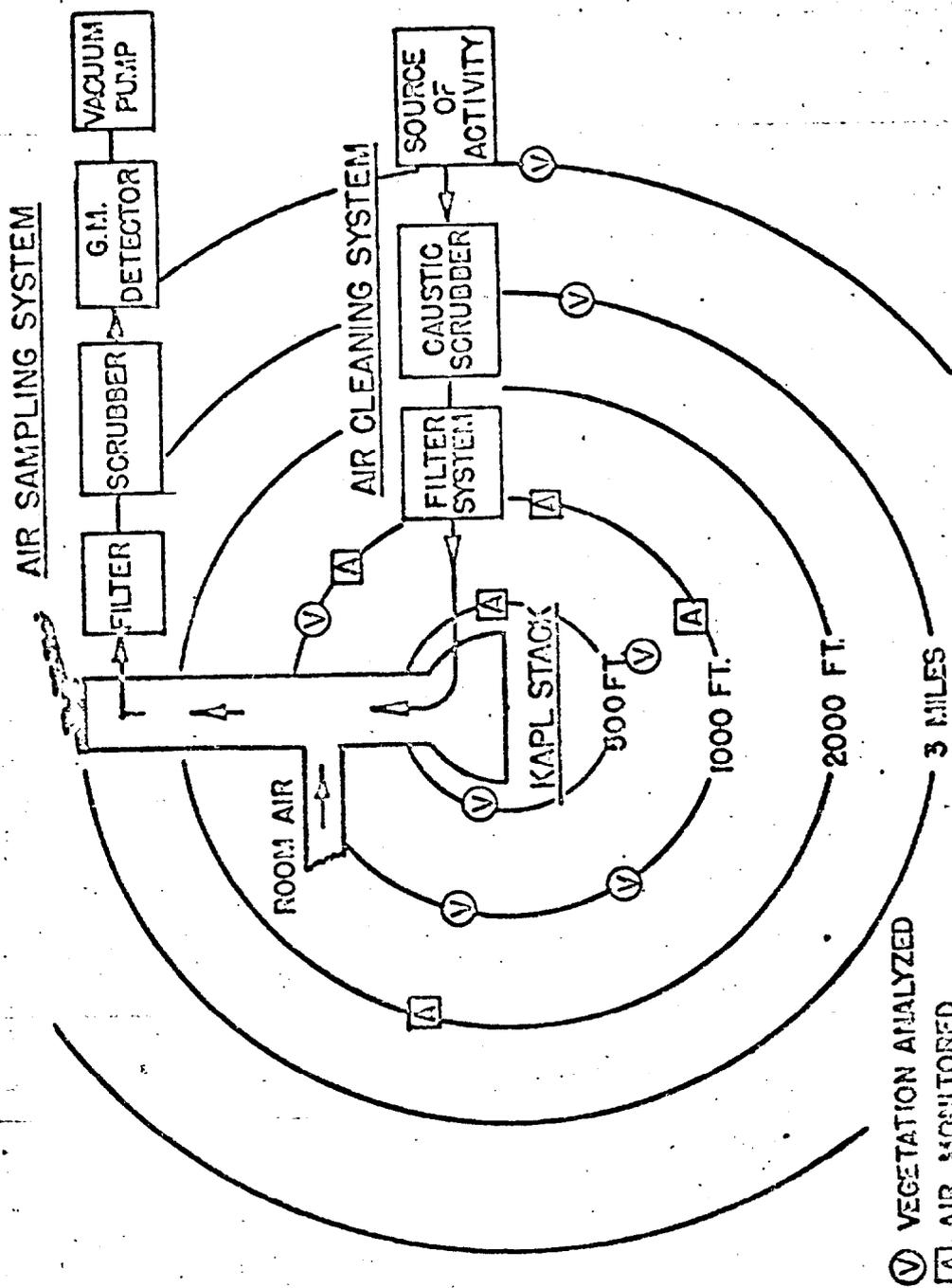
MAXIMUM PERMISSIBLE CONCENTRATIONS IN AIR AND STACK EFFLUENT

| <u>Isotope</u> | <u>Max. Percentage in Stack Effluent</u> | <u>MPC in Air, $\mu\text{c}/\text{cc}$</u> | <u>MPC in Stack, $\mu\text{c}/\text{cc}$</u> |
|-------------------------|------------------------------------------|-------------------------------------------------------|---------------------------------------------------------|
| <u>Beta-Gamma</u> | | | |
| Kr-85 + Xe-133 + Xe-135 | 99 | $4 \times 10^{-6}^{**}$ (body) | 4×10^{-4} |
| Rare Earths & Y-91 | 14 | $7 \times 10^{-9}^*$ (bone) | 5×10^{-6} |
| Ru-106 | 20 | $3 \times 10^{-8}^*$ (kidney) | 2×10^{-5} |
| Ru-103 | 50 | $2 \times 10^{-7}^{***}$ (kidney) | 4×10^{-5} |
| Sr-89 | 1 | $2 \times 10^{-8}^*$ (bone) | 2×10^{-4} |
| Zr-95 | 1 | $1 \times 10^{-8}^{***}$ (lung) | 1×10^{-4} |
| Nb-95 | 4 | $4 \times 10^{-7}^*$ (bone) | 1×10^{-3} |
| Ba-140 | 1 | $6 \times 10^{-8}^*$ (bone) | $<6 \times 10^{-4}$ |
| I-131 | 1 | $3 \times 10^{-9}^*$ (thyroid) | 3×10^{-5} |
| <u>Alpha</u> | | | |
| Pu-239 | 100 | $2 \times 10^{-12}^*$ (bone) | 2×10^{-10} |

*MPC listed in National Bureau of Standards Handbook 52.

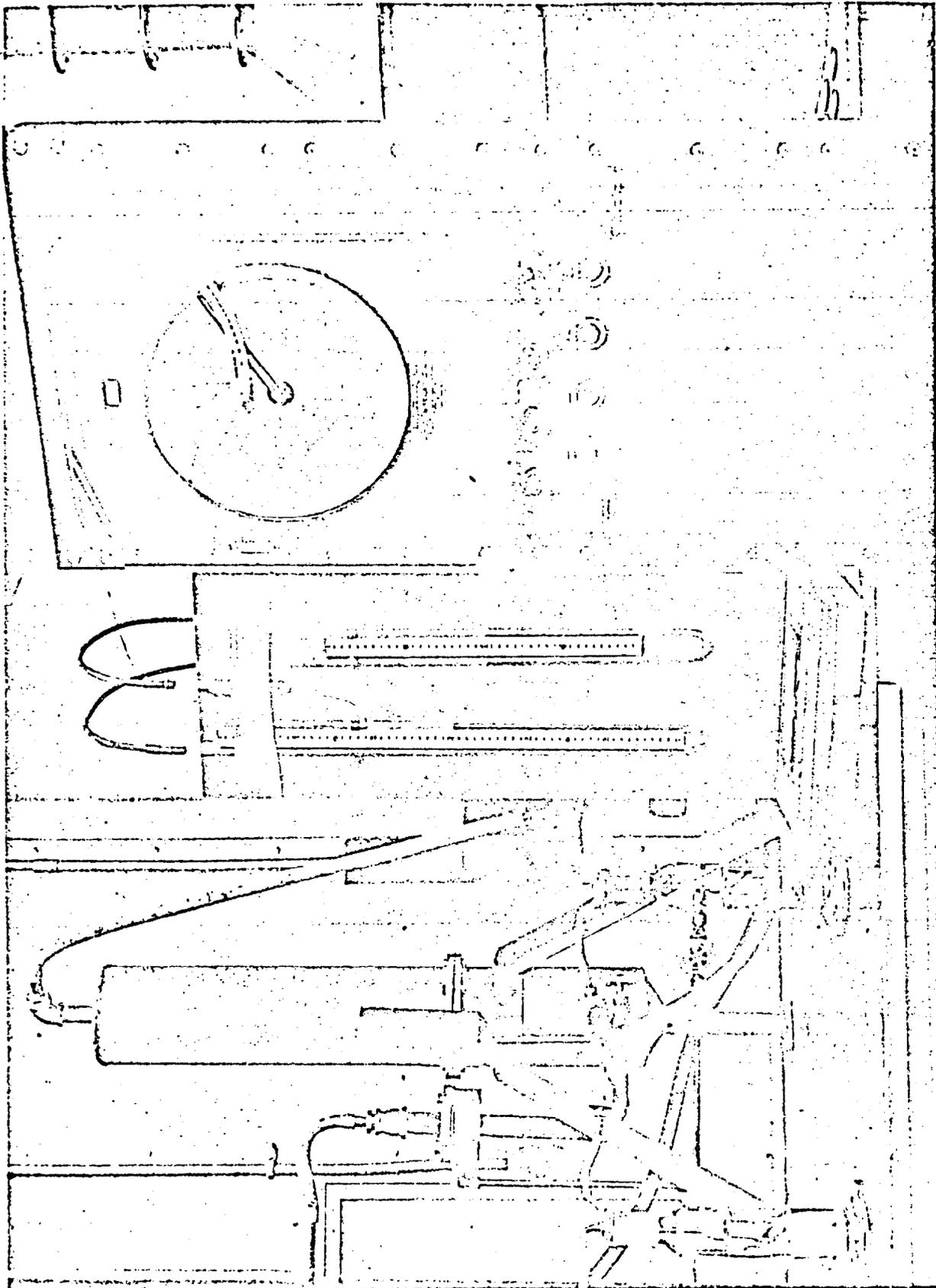
**MPC listed in Handbook 52 or calculated using formula in Handbook 52.

***MPC calculated using formula listed in Handbook 52.

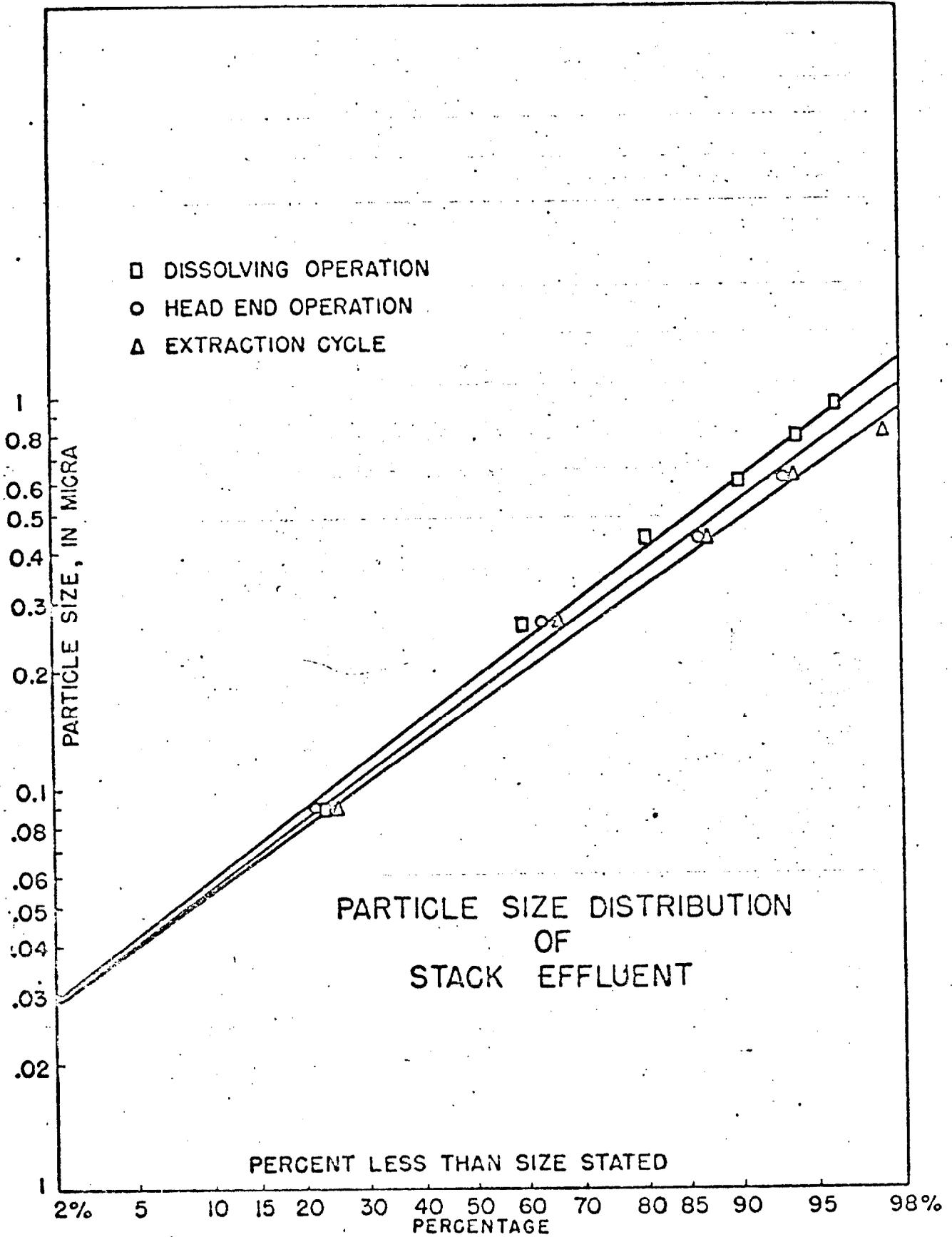


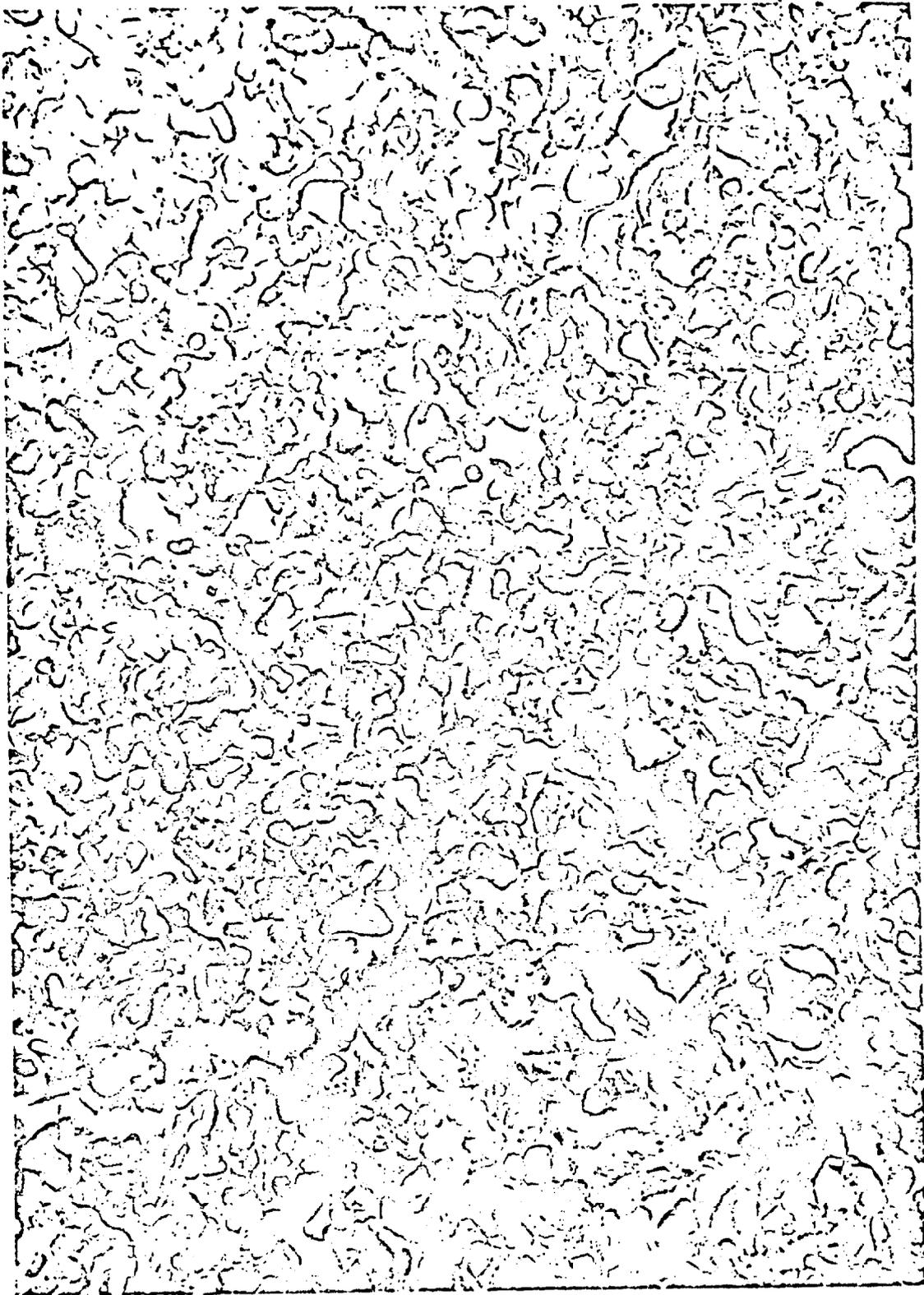
KAPL - AIR MONITORING AND CLEANING SYSTEMS

KH-9A2403



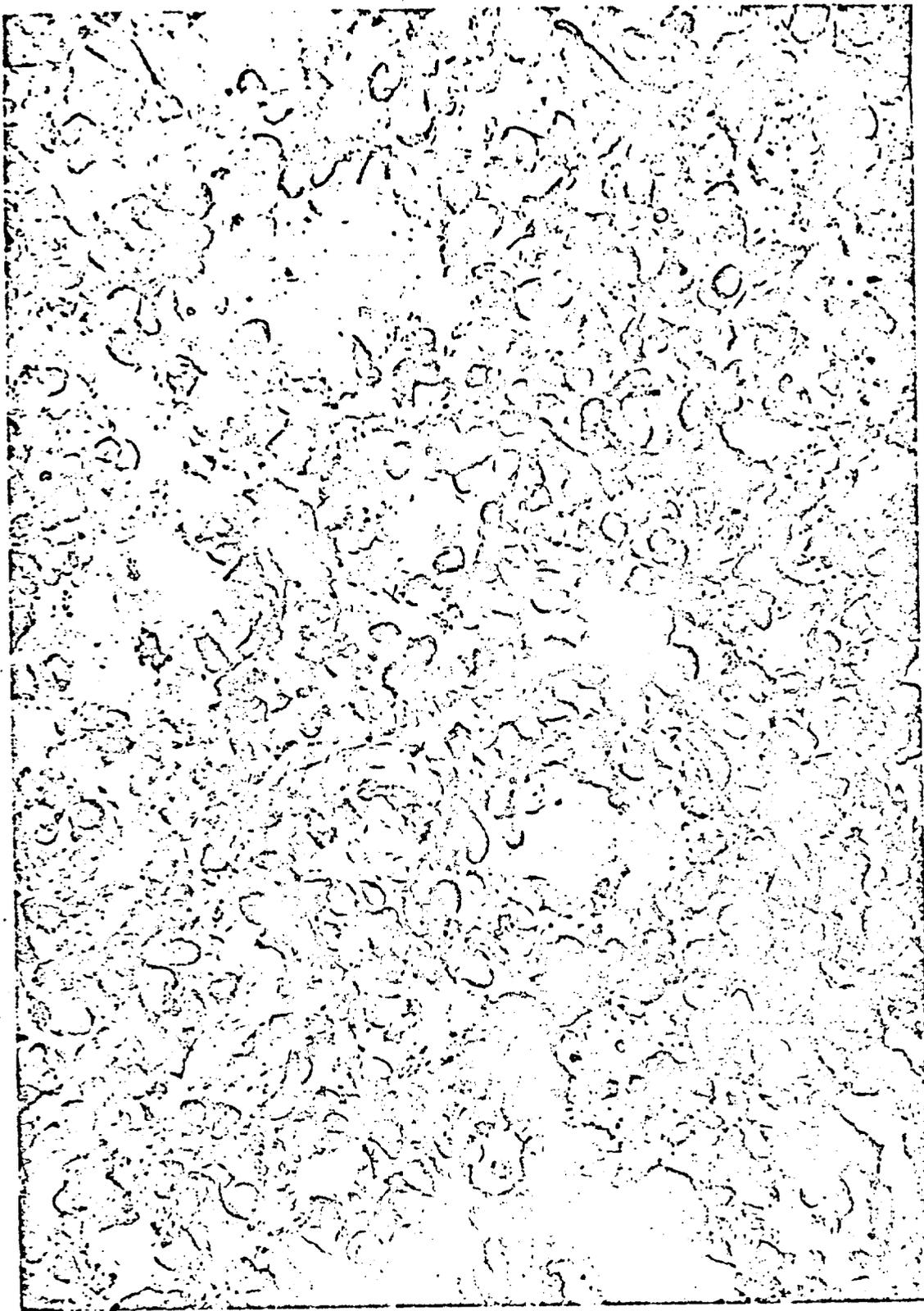
41141011-EM





MILLIPORE FILTER UNEXPOSED-CONTROL FILTER
Magnification - 15000 — Scale 0.5 micron

KH-1121212



MILLIPORE FILTER EXPOSED TO KAPL STACK EFFLUENT
Magnification - 15000 — Scale 0.5 micron

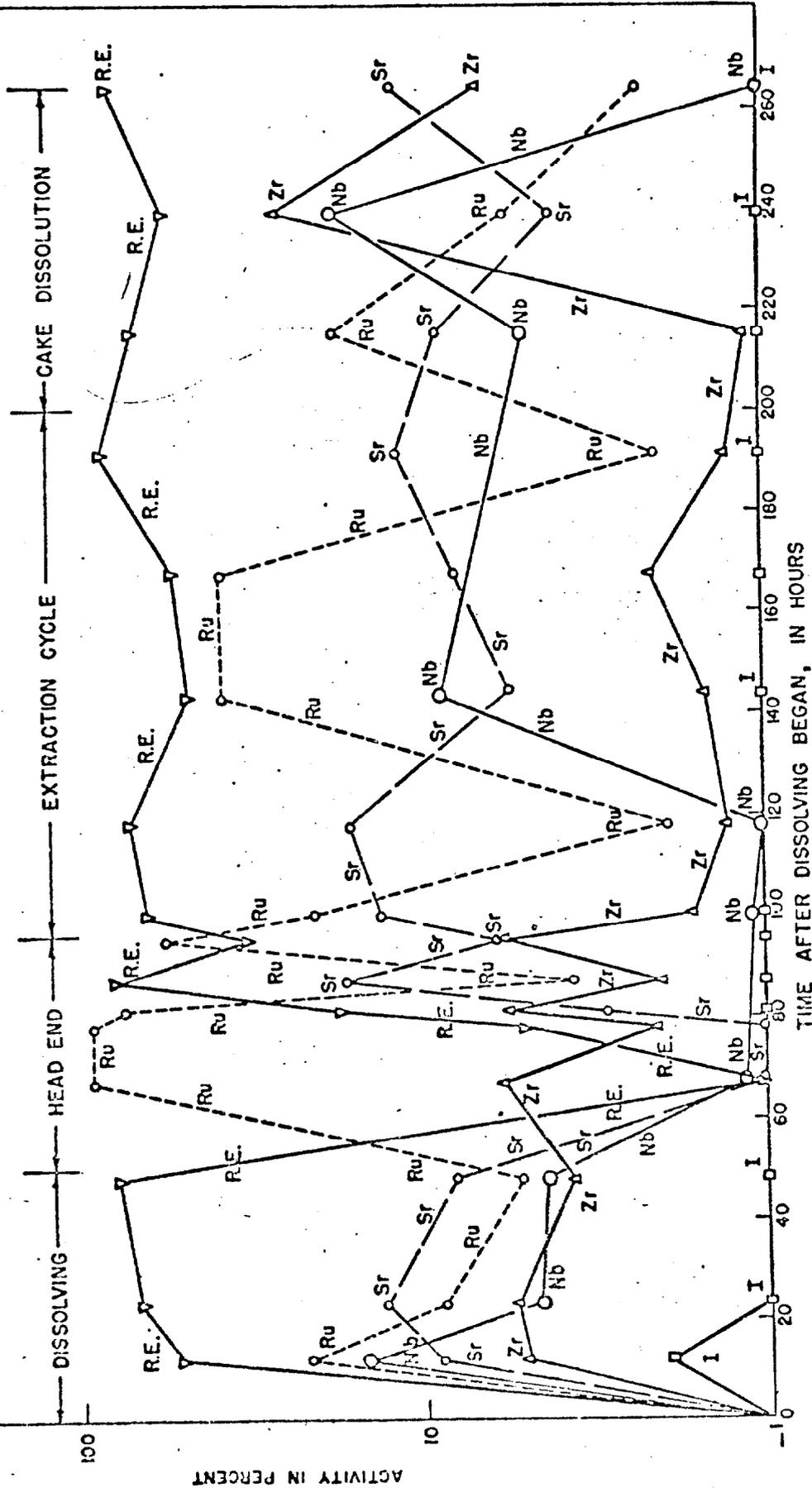
KH-1121213

GENERAL ELECTRIC CO.
KNOLLS ATOMIC POWER LAB.

RELATIVE PROPORTIONS OF PARTICULATE FISSION PRODUCTS RELEASED FROM STACK DURING THIRD REPETITIVE RUN

[EACH PLOTTED POINT REPRESENTS THE AVERAGE RELATIVE ACTIVITY DURING THE
INTERVAL PRECEDING IT.]

CONFIDENTIAL
SECURITY INFORMATION



TIME AFTER DISSOLVING BEGAN, IN HOURS

MI-9A8127

AEROSOL INVESTIGATIONS

FOREWORD

H. F. Johnstone
Technical Director, Contract AT(30-3)-28

Engineering Experiment Station
University of Illinois
Urbana, Illinois

At the air Cleaning Conference at Ames in September 1952, reports were given by the Illinois group on the fundamental investigations on aerosols which were being studied at that time. The following reports have been prepared by the members of the research staff to show the status of the current work.

Most of the work on the contract at Illinois is carried on by graduate students in Chemical Engineering. These men are being trained in research methods and in the applications of physics and mathematics to aerosol technology. By working as a group, they have the advantages of using standardized procedures and of group discussions. Of those who have completed their work, several have taken positions in university and industrial laboratories where they have continued their interest in fundamental and practical aerosol problems. Because of the need for greater knowledge in this field of science in this country, it is felt that the training of scientists is one of the important contributions of the work.

All of the work on the project is not supported directly by the AEC contract. A part of it is being carried on in the regular graduate thesis program in Chemical Engineering. The work of Mr. H. F. Kraemer on properties of charged aerosols falls in this category. During the past year, the Chemical Corps, through Contract No. DA-18-108-CML-4789, has expanded the investigation on the theory of filtration of very small particles. This work is being carried on by Dr. C. Y. Chen, a Research Associate in the Engineering Experiment Station. Since these studies are related to the fundamental properties of aerosols, they are summarized here for the interest of those in the AEC who are concerned with aerosol work.

During the year, one phase of the theoretical studies and one experimental program were completed. The results were reported in two technical reports as follows:

"I. The Role of Particle Diffusion and Interception in Aerosol Filtration; II. Determination of the Drag on a Cylindrical Fiber at Low Reynolds Number". Technical Report No. 8, Serial No. SO-1009, January 1, 1953; cf. also errata sheet issued with Technical Report No. 9.

"Particle Size Distribution in Hygroscopic Aerosols".
Technical Report No. 9, Serial No. SO-1010, May 1, 1953.
This work was presented at the Symposium on Fumes and
Mists at the meeting of the American Institute of Chemi-
cal Engineering in St. Louis, in December, 1953; the
paper was published in Chemical Engineering Progress
Symposium Series.

TURBULENT DEPOSITION AND THE BEHAVIOR
OF DEPOSITS OF SOLID PARTICLES

by

S. K. Friedlander, Research Assistant

When a gas containing particles flows in turbulent motion past a surface, some of the particles are deposited even though there is no net velocity in the direction of the surface. This turbulent deposition results from the fluctuating velocity component normal to the collecting area. It occurs in the movement of aerosols through straight ducts, through diffuser sections, and on any body whose boundary layer becomes turbulent when passing through a gas containing particles. It undoubtedly contributes to removal in such devices as cyclones and cyclone scrubbers operated at high levels of turbulence.

In essence, turbulent deposition is a form of inertial removal in which sudden gusts of fluid move towards the surface, change their direction, and thereby cast out the particles which they carry. There is no real distinction between this phenomenon and impaction. For example, when a turbulent gas flows past a flat surface, the motion of the eddies toward the surface can be thought of as a series of impactions on flat plates, for which we have experimental and theoretical data. Similarly, a spherical water droplet moving out of phase with an eddy probably removes particles from the surrounding aerosol by impaction. The difficulty in a theoretical analysis of turbulent impaction derives from our inability in most cases to characterize the velocity and scale of the turbulence. However, since impaction is the mechanism of deposition, the important parameter should be the inertial group (2):

$$\Psi = \frac{C\rho_p V_e}{18\mu d_e} d_p^2$$

where

C = Cunningham correction factor

ρ_p = particle density

V_e = eddy velocity

d = some characteristic length

μ = gas viscosity

d_p = particle diameter

By studying the effect of these variables on turbulent deposition, one should at least be able to correlate experimental data, although prediction of results from theory is more difficult.

EQUIPMENT

In order to study turbulent deposition and the behavior of deposits of solid particles, the equipment outlined in Fig. 1 was set up. The aerosol employed was carbonyl iron powder (Grade SF) manufactured by the Antara Chemicals Division of the General Dyestuff Corporation. According to the manufacturer's catalog, the mass median diameter of the particles was 3 microns with a geometric standard deviation of about 1.4. This material was chosen because the particles are quite spherical, easy to see under the microscope, and easy to disperse. Tests disclosed that about 10 percent of the particles were agglomerates and most of these were doublets. It has the disadvantage of a density (7.8 g./cc.) considerably higher than that of the usual aerosol particles.

The iron powder was placed in a brass "boat", about 1 1/2 feet long, which was pushed forward by a threaded steel rod of similar length attached to the shaft of a small 10 rpm. motor. In this way, the powder was fed at a steady rate to an atomizing nozzle. In order to remove the larger particles and increase the homogeneity of the aerosol, a 1-inch cyclone was installed after the atomizer and before the mixing chamber leading to the sampling tube. The aerosol concentration was determined by passing a known volume of air from the sampling tube through a Millipore filter (Lovell Chemical Co.). The main body of air passed through a rotameter and was expelled from the system by a Roots-Connersville blower.

Two sampling tubes have been used up to the present, one 5.4 mm. I.D. and the other 13 mm. I.D. Both tubes were of thin wall Pyrex, and each was ground at one point to permit observation of the inner wall using a microscope with an oil immersion technique. The observation points for the 5.4 and 13 mm. tubes were placed 50 and 30 diameters, respectively, from the entrance, to minimize entrance effects. In order to restrict the tests to a known particle size, only those particles with diameters ranging from about 0.6 to 1 micron were counted both on the Millipore filter (for determining concentration) and on the tube wall (for determining deposition), and a mean particle size of 0.8 microns was assumed.

RESULTS

In general, when particles deposit on a surface, two stages can be recognized. In the first, the individual aerosol particles scatter about the surface and, unless the velocity is high (above 100 ft./sec.), there is little re-entrainment. In the second stage, as a result of increased deposition clumps of particles appear and parts of these may break away, even at moderate gas velocities. Since the first stage seemed more amenable to investigation, it has received most attention in our experimental work.

The deposition rate was characterized by defining a particle transfer coefficient, k , with the dimensions of cm./min.

$$k = N/c$$

where

N = deposition rate, particles/(cm.²)(min.)

c = particle concentration, particles/cc.

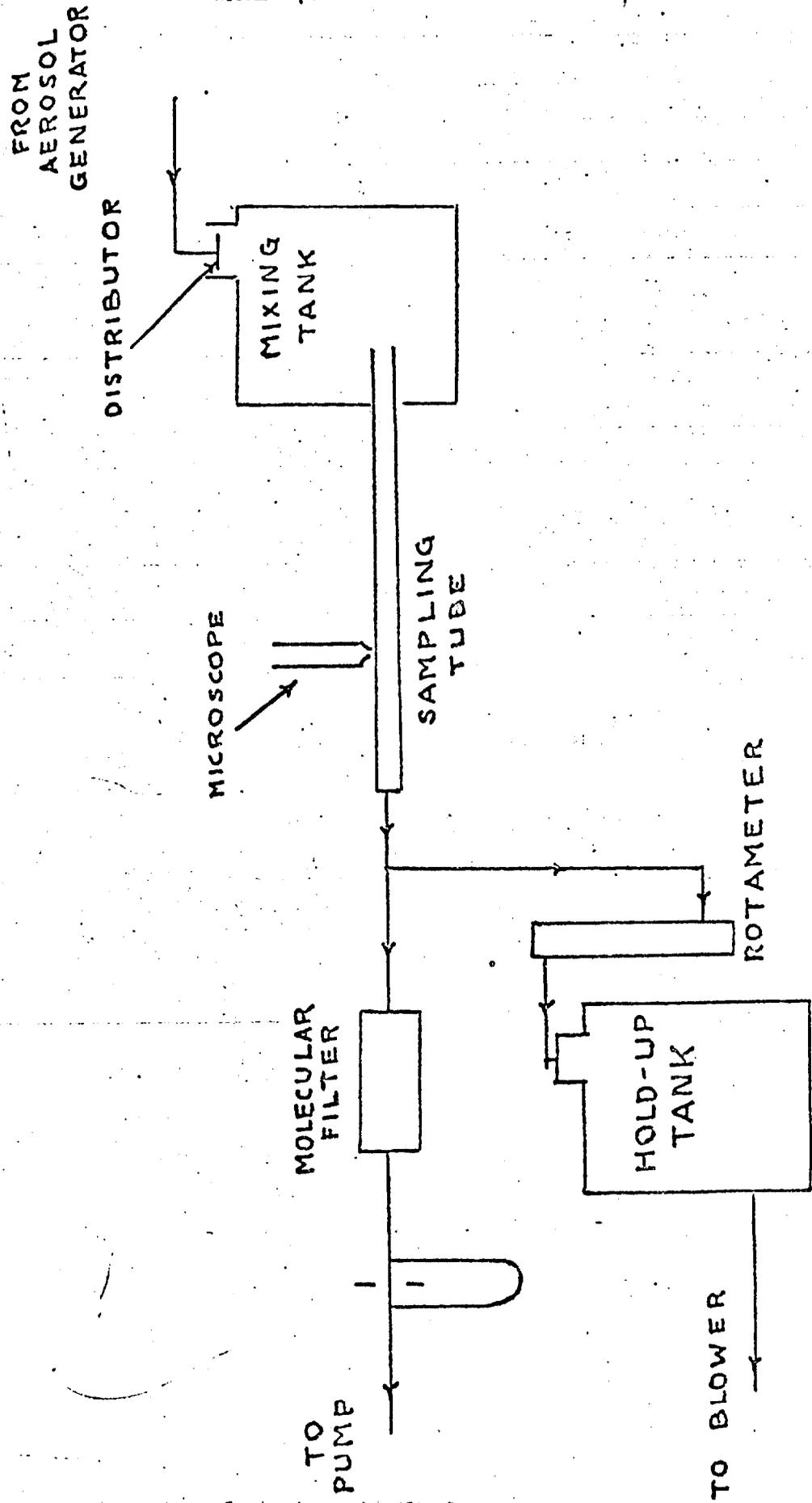
A plot of this coefficient as a function of velocity for both experimental tubes is shown in Fig. 2. The data for both tubes fall essentially along the same line. Most evident, however, is the extreme effect of increasing velocity on the transfer rate which is proportional to V^5 . The cause of this extreme velocity dependence is not certain although a somewhat similar effect is found for impaction on flat plates (1). In passing, it should be noted that at the very high velocity (180 ft./sec.) in the smaller tube, 2.5 percent of the particles were removed per inch of duct length.

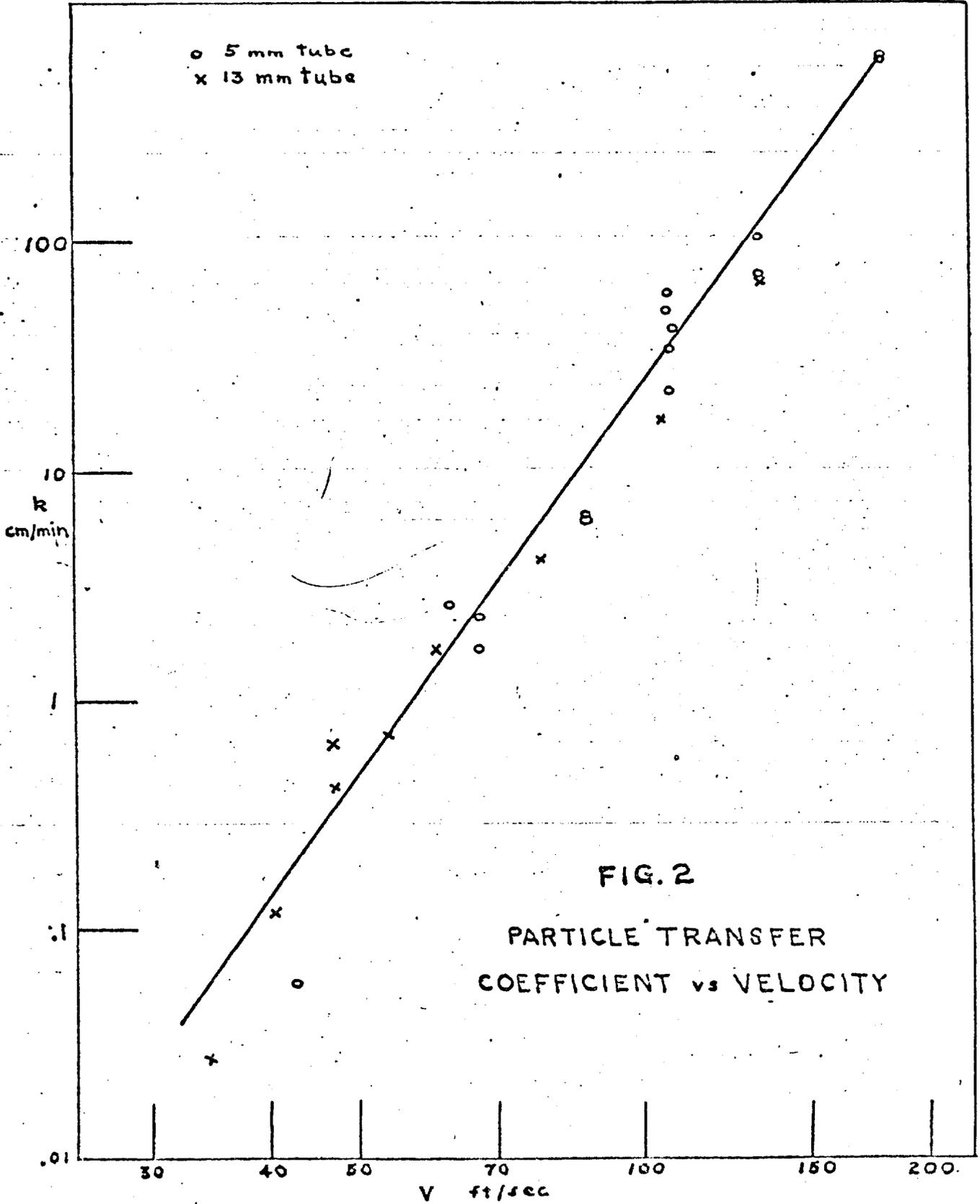
Larger particles (those above 2 or 3 microns) appeared to have a greater tendency to deposit than the smaller sizes and this tendency would be predicted from the impaction mechanism; however, the larger particles are also reentrained considerably faster since they project into the higher velocity regions of flow. Thus at high velocities, the initial deposit consisted mostly of smaller particles. This effect has also been noted by Rumpf (3).

REFERENCES

1. Ranz, W. E. and Wong, J. B., "Jet Impactors for Determining the Particle Size Distributions of Aerosols", Eng. Expt. Sta., University of Illinois, Tech. Report No. 4, Serial No. SO-1004, July 31, 1951.
2. Ranz, W. E. and Wong, J. B., "Impaction of Dust and Smoke Particles", Ind. Eng. Chem. 44, 1371 (1952).
3. Rumpf, H., "The Formation of Finely Distributed Substances on the Walls of Pipe Lines", Chemie Ingenieur Technik, Part 6, p. 317, (1953).

FIG. 1
APPARATUS FOR MEASUREMENT
OF TURBULENT DEPOSITION





COLLECTION OF AEROSOLS BY FIBER MATS

by

James B. Wong, Research Assistant

A major class of aerosol filters consists of beds of individual fibers. The efficiency of collection and the pressure drop are the important practical considerations in the design of these fibrous filters. An understanding of the mechanisms by which the particles are collected on isolated cylinders and the flow pattern around the cylinders is fundamental in the design. In view of the several mechanisms of particle collection, it is best to investigate them individually. In the present work, emphasis is placed on the mechanism of inertial impaction. This mechanism takes place when a particle approaching a fiber crosses the streamlines because of its inertia and strikes the surface of the fiber.

The work is divided into two parts. Part I deals with the impaction of aerosol particles on single cylinders (metallic wires) with axes perpendicular to the direction of the aerosol flow. Part II deals with the collection efficiency and the pressure drop of fiber mats.

PART I. IMPACTION ON SINGLE CYLINDERS (METALLIC WIRES)

The theory of impaction of particles on circular cylinders with their axes perpendicular to the direction of flow has been studied by Sell (12), Albrecht (1), Langmuir and Blodgett (9), Landahl and Herrmann (7), and Davies (3). Davies indicates that the efficiency of inertial impaction should be a function of the inertial parameter Ψ and the Reynolds Number based on the diameter of the cylinder. Albrecht, and Langmuir and Blodgett predict on theoretical grounds that a critical value of Ψ exists below which inertial impaction does not occur. Albrecht gives 0.09 whereas Langmuir and Blodgett give 0.0625 for the critical value. The other authors do not indicate such a critical value.

Since experimental verification of the theoretical conclusions is lacking, the present work was undertaken with the purpose of ascertaining the correct function of the efficiency of inertial impaction and the existence or non-existence of the critical value of Ψ .

One-mil and 3-mil platinum wires and 2-mil and 4-mil tungsten wires were used as the circular cylinders. The average diameters from measurements under the microscope, were 29.0, 82.6, 53.1, and 105.7 microns, respectively, with a maximum deviation from the average of less than 9 percent. Homogeneous sulfuric acid aerosols were used in the experiments. The aerosols were generated with a condensation aerosol generator similar to that used by Sinclair and LaMer (13). The particle sizes were measured with a calibrated Owl (No. G-2) obtained from the U. S. Army Chemical Corps. The acid concentration of the aerosol was determined by collecting a weighable quantity of the particles in the cup of a high velocity impactor (11) and analyzing the contents of the cup by titrating

with 0.1 N sodium hydroxide solution.

The experimental procedure included generating a homogeneous sulfuric acid aerosol of the desired particle size, impacting the aerosol particles on the wire which was perpendicular to the direction of the aerosol flow, collecting the remaining particles in a glass fiber filter train, and analyzing the amount of acid collected on the wire. In order to collect enough acid on the wire for accurate analysis, a brass drum which could be rotated was attached to the top of the impacting nozzle and about four feet of wire was unwound from the drum to pass through the nozzle during a run. The wire, after being exposed to the aerosol at the nozzle throat, was passed down into an 8-mm. Pyrex glass tube. At the end of the run, conductivity water was used to wash off the acid particles impacted on the wire and the quantity of acid was determined by measuring the concentration of the wash solution with a precision conductivity bridge and dip cell which accurately indicated concentrations as low as 10^{-6} N. From the quantity of acid impacted on the wire and the total amount of acid in the aerosol passing the nozzle, the efficiency of impaction could be calculated.

Figure 1 shows the experimental impaction efficiencies on the four wires. The range of variables represented are: D_p , diameter of aerosol particles, 0.56 to 1.40 microns; V_0 , velocity of the aerosol stream passing the wires, 400 to 5100 cm./sec.; and Reynolds Number ($NR_e = D_c V_0 \rho / \mu$) based on the measured wire diameters, 13.0 to 330. The density of the sulfuric acid particles, ρ_p , was substantially constant with an average of 1.48 g./cc. C is the Cunningham correction factor and μ is the viscosity of the gas.

In the ranges of particle diameter and aerosol stream velocity employed in the experiments, collection due to the Brownian diffusion was negligible. Collection by electrostatic forces was improbable since both the aerosol particles and the wires were uncharged. Gravity settling should also be unimportant with the wires in the vertical position. The collection due to interception was estimated to be less than 10 percent of the total collection in all cases, and thus had very little effect on the shape or position of the resulting efficiency curve. The curve drawn through the points in Figure 1, therefore, represents the experimental efficiencies of inertial impaction.

The experimental curve is S-shape, characteristic of the inertial impaction mechanism on surface and body collectors. It indicates a critical value of $\sqrt{\Psi}$ of approximately 0.25, below which impaction does not occur. At high values of the inertial parameter, the curve appears to be asymptotic to the value of $\eta_I = 1$. The accuracy and reliability of the results depend largely on the homogeneity of the particle size and the accuracy of the particle size measurements. The impaction efficiencies were reproducible in terms of $\sqrt{\Psi}$, in view of the ten-fold variation in velocity, the three-fold variation in particle size, and the insensitivity of the Owl for detecting small variations in the particle size.

Comparisons of the data for the two platinum wires show that the higher the Reynolds Number, the higher is the impaction efficiency for the same value of the inertial parameter. The same observation can be made on the two tungsten wires. This agrees with the theoretical conclusions. Comparison of the data for the 1-mil platinum wire with those for the 2-mil tungsten wire, and the data for the 3-mil platinum wire with those for the 4-mil tungsten wire, however, show opposite effects of the Reynolds Number, i.e., the impaction efficiencies on the 3-mil wire at lower values of the Reynolds Number are generally higher than those on the 4-mil wire for corresponding value of $\sqrt{\Psi}$. The explanation of this is not apparent. When these wires were observed under the microscope, it was noted that the surface of the platinum wire was much smoother than that of

the tungsten wire. Possibly the aerosol particles adhere to the surface of the platinum better than to the tungsten wire.

Figure 2 is a plot of the experimental inertial impaction efficiency curve together with the various theoretical curves proposed. The experimental curve agrees closely with that calculated by Landahl and Herrmann based on Thom's flow lines for the Reynolds Number of 10, up to $\sqrt{\Psi} = 1.4$. For values of $\sqrt{\Psi}$ between 0.4 and 1.2, the data indicate impaction efficiencies somewhat smaller than those shown by the curve of Langmuir and Blodgett and considerably smaller than the values of Sell, and of Albrecht. This is to be expected since the curves of Langmuir and Blodgett, and Albrecht were based on the potential flow of an ideal fluid, and that of Sell was based on an observed flow pattern obtained at large values of the Reynolds Number on a 10 cm. cylinder. No comparison can be made with Davies' theoretical curve since it was based on viscous flow at a Reynolds Number of 0.2, far below the range attainable with the method used in the experiment.

For values of $\sqrt{\Psi}$ greater than about 1.4, the experimental efficiencies are higher than those according to the curves of Langmuir and Blodgett, and Landahl and Herrmann. The reason for this discrepancy is not entirely clear. One point to be noted is that, for high efficiencies of inertial impaction, i.e., efficiencies approaching unity, the particle trajectories must be nearly parallel to the direction of flow and the particles must cut across the streamlines upstream of the wire where the streamlines begin to spread. In step-wise calculations of particle trajectories, it is not practical to start the calculation more than a few diameters (of the collector) upstream. It is possible that errors introduced by this could cause the calculated impaction efficiencies in the high efficiency range to be lower than the correct values.

The critical value of $\sqrt{\Psi}$ at approximately 0.25 shown by the experimental impaction efficiencies agrees with the values of 0.3 and 0.25 explicitly stated by Albrecht, and Langmuir and Blodgett, respectively. The curve of Landahl and Herrmann also implies that the efficiency of inertial impaction is negligible at the value of $\sqrt{\Psi}$ less than 0.25.

PART II. COLLECTION EFFICIENCY AND PRESSURE DROP OF FIBER MATS

The theory of the collection of particles on fibrous filters has been studied by Albrecht (1), Langmuir (8), and Davies (3). Albrecht's theory is based on the potential flow of an ideal fluid, a condition very different from viscous flow which ordinarily takes place in these filters. Langmuir's theory takes into account only two mechanisms of collection, interception and Brownian diffusion. The experimental data of LaMer (6), and Ramskill and Anderson (10) show that the mechanism of inertial impaction also plays an important part in the collection efficiency of these filters. However, these authors have not evaluated this mechanism quantitatively. Davies' theory takes into account all of the major mechanisms of particle collection. He proposed an equation derived on theoretical grounds for the efficiency of the fibers in the filter. The present work was conducted with the purpose of evaluating quantitatively the mechanism of inertial impaction.

Pressure drop across fibrous media has been studied on the basis of the hydraulic radius concept of Kozeny (5) and Carman (2). Davies (3) studied the problem by dimensional analysis. Iborall (4) and Langmuir (8) derived theoretical equations for the pressure drop. The conclusions of these authors are not

in good agreement. Another object of the present work was to test the proposed equations experimentally.

By assuming (a) all fibers in the filter mat are perpendicular to the direction of flow; (b) the fibers do not interfere with each other; and (c) the ends of fibers have negligible effect, the following equations have been derived for the collection efficiency and the pressure drop of the fiber mat:

$$\eta_{\text{mat}} = 1 - (N_h/N_o) = 1 - e^{-\left(\frac{4\alpha\eta}{\pi D_f}\right) h} \quad (1)$$

$$\Delta P = \frac{2\rho V_o^2 \alpha h C_D}{\pi D_f} \quad (2)$$

where

η_{mat} = collection efficiency of the fiber mat

N_h/N_o = fraction of particles penetrating the mat

α = fiber volume fraction, i.e., volume of fibers per unit volume of mat

D_f = diameter of fibers in the mat

h = thickness of the mat

ρ = density of the gas

V_o = volumetric velocity of the aerosol stream passing the mat

η = total efficiency of the single fiber

C_D = drag coefficient on the single fiber

In actual fiber mats, none of these assumptions is completely justified. The approach followed in the present work was to use the equations as bases for correlating the experimental data, incorporating all of the effects which were not already taken into account as an effective fiber efficiency, η_e , and an effective fiber drag coefficient, C_{De} , instead of η and C_D in the equations.

The fiber mats used in the present work were formed from three types of glass fibers made by Glass Fibers, Inc., Toledo, Ohio, unbonded "B" fibers, "450" yarns, and "150" yarns. The diameters of the fibers were measured under the microscope and were found to average 3.51, 6.24, and 9.57 microns, respectively. The mats were formed by Arthur D. Little, Inc., Cambridge, Massachusetts. Four bulk densities of approximately 1.0, 1.3, 1.6, and 2.0 g./cc. were formed from each type of fiber. The thickness of the mats ranged from 0.13 to 0.22 cm. Most mats were uniform after the binding agent had been burned off.

The experimental procedure was similar to that followed on the impaction of single wires. The aerosol was directed to pass the mat which was placed in a Lucite holder with the mat face perpendicular to the direction of flow and the pressure drop was measured by means of inclined and ordinary manometers. The collection efficiency of the mat was calculated from the quantities of acid collected on the mat and in the filter train following the mat as determined by titration with standard sodium hydroxide solution and by conductivity measurement.

Figure 3 shows the experimental collection efficiencies. The ranges of variables represented are: diameter of aerosol particles, 0.43 to 1.3 microns; volumetric velocity of aerosol stream passing mats, 17 to 260 cm./sec./ Reynolds Number based on the fiber diameter, 0.04 to 1.4; fiber volume fraction, 0.045 to 0.098; and thickness of mats, 0.13 to 0.40 cm. The collection efficiency on the mats ranged from 0.04 to 0.998.

In the experiments, Brownian diffusion, electrostatic attraction, and gravity settling were negligible. The best curves for the effective fiber efficiency through the points at the interception parameters ($R = D_p/D_f$) of 0.1, 0.2, and 0.3, therefore, represent the total efficiency of impaction, which includes the inertial impaction and interception efficiencies, and the effect of fiber interference, fiber ends, and non-uniformity on the total efficiency of impaction. At $\sqrt{\Psi}$ of approximately 0.4, inertial impaction becomes unimportant and interception becomes the controlling mechanism as shown by the flattening of the curves. This critical value of $\sqrt{\Psi}$ of 0.4 is between the values of 0.52 and 0.3 predicted by Langmuir and Albrecht, respectively. It is greater than the value of 0.2 obtained experimentally by Ramskill and Anderson. Figure 3 shows that the mechanism of inertial impaction can be represented quantitatively in terms of the effective fiber efficiency.

Figure 4 shows the experimental pressure drop data correlated on the basis of the effective fiber drag coefficient. The ranges of variables are the same as those described for the collection efficiencies since the measurements were taken simultaneously. The pressure drop across the fiber mats ranged from 0.3 to 30 cm. of water. The fiber volume fraction, α , has a marked effect on the effective fiber drag coefficient. The higher the volume fraction, the higher the effective fiber drag coefficient. The effective fiber drag coefficient can be predicted by means of a theoretical equation based on an idealized mat with its fibers equally oriented in the three perpendicular directions one of which is in the direction of flow and an empirical factor, $1 + 60\alpha^{1.8}/N_{Re}^{0.3}$. This correction factor agreed with previous conclusions in that the drag on the fiber increases with the fiber volume fraction and the drag decreases with the Reynolds Number. Curves for this equation for α of 0.08, 0.04, and zero are shown in the figure. The figure also shows the theoretical and semi-theoretical curves of Kozeny-Carman, Davies, Iberall, and Langmuir. Calculated for $\alpha = 0.06$, the average fiber volume fraction in the experiments. The Kozeny-Carman, Davies, and Langmuir equations all predict the effective fiber drag coefficient to be inversely proportional to the Reynolds Number, i.e., a straight line with a slope of -1 in this plot. The experimental data, however, show a definite curvature. This indicates that the equations of these authors, while applicable in a limited range of the Reynolds Number for particular types of fibrous media, are functionally incorrect. Iberall's theoretical equation ("Iberall I" in the figure) shows approximately the correct curvature. The reason that his equation predicts too high a pressure drop can be explained on the basis of his erroneous assumption that the drag force per unit length for fibers parallel to the direc-

tion of flow was greater than for fibers perpendicular to the flow. It is concluded that the pressure drop across fiber mats can be correlated on the basis of the effective fiber drag coefficient.

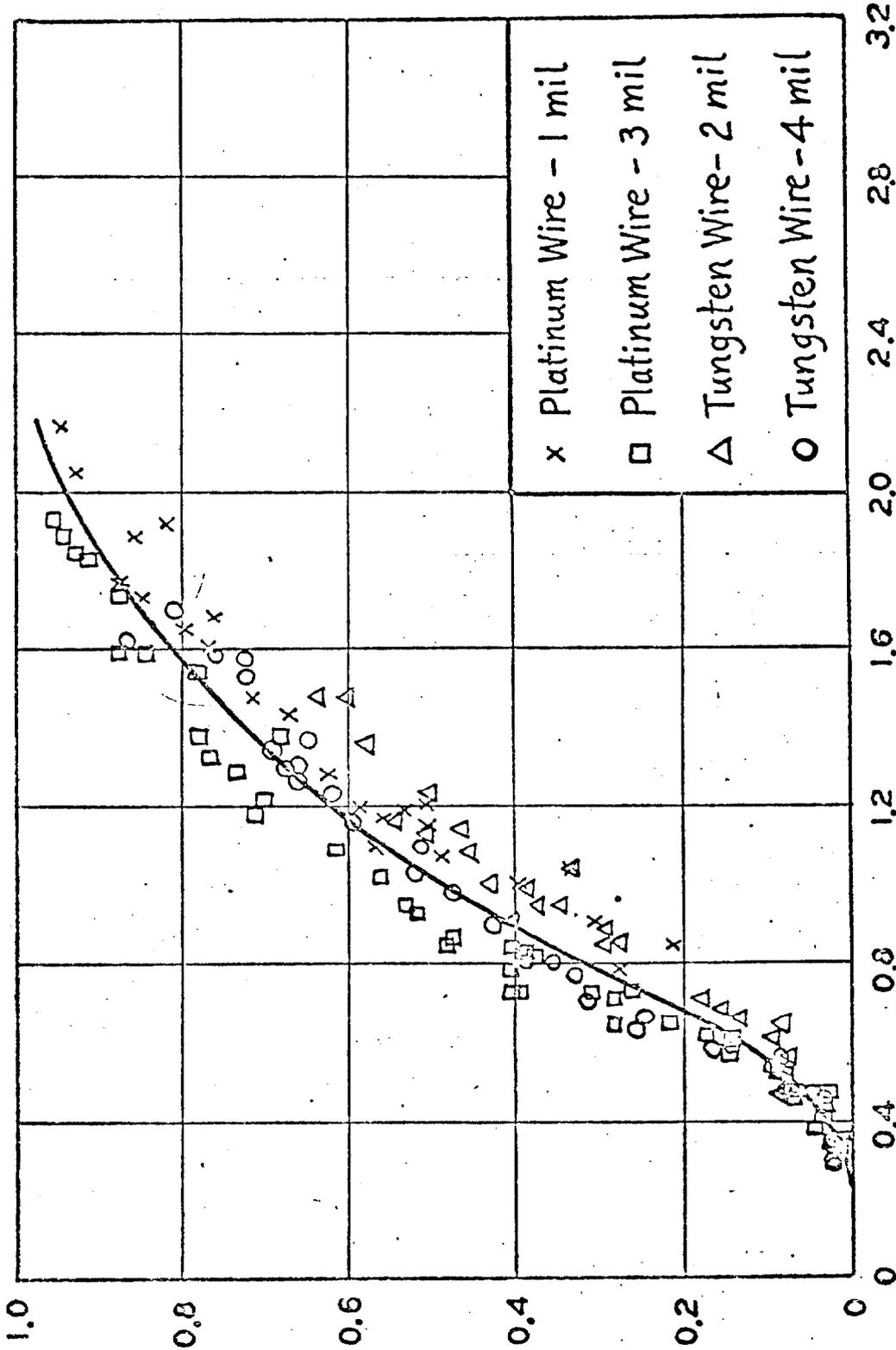
From Equations 1 and 2 and the results of the experimental work, the optimum fiber mat can be derived for filtration of aerosols in the range in which inertial impaction is the important mechanism of collection.

LITERATURE CITED

1. Albrecht, F., Physik, Z., 32, 48 (1931).
2. Carman, P. C., Trans. Inst. Chem. Eng., (London), 15, 150 (1937).
3. Davies, C. N., Proc. Inst. Mech. Engrs. (London), B 1, 185 (1952).
4. Iberall, A. S., J. Research Nat. Bur. Standards, 45, 398 (1950).
5. Kozeny, J., Wasserkraft u. Wasserwerk, 22, 67, 86 (1927).
6. LaMer, V. K., "Studies on Filtration of Monodisperse Aerosols", Columbia University, Final Report, N.Y.O. Rept. No. 512, March 31, 1951, A.E.C. Contract No. AT(30-1)-651.
7. Landahl, H. D., and Herrmann, R. G., J. Colloid Sci., 4, 103 (1949).
8. Langmuir, I., "Filtration of Aerosols and the Development of Filter Materials", O.S.R.D. Rept. No. 865, Sept. 4, 1942.
9. Langmuir, I., and Blodgett, K. B., "Mathematical Investigation of Water Droplet Trajectories", General Electric Research Laboratory, Schenectady, New York, Rept. No. RL 225, 1944-45.
10. Ramskill, E. A., and Anderson, W. L., J. Colloid Sci., 6, 416 (1951).
11. Ranz, W. E., and Wong, J. B., Arch. Ind. Hyg. Occupational Med., 5, 464 (1952).
12. Sell, W., Forsch. Gebiete Ingenieurw., 2, Forschungsheft, 347 (August, 1931).
13. Sinclair, D., and LaMer, V. K., Chem. Rev., 44, 245 (1949).

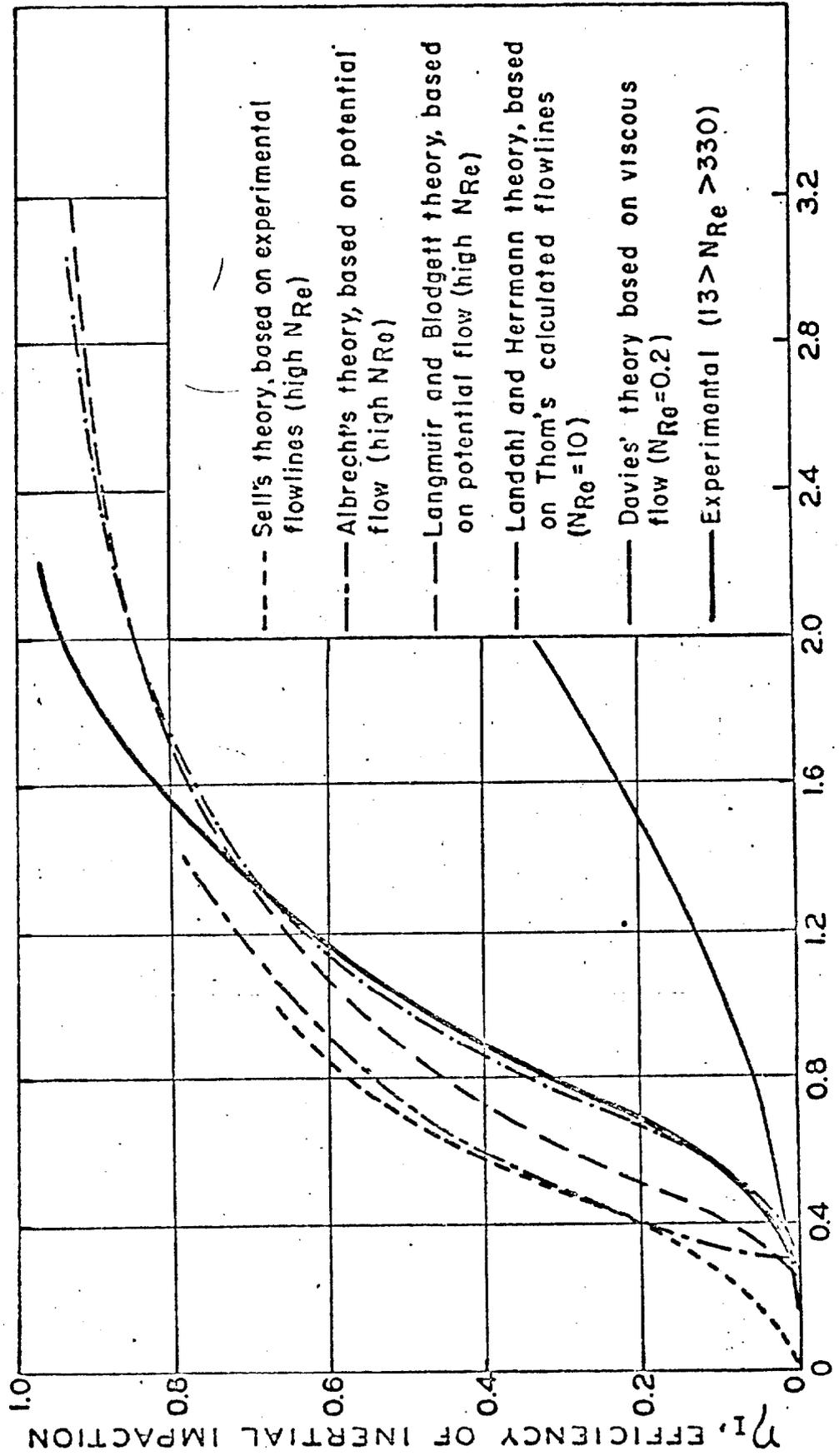
FIG. I. EXPERIMENTAL EFFICIENCIES OF INERTIAL IMPACTION ON CIRCULAR CYLINDERS

η_i , EFFICIENCY OF INERTIAL IMPACTION



$$\sqrt{\Psi} = (C_p V_p / 18 \mu D_p)^{1/2} D_p$$

FIG. 2. COMPARISON OF THEORETICAL AND EXPERIMENTAL EFFICIENCIES OF INERTIAL IMPACTION ON CIRCULAR CYLINDERS



$$\sqrt{\Psi} = (Cp_p v_0 / 18 \mu D_c)^{1/2} D_p$$

FIG. 3. EXPERIMENTAL EFFECTIVE FIBER EFFICIENCIES

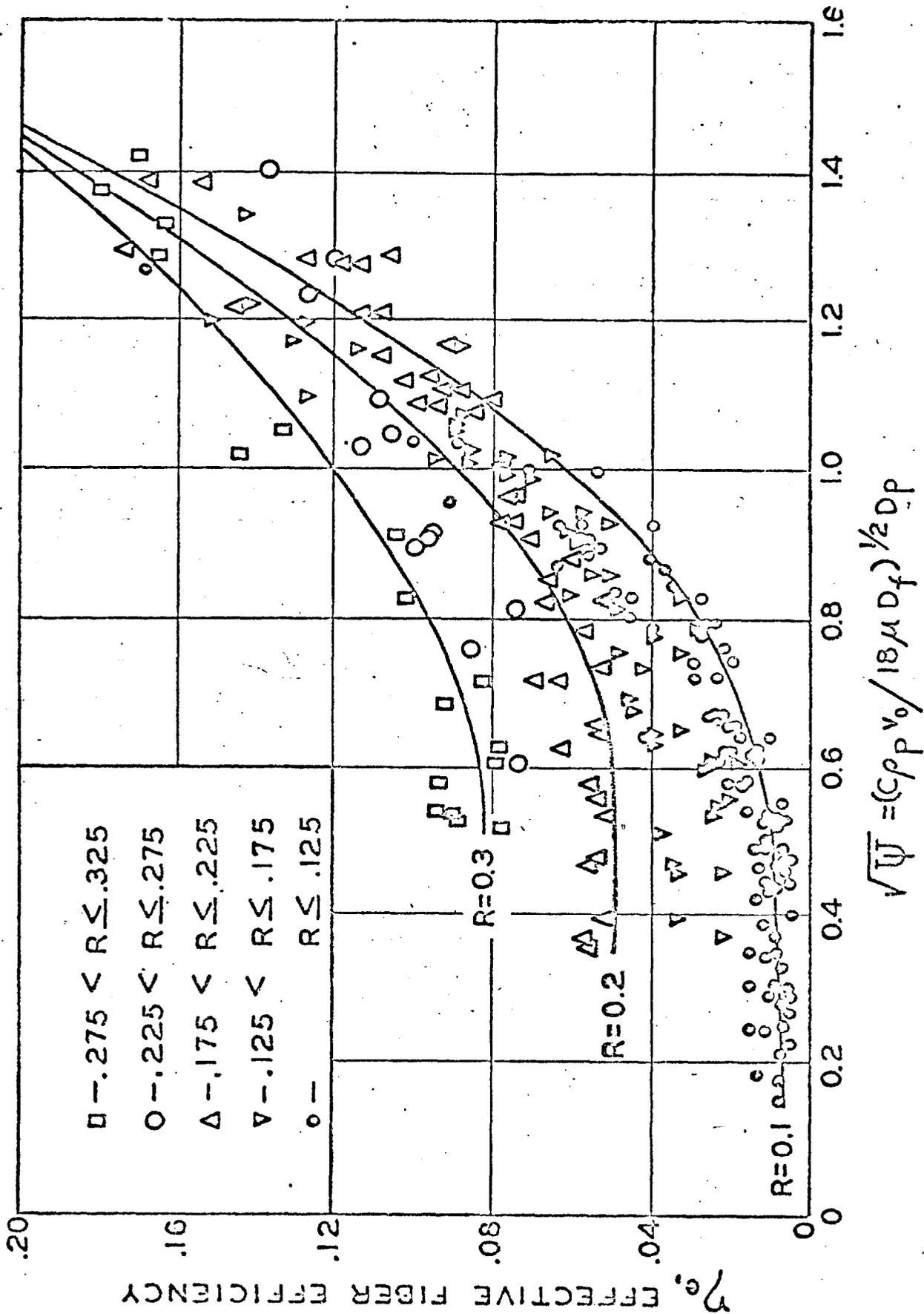
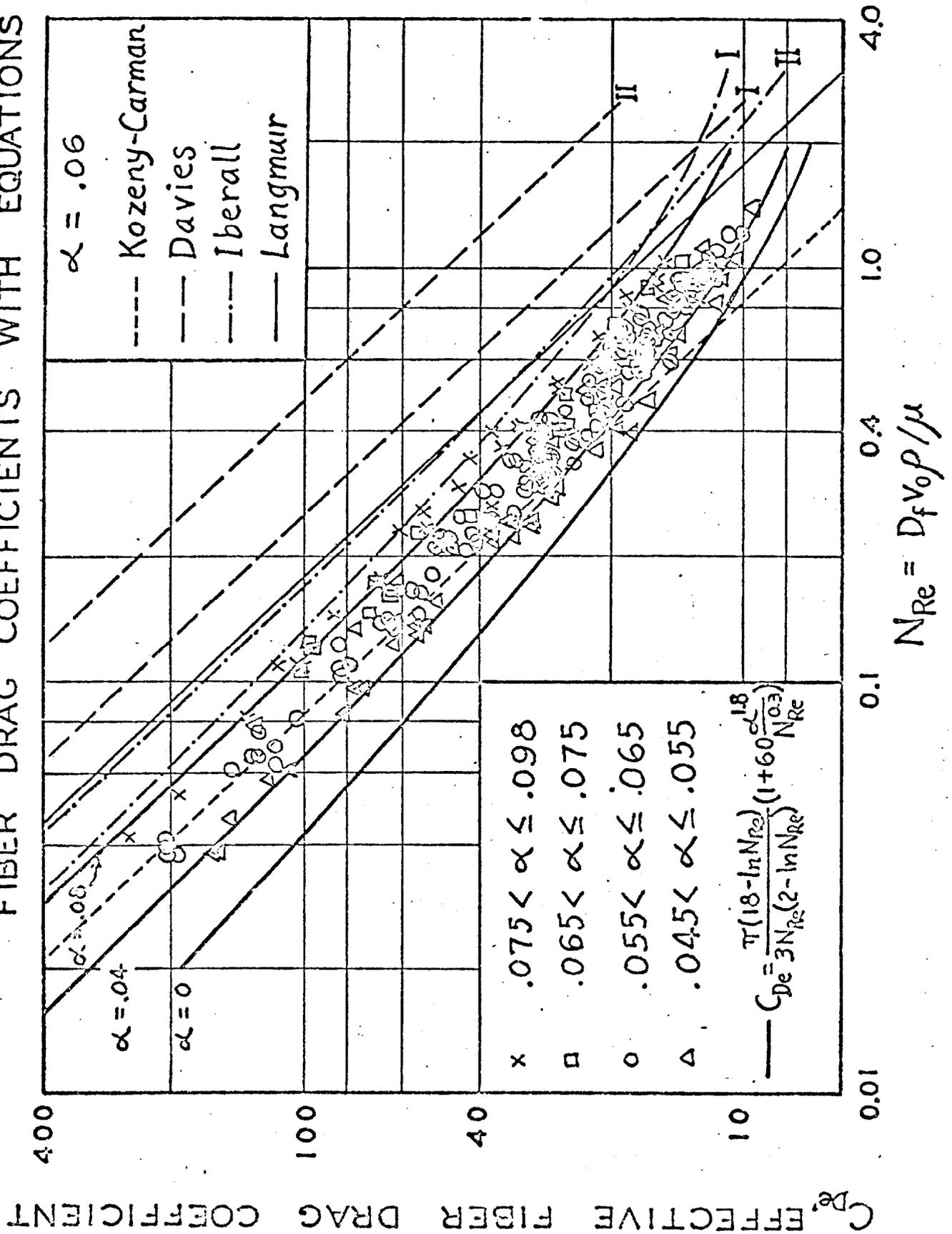


FIG. 4. COMPARISON OF EXPERIMENTAL EFFECTIVE FIBER DRAG COEFFICIENTS WITH EQUATIONS



FILTRATION OF SUBMICRON SIZE AEROSOLS
BY FIBROUS MEDIA

by

C. Y. Chen, Research Associate
Chemical Corps Contract No. DA-18-108-CML-4789

The object of this research is to study the filtration of aerosol particles through a fiber mat both theoretically and experimentally. Much work has been done on the development of new filter material and on the measurement of penetration of aerosols through filter material, but not much has been done on the theoretical prediction of the penetration of filter materials and on the experimental study based on the theoretical prediction. The present study is along this line.

THEORY

For filtration of uncharged submicron size aerosols with uncharged filtering medium, the particles might be removed either by inertial impaction, direct interception or Brownian diffusion. To study the filtration of aerosols by fiber mats, it is necessary first to learn the filtration or collection efficiency of a single fiber which composes the mat.

For single fibers, the efficiency of collection of aerosols (η) by any mechanism can be expressed as the ratio of the cross sectional area of the original stream from which particles of a given size are removed because their trajectories intersect the collector surface to the projected area of the collector in the direction of flow. The efficiency of collection by inertia impaction is a function of $\Psi = (C_{pp} d_p^2 v) / (18\mu d_f)$ and N_{Re} ; by direct interception, η is a function of $R = d_p/d_f$ and N_{Re} ; and by diffusion, η is a function of $D = D_{BM}/v d_f$ and N_{Re} . The collection by inertial impaction and diffusion increases with Ψ and D , respectively, and always increases with increase of N_{Re} . The importance of direct interception increases with increase of R and decreases with increase of Ψ and D .

Not much experimental work has been done on the collection efficiency of a single fiber especially under the conditions present during the filtration by fiber mats, that is, very low Reynolds number. Until recently, the calculation of collection efficiency by inertial impaction was based on potential flow which can hardly be in the case in the fiber mats when the Reynolds number is usually much less than 1. Davies⁽¹⁾ calculated the inertial impaction and direct interception on fibers assuming viscous flow. From his results, η could be plotted as a function of Ψ with R as a parameter. Davies' results indicated that inertial impaction efficiency based on viscous flow is much lower than that calculated from potential flow. Langmuir⁽²⁾ has derived equations for predicting the collection efficiency of a single fiber by interception, by diffusion, and by interception and diffusion combined. He derived his equations from Lamb's equation for viscous flow around a cylinder transverse to the flow. Figure 1 shows the collection efficiency by diffusion and interception at a Reynolds number of 10^{-2} .

An interesting conclusion from these calculations is that the collection efficiency due to both effects is higher than the sum of the efficiencies due to the individual effects alone. The same conclusion can be drawn from the Davies calculation of the combined effects of inertial impaction and interception.

The overall efficiency due to inertial impaction, interception and diffusion is very difficult to calculate. A reasonable assumption is that the overall efficiency will be equal to the sum of the efficiencies due to inertial impaction and interception and that due to diffusion and interception. Calculated efficiencies based on this assumption for 2 μ and 3 μ diameter fiber for different particle size and velocity are shown in Figures 2 and 3.

The orientation of fibers in ordinary fiber mats can be considered as lying between two extreme cases. In the first case, the fibers are dispersed uniformly and far apart and the neighboring fibers are staggered with respect to each other. In the second case, the fiber in each layer of mat is lined up to form a group of capillaries. The ordinary fiber mat with high porosity approximates the first case.

In a fiber mat of the first case with porosity approaching 100 percent, all the fibers are available for collection. It is possible to express the overall collection efficiency of this ideal fiber mat as a function of individual fiber total collection efficiency η as defined above.

$$-\ln \frac{N}{N_0} = \frac{4}{\pi} \cdot \eta \cdot \frac{1-\epsilon}{\epsilon} \cdot \frac{L}{d_f} \quad (1)$$

This equation applies only when the fibers are far apart and there are no interference effects between neighboring fibers. Actually, the equation is approximately true for high porosity fiber mats. It is reasonable to express the neighboring fiber interference effect as a function of interfiber distance, or as a function of porosity only for the same type of mat within a narrow range of Reynolds number. Thus, the following equation can be used to express the fiber mat collection efficiency.

$$-\ln \frac{N}{N_0} = \frac{4}{\pi} \cdot \eta \cdot \frac{1-\epsilon}{\epsilon} \cdot \frac{L}{d_f} \cdot F(\epsilon) \quad (2)$$

$F(\epsilon)$ has a limiting value of 1 for mats with porosity of 100 percent; it is greater than 1 when the porosity decreases, and has an asymptotic value for low porosity mats. The function can be calculated from pressure drop measurements across the mat. For a fiber mat with porosity approaching 100 percent with all the fibers transverse to the flow, the pressure drop can be expressed in the following form, based on the Langmuir equation for the drag force of a single cylinder transverse to the flow when N_{Re} is less than one:

$$\Delta p = \frac{16(1-\epsilon)}{2-\ln N_{Re}} \frac{\mu L}{d_f^2 \epsilon c} \quad (3)$$

White (3) has shown that the viscous drag force for a single cylinder in a finite container is higher than that predicted by Lamb's equation for an isolated cylinder. The deviation is a function of the ratio of the distance between the fiber and the container and the fiber diameter. It can be expressed as a function of porosity for fiber mats to account for the effect of neighboring fibers. This function also has a limiting value of one for 100 percent porosity; it increases to an asymptotic value for low porosity mats and will be approximately the same function of porosity used above to describe the neighboring fiber interference effect on collection efficiency. Thus the pressure drop across the fiber mat can be expressed as

$$\Delta p = \frac{16(1-\epsilon)}{2-\ln N_{Re}} \cdot \frac{\mu L}{d_f^2 g_c} \cdot F(\epsilon) \quad (4)$$

From this discussion, we are able to calculate the penetration of a fiber mat from the physical factors of the mat (thickness, fiber diameter and porosity), the pressure drop across the mat and the collection efficiency of a single fiber calculated for the operating conditions (velocity, particle density and diameter).

It is now possible to show whether a size of maximum penetration exists for a certain fiber mat from the calculation of the single fiber collection efficiency. Table I shows the results for mats of 3μ and 2μ fibers. It is not surprising from the table that the controversy concerning maximum penetration arises. It is simply due to the fact that only a few experiments have been carried out under very limited experimental conditions.

TABLE I. PARTICLE SIZE AT MAXIMUM PENETRATION

Particle density = 1 g./cc.

| <u>Average Velocity</u> | <u>For Fiber Size</u> | |
|-------------------------|-----------------------|------------------|
| | <u>3 microns</u> | <u>2 microns</u> |
| in mat | d_p | d_p |
| cm./sec. | microns | microns |
| 0.1 | 0.52 | 0.45 |
| 1 | 0.28 | 0.23 |
| 6 | 0.19 | 0.16 |
| 10 | 0.15 | 0.14 |
| 40 | 0.11 | 0.10 |
| 100 | 0.075 | 0.070 |

EXPERIMENTAL

A LaMer-Sinclair type homogeneous liquid aerosol generator was built for this study with DOP as aerosol material. The particle size was measured either by the polarization "Owl", the growth method (4), or by the diffusion battery (5)

depending on the range of the size of the particles. Penetration through the mat was measured by the NRL-E3 pantrometer. Extensive penetration measurements on air-formed B glass fiber mats are in progress. The present mats used contain a wide range of fiber size. Some of the initial experiments indicate that the theory is quite satisfactory.

Table II contains some experimental results compared with the theory assuming the diameter of fiber is 3.5 microns. The actual size of the fibers has a wide range of distribution and the average size is about 3.5 microns.

TABLE II. COMPARISON OF EXPERIMENTAL RESULTS
WITH THEORETICAL PREDICTION

B glass fiber mat porosity 98.6%; thickness 1.2 cm.

Aerosol material: DOP; particle size, 0.30 μ

| Velocity cm./sec. | η | |
|----------------------|-----------------------|--------------------------------------------|
| | From Expt. | by calculation based on $d_f = 3.5 \mu$ |
| 26.8 | 2.29×10^{-2} | 2.58×10^{-2} |
| 12.0 | 2.61 | 2.38 |
| 5.33 | 2.70 | 2.76 |
| 2.98 | 2.66 | 3.16 |
| 1.69 | 3.85 | 3.48 |
| 0.89 | 4.35 | 4.18 |

CONCLUSIONS

From the experimental data available at the present time, the results agree with the theoretical prediction fairly well. Additional experimental work is in progress. The results indicate that the penetration of a fiber mat for the first time can be predicted by theoretical calculation. Also, the development of a new filter material can be made on a scientific basis rather than by a cut-and-try method. The controversy on whether a maximum penetration size exists has been solved by theoretical calculations and the experimental confirmation of the theory will be presented in the near future.

NOMENCLATURE

C = empirical correction for resistance of air to the movement of small particles (at room temperature and atmospheric pressure, $C = 1 + 0.16/d_p$, where d_p is particle diameter in microns).

d_p = particle diameter

v = upstream velocity or average velocity

d_f = fiber diameter

D_{BM} = Brownian diffusion coefficient of aerosol particles

N/N_0 = fraction of penetration of aerosol through fiber mat

L = thickness of fiber mat

Δp = pressure drop across fiber mat

g_c = conversion factor, $32.2 \frac{\text{lb. mass} \times \text{ft.}}{\text{lb. force} \times \text{sec.}^2}$

$F(\epsilon)$ = a function of porosity representing neighboring fiber interference effect

D = diffusion parameter, $\frac{D_{BM}}{v d_f}$

R = interception parameter, d_p/d_f

Ψ = inertia parameter $\frac{C \rho_p d_p^2 v}{18 \mu d_f}$

ρ_p = particle density

ρ = fluid density

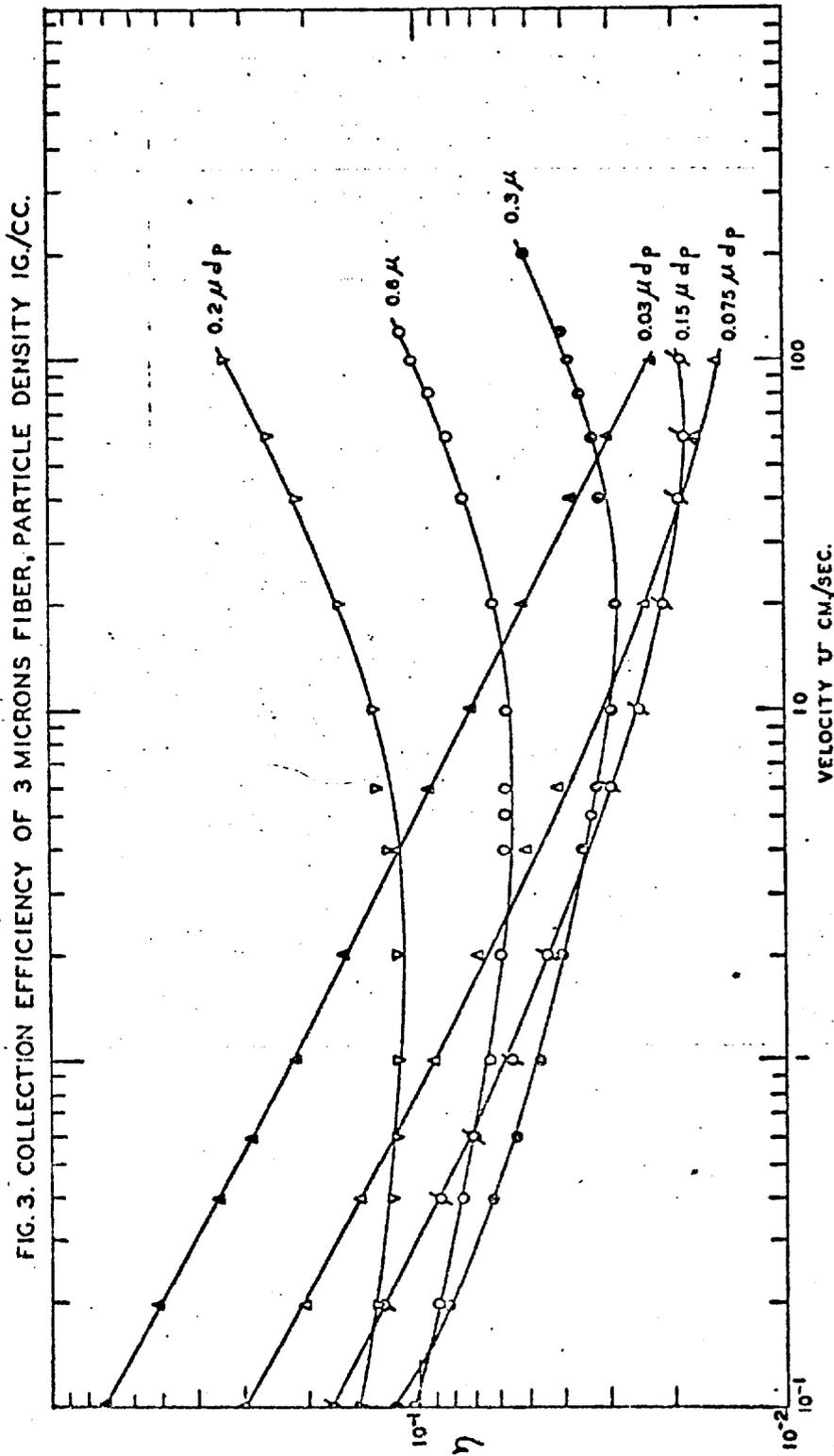
μ = fluid viscosity

η = collection efficiency of a single fiber

ϵ = porosity of fiber mat

LITERATURE CITED

1. Davies, C. M., Preprint, Inst. of Mech. Eng. (London) July 1, 1952.
2. Langmuir, I., OSRD Report No. 865 (1942).
3. White, C. M., Proc. Royal Soc. (London) A186, 472 (1946).
4. LaMer, V. K., Final Report NYO-512, Contract AT-(30-1)-651. (June 1951).
5. DeMarcus, W., Thomas, J. W., ORNL-1413 (Oct. 1952).



INFLUENCES OF ELECTROSTATIC FORCES ON THE DEPOSITION OF AEROSOLS

by

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In recent years several studies have been made on the mechanisms by which particulates can be removed from an aerosol. Although emphasis has been placed on the inertial mechanism of collection, the effects of small electrostatic charges on the aerosol particles and on the collecting surface must not be overlooked in promoting the collection efficiency. Many natural aerosols are electrically charged, as are some collecting surfaces such as the fibers in a resin-wool filter. Uncharged surfaces or aerosols readily can be given an electric charge, thereby increasing the separation of particles from the aerosol.

The utilization of electrostatic forces in promoting aerosol deposition may be advantageous in several ways. The foremost advantage is the high collection efficiency (based on projected cross-sectional area of the collector) that is possible. Although a collection efficiency of more than 100 percent is not possible when only inertial forces are used, efficiencies of 10,000 percent or higher may be achieved if both the collector and the aerosol are charged.* The collection efficiency using electrostatic forces remains high even for sub-micron particles, although inertial forces in this case may be negligible. Another consideration is the fact that electrostatic mechanisms of collection require low aerosol velocities of flow across the collecting surface. The pressure drops in the system consequently will be much lower than would be the case for similar collection by the inertial mechanism.

The purpose of the current research is to investigate the mechanisms of aerosol deposition under the influence of electrostatic forces and to indicate the conditions and types of equipment wherein electrical charging may be beneficial.

THEORY

Studies are being made of the motion of a charged aerosol particle flowing past a single spherical collector Figure 1. The collection efficiency can be calculated theoretically if the outermost limiting trajectory is known for the aerosol particles just grazing the collector.

The differential equations of motion of a single aerosol particle approaching the spherical collector are given in Figure 2. The equations are derived from force balances of the fluid resistance and of the electrostatic forces of

*The collection efficiency is defined as the fraction of the aerosol removed from a tube of gas subtended by the collecting obstacle as the gas flows past.

attraction between (1) a charged collector and a charged aerosol (parameter K_E), (2) a charged collector and its image in an uncharged aerosol particle (parameter K_I), (3) a charged aerosol and its image in an uncharged collector (parameters K_M and K_S). The several electrostatic forces can be shown to be approximately additive. Potential flow streamlines and Stokes' law are also used in deriving the equations. Since the differential equations have been made dimensionless, all of the experimental variables are contained in the dimensionless parameters K_E , K_I , K_M , K_S Figure 3.

Although the solution of the two simultaneous differential equations is possible only by a numerical method, order of magnitude solutions may be obtained by ignoring the bending of the air streamlines around the spherical collector and by considering only one collection parameter, K_E , K_I , K_S or K_M , at a time.

The numerical solution of the trajectory equations has been completed by means of the electronic digital computer, the ILLIAC. Collection efficiencies were calculated for a range of values of the four parameters, K_E , K_I , K_S and K_M . Some of the results are shown in Figure 4.

In order to interpolate between solutions obtained with the computer, the collection efficiencies and the collection parameters may be correlated by curve-fitting with a high-order multivariate polynomial.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

The equipment is shown in Figure 5. A dioctylphthalate (DOP) fog is produced by condensation of the vapor in the presence of salt nuclei. The particle diameter is about 0.8 ± 0.2 micron. The aerosol is charged electrically by passing it through coaxial electrodes in a state of corona. Charges of +10 to +80 electronic units can be obtained. A description of the mechanism of the charging process and of the method of measuring the charges on the aerosol particles was given at the Ames Conference in 1952.

The charged aerosol then flows past the spherical collector which is a $7/16$ " steel ball mounted on the end of a semi-conducting cone. The cone acts as an electrostatic shield around the wire connecting the sphere to a high voltage D.C. power supply (0-10,000 volts). Without it, the electric charge on the wire affects the collection on the sphere.

The electrical charge on the aerosol is determined from the deflection of a streamer of aerosol flowing in a transverse electric field. The aerosol is carried through the field by an envelope of moving air. The size of the particles is measured by the "Owl" and by a high velocity cascade impactor. The mass concentration of the aerosol is determined by precipitation of a sample in a small glass and platinum Cottrell precipitator.

The collection efficiency is determined experimentally by measuring the amount of aerosol deposited on the sphere and in the sampling Cottrell precipitator. The DOP is removed from the collecting surfaces by washing with ethyl alcohol and the concentration found by ultra-violet spectrophotometry. Collection on the sphere ranges from 1 to 10 micrograms of DOP per minute.

EXPERIMENTAL RESULTS

The preliminary data are shown in Figures 6 and 7. The inertial parameter Ψ is about 10^{-6} . According to theory, the inertial forces should therefore have a negligible effect on the deposition.

The actual collection agrees approximately with that predicted by theory. In the case of the uncharged aerosol flowing near a charged collector, the data have a high experimental variability on account of the small amounts of DOP that were collected and measured.

In Figure 7 the data are plotted versus a modified parameter. Whenever a collector is grounded, even through a high resistance, charges are induced on the collector by all the surrounding charged particles. This induced charge occurs in addition to the image and void space effects described by the parameters K_M and K_S . The induced charge is calculated by an integration process and its contribution to deposition is combined with that of the K_S parameter. The combined parameter is K_S . Figure 7 illustrates data in which the induced charge resulting from grounding the collector was the major factor influencing deposition.

PRELIMINARY CONCLUSIONS

A practical application of electrostatic forces is illustrated in the use of charged water droplets for collection of aerosol particles which themselves are charged by passage through a corona discharge. An electrified wet scrubber would have several advantages over both the conventional wet cyclone and the Cottrell precipitator. Compared to a conventional scrubber, the electrified scrubber should provide better removal of submicron aerosol particles. Conversely, it would require less water and could operate at lower velocities and pressure drops for the same efficiency of aerosol removal. Furthermore, it would have several advantages over the Cottrell precipitator. The precipitated material would be removed continuously on the surfaces of the spray droplets, thereby eliminating the problems often encountered in precipitating dusts that have a tendency for reentrainment. The retention time in an electrified scrubber would be lower than in a Cottrell precipitator because an aerosol particle must travel a shorter distance to the nearest spray droplet. Also, the electrified scrubber would be operated at relatively lower voltages (1000 to 10,000 volts) since the collection distances are smaller.

An electrified spray scrubber is now being constructed to evaluate its potentialities.

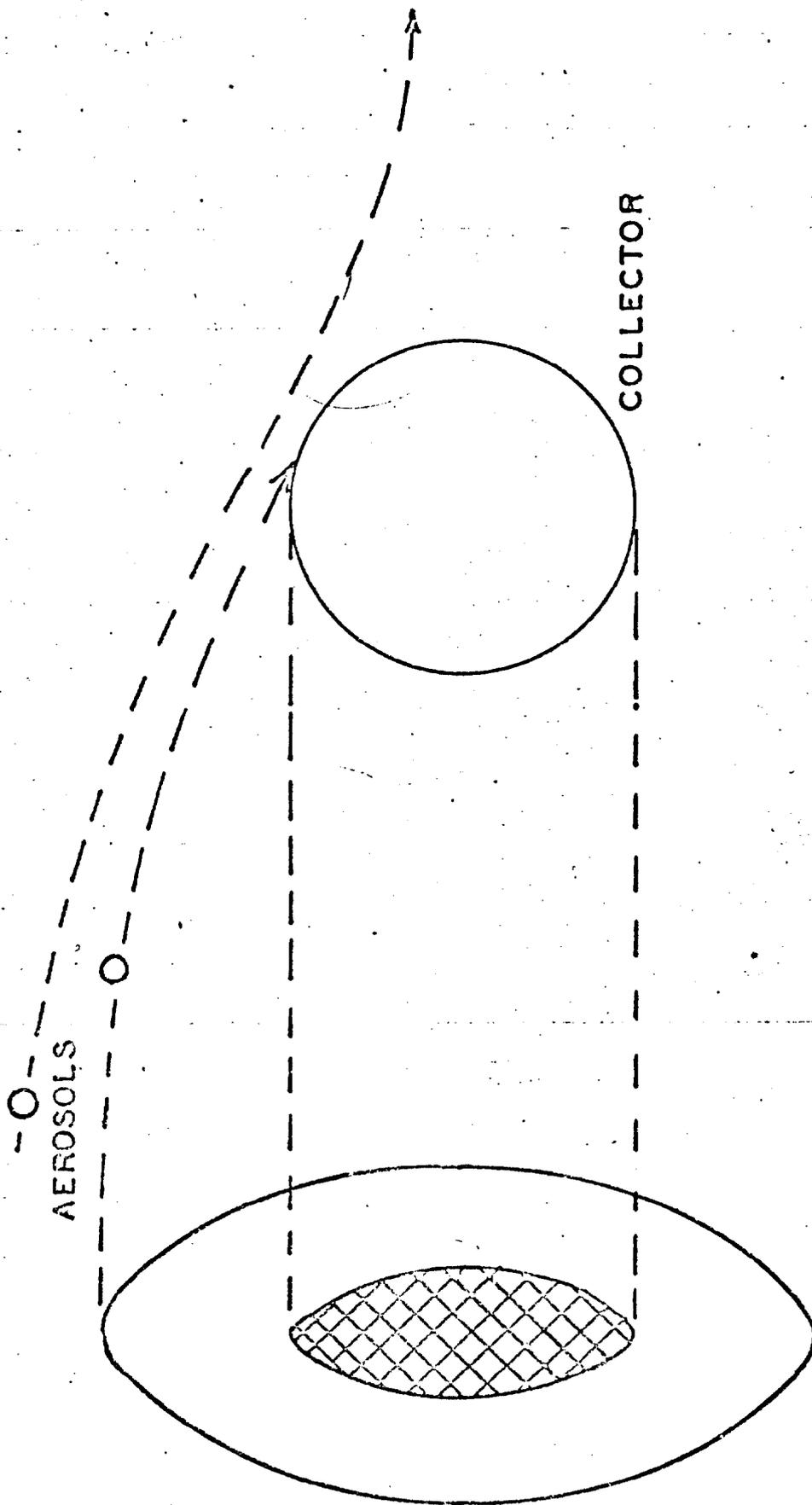


FIG. 1 - TRAJECTORY OF AEROSOL PARTICLE UNDER
INFLUENCE OF ELECTROSTATIC CHARGE ON COLLECTOR

Angular Velocity of Aerosol Particle

$$\frac{d\theta}{dt} = - \frac{(2r^3 + 1)}{2r^4} \sin\theta$$

Radial Velocity of Aerosol Particle

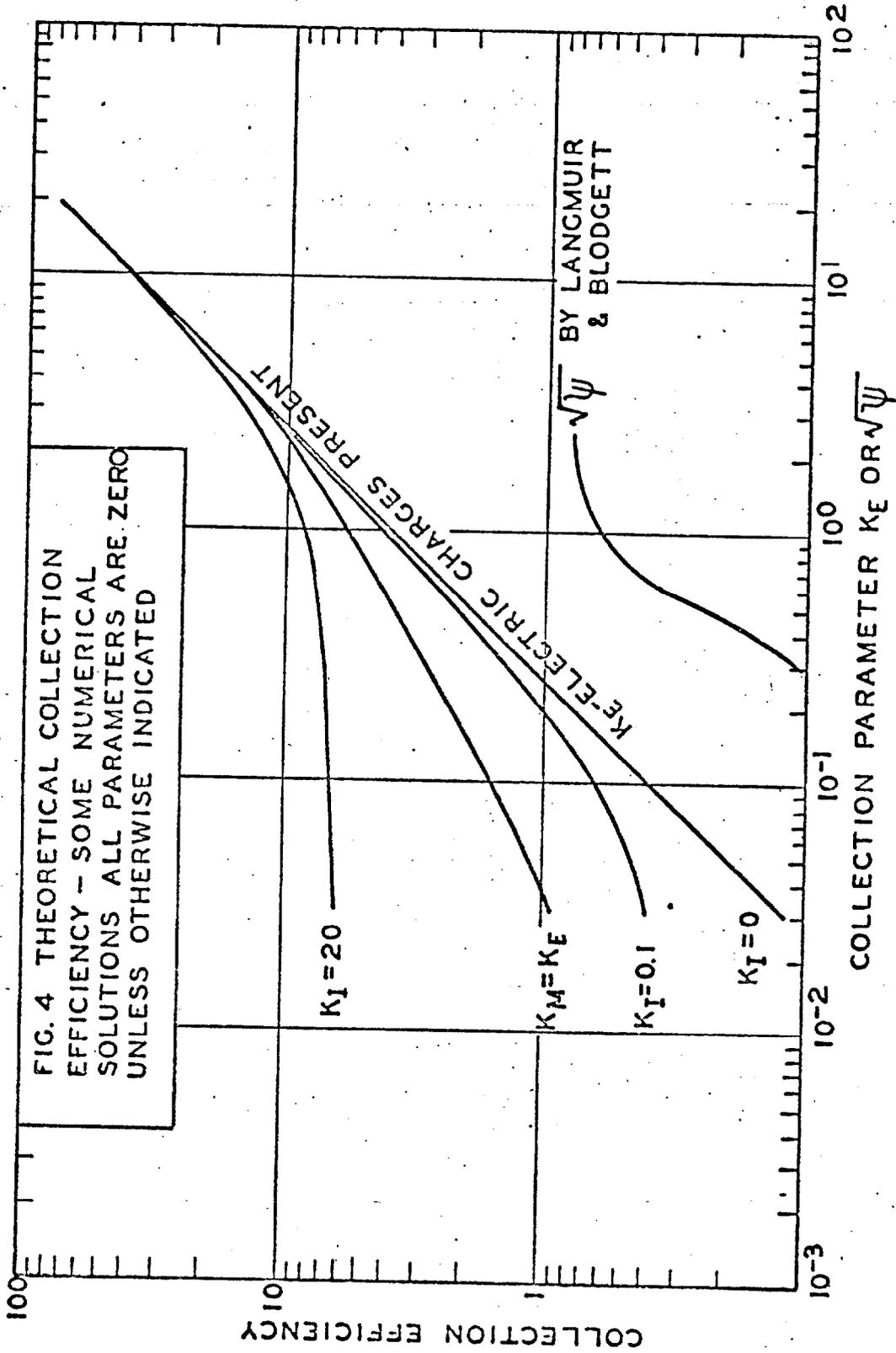
$$\frac{dr}{dt} = \frac{(r^3 - 1)}{r^3} \sin\theta - \frac{(K_E + K_S)}{r^2} - \frac{K_I}{r^5} - K_M \left(\frac{r}{(r^2 - 1)^2} - \frac{1}{r^3} \right)$$

FIGURE 2 - DIFFERENTIAL EQUATIONS OF TRAJECTORY OF AEROSOL PARTICLE

Potential Flow with Electrostatic Forces and
Stokes' Resistance

| | | | |
|-------|---|-----------------------------------------------------------------------------------|----------------------------------------------------------|
| K_B | = | $\frac{q_p q_{ac} C}{3\pi \mu D_p v_o \epsilon_o}$ | Coulombic attraction |
| K_S | = | $\frac{q_p^2 n D_c C}{18\pi \mu D_p v_o \epsilon_o}$ | Repulsion by surrounding aerosol |
| K_I | = | $\frac{2(\epsilon - 1) D_p^2 q_{ac}^2 C}{3(\epsilon + 2) \mu v_o \epsilon_o D_c}$ | Image force of charged collector on uncharged aerosol |
| K_M | = | $\frac{q_p^2 C}{3\pi^2 \mu D_p v_o \epsilon_o D_c^2}$ | Image force of charged aerosol on uncharged collector |

FIGURE 3 - ELECTROSTATIC COLLECTION PARAMETERS



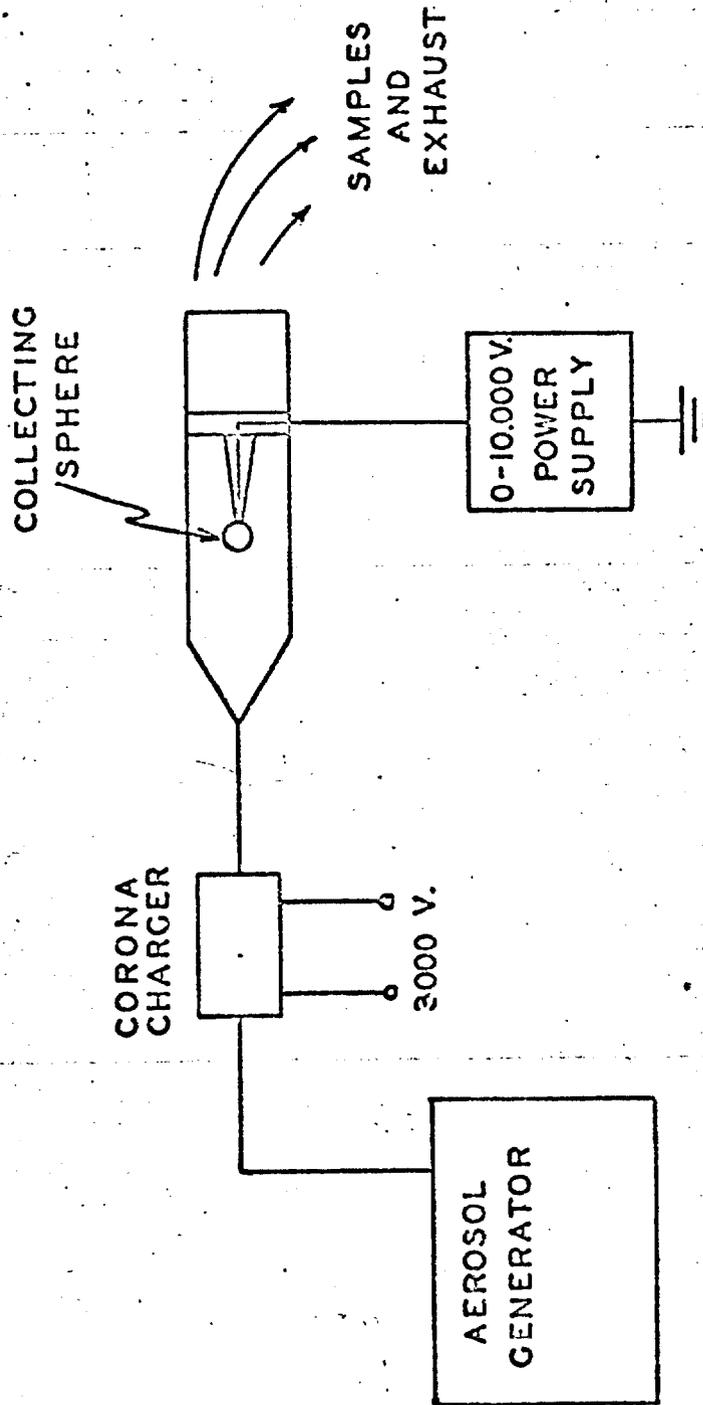
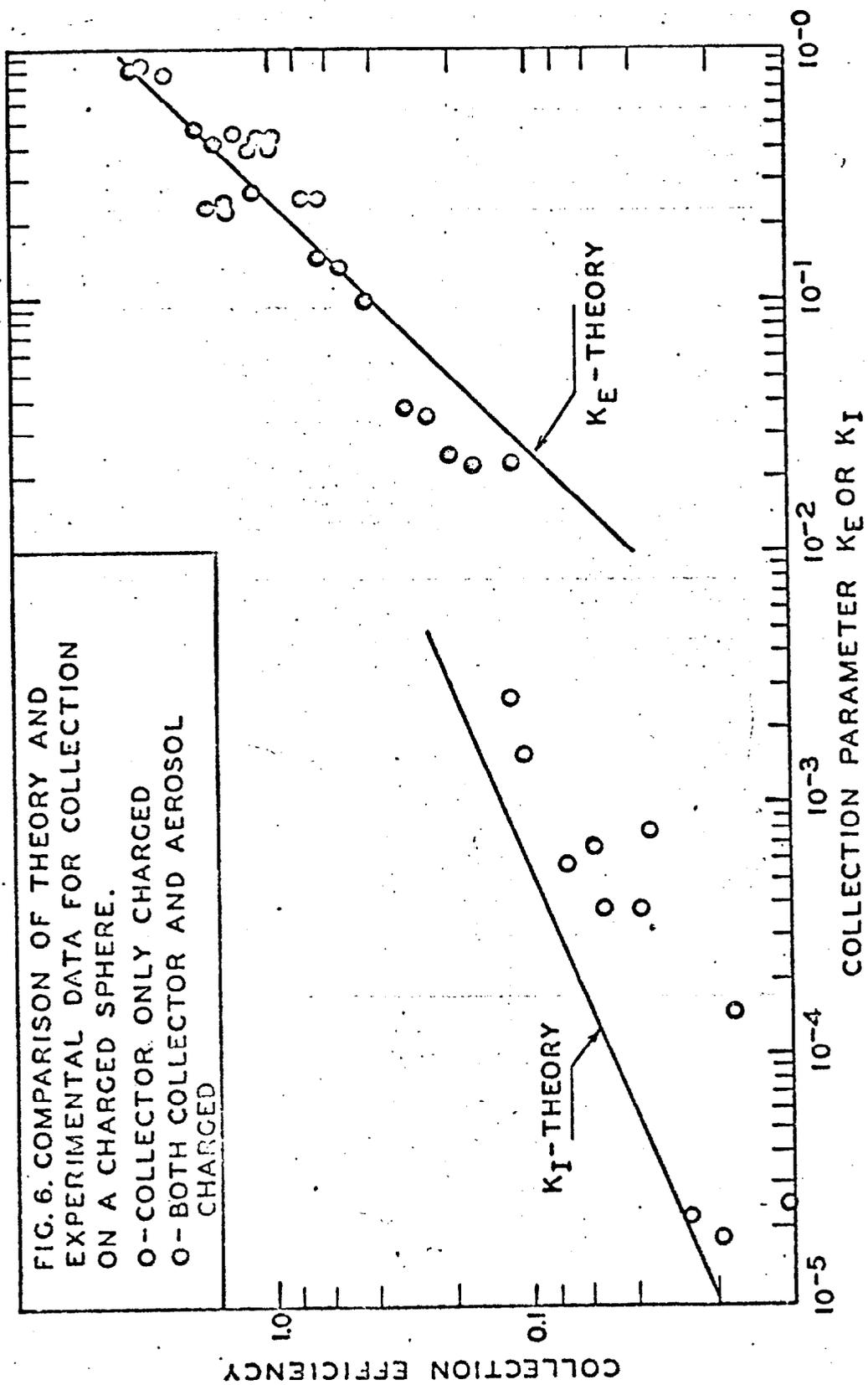
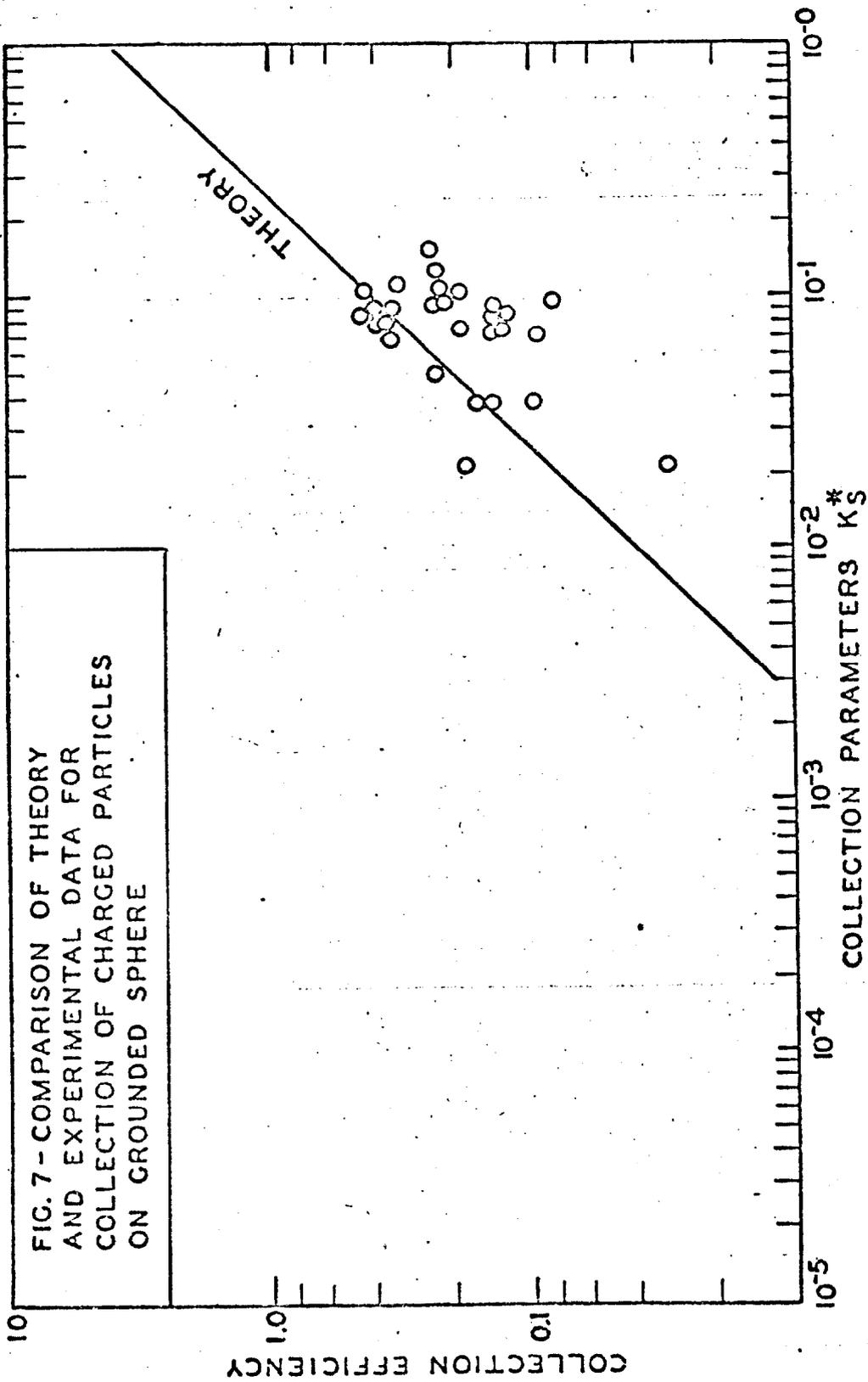


FIG. 5 - FLOW DIAGRAM OF EXPERIMENTAL EQUIPMENT

WASH-170





WASH-170

AUTHOR INDEX

PERSONAL AUTHORS

- | | | | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Barnes, E. C., 99 Baumann, W. H., 13 Biladeau, A. L., 63 Billings, C. E., 251, 262 Blasewitz, A. G., 40 Bradley, J. E., 146</p> | <p>Fisher, R. W., 165 Fitzgerald, J. J., 118, 334 Friedlander, S. K., 351</p> | <p>Lapple, C. E., 205 Mason, M. G., 68 Miller, H. I., Jr., 79 Morgan, D. M., 102</p> | <p>Silverman, L., 251, 262 Smith, W. H., 87 Smith, W. J., 305, 330 Spano, L. A., 281 Stockdale, W. G., 21 Surprenant, N. F., 305</p> |
| <p>Chen, C. Y., 368 Cherubin, L. J., 118 Clark, J. R., 155 Coleman, R. D., 272 Corey, R. C., 281</p> | <p>Gemmell, Lee, 142 Graham, J. B., 7</p> | <p>O'Neill, D. P., 48</p> | <p>Thaxter, M. D., 170, 218</p> |
| <p>Decker, H. M., 227 Dennis, R., 251, 262</p> | <p>Hampson, D. C., 58 Harris, W. B., 68 Harstad, J. B., 227 Humphrey, P. A., 102, 191 Johnstone, H. F., 349 Kraemer, H. F., 374</p> | <p>Piper, F. J., 227 Rodger, W. A., 58 Rossano, A. T., 235 Rueth, J. A., 146 Saunders, G. T., 185, 222 Schulte, H. F., 11</p> | <p>Van Valzah, R. W., 55 Walker, R. J., 161 Wilkins, E. M., 102, 191 Wilson, Myrl E., 227 Wong, J. B., 356</p> |

CORPORATE AUTHORS

- | | | |
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| <p>Ames Lab., 165 Argonne National Lab., 48, 55, 58 Atomic Energy Commission (See also <u>Health and Safety</u> <u>Div., AEC, and Idaho Operations</u> <u>Office, AEC.</u>) 63 Brookhaven National Lab., 142 Bureau of Mines, 281 California Research and Develop- ment Co. (See <u>Livermore Research Lab.</u>) Carbide and Carbon Chemicals Co. (Y-12), 13 Catalytic Construction Co., 79 Chemical Corps., 227 Department of the Air Force, 227 Dow Chemical Co., Western Div., 161 Du Pont de Nemours, E. I., and Co., Explosives Dept., Atomic Energy Div., 155 General Electric Co., ANP Project, 87</p> | <p>General Electric Co., Hanford Atomic Products Operation (See <u>Hanford Works.</u>) General Electric Co., Knolls Atomic Power Lab. (See <u>Knolls Atomic Power Lab.</u>) Hanford Works, 40 Harvard Univ. School of Public Health, 235, 251, 262, 272 Health and Safety Div., AEC, 68 Idaho Operations Office, AEC, 102 Illinois Univ., 349, 351, 356, 366, 374 Knolls Atomic Power Lab., 118, 334 Little, Arthur D., Inc., 305, 330 Livermore Research Lab., Calif. Research and Development Co., 185, 222 Los Alamos Scientific Lab., 7, 11 Mallinckrodt Chemical Works, 68 Monsanto Chemical Co. (See <u>Mound Lab.</u>) Mound Lab., 146</p> | <p>National Reactor Testing Station, 102 Oak Ridge National Lab., 21 Ohio State Univ., 205 Radiation Lab., Univ. of Calif., Berkeley, 170, 218 Savannah River Lab. (See <u>Du Pont de Nemours, E. I.,</u> <u>and Co.</u>) Univ. of California, Radiation Lab. (See <u>Radiation Lab., Univ. of</u> <u>Calif., Berkeley.</u>) U. S. Army Chemical Corps. (See <u>Chemical Corps.</u>) U. S. Bureau of Mines (See <u>Bureau of Mines.</u>) U. S. Department of the Air Force (See <u>Department of the Air</u> <u>Force.</u>) U. S. Weather Bureau (See <u>Weather Bureau.</u>) Weather Bureau, Idaho Falls, Idaho, 102, 191 Westinghouse Atomic Power Div., 99</p> |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

SUBJECT INDEX

- Aerodyne dust collectors**
(See Dust collectors.)
- Aerosol charge-measurement unit**
design, 247
- Aerosols**
filtration, 205, 235, 305, 356, 366
- Aerosols (charged)**
preparation, 375, 381
properties, 349
- Air**
purification, 39, 48, 227
- Air cleaning**
meteorological aspects, 191
- Air cleaning equipment**
maintenance, 17, 25
performance, 22, 149
- Air conditioning systems**
design, 55, 149, 152
- Air-sampling equipment**
design, 160, 230
performance, 186, 305, 330, 335, 343
- Aircraft engines**
decontamination, 66
- Aircraft Reactor Experiment**
air-cleaning facilities, 35
- Ames Lab.**
air-cleaning activities, 165
- Arco Chemical Plant**
(See also National Reactor Testing Station.)
air-cleaning facilities, 36, 37, 64
- Argonne incinerator**
(See Incinerators.)
- Argonne National Lab.**
air-cleaning activities, 48, 55
- Asbestos-glass filter paper**
efficiency, 227
- Bacteria**
(See Serratia indico.)
- Berkeley boxes**
(See Fume hoods and Dry boxes.)
- Bromine**
(See Halogen gases.)
- Brookhaven National Lab.**
air-cleaning activities, 142
- Carbide and Carbon Chemical Co. (Y-12)**
air-cleaning activities, 13, 20
- Carbon canister filters**
effectiveness, 165
- Carbonyl iron powders**
as test dust, 352
- Copper oxide powders**
as test dust, 87
- Copper sulfate powders**
as test dust, 269
- Cotton fiber filters**
efficiency, 272, 278
- Di-octyl phthalate smoke**
(See Aerosols.)
- DOP tester**
(See Smoke penetration meters.)
- Dry boxes**
design, 146, 170, 220
- Dust collectors**
cost factors, 18, 76
design, 17, 81, 85, 87, 92, 96, 100, 251, 263
efficiency, 63, 69, 83, 88, 90, 97, 251, 253, 262, 264
maintenance, 73, 100
operation, 71
- Dust generators**
design, 95
- Dust hazards**
in U production plants, 69
- Dust loading**
altitudinal factors, 102
at Brookhaven area, 142
meteorological factors, 102
at National Reactor Testing Station, 102
at Rocky Flats plant, 161
- Dusts**
physical properties, effects of altitude, 87, 103, 105, 106
physical properties, effects of meteorological conditions, 102, 105, 110
- Electro-polar filter unit**
(See Dust collectors.)
- Electrostatic precipitation**
effect of fiber charge, 242
effect of particle charge, 237
theory, 235
- Electrostatic precipitators**
design, 34
efficiency, 28
- Entoleter unit**
(See Dust collectors.)
- Exhaust systems**
design, 166
efficiency, 13, 28, 45, 81
- Experimental Breeder Reactor**
coolant air processing, 65
- Fibrous filters**
(See Membrane filters.)
- Filter house**
for ORNL graphite reactor, design, 22, 23
- Filter materials**
(See also Asbestos-glass filter paper; Carbon canister filters; Cotton fiber filters; Glass-fiber paper filters; Glass-wool filters; Membrane filters; Metallic filters; Mineral filter papers; Sand-bed filters.)
cost factors, 46
efficiency, 14, 22, 24, 28, 40, 43, 52, 55, 57, 61, 64, 121, 131, 142, 150, 157, 161, 165, 186, 205, 227, 259, 262, 305, 303, 318, 324, 330, 356
properties, 313, 323
- Filtration**
of very small particles, theory, 349
- Fluorine**
removal from air stream, 49

Fume hoods

- cost factors, 224
- design, 146, 170, 222
- efficiency, 14, 28, 52, 56, 227

Gamma radiation

- permissible limits in air, 79

General Electric, ANP Project

- air-cleaning activities, 87

Glass-fiber-paper filters

- efficiency, 227

Glass wool filters

- efficiency, 14, 40, 43, 57, 59, 64, 131, 142, 157, 163, 166, 186, 262

Halogen gases

- removal from air stream, 48

Hanford Works

- air-cleaning activities, 40

Hersey unit

- (See Dust collectors.)

Homogeneous Reactor Experiment

- air-cleaning facilities, 36

Hoods

- (See Fume hoods.)

Hydrogen fluorides

- handling, 81
- removal from air stream, 48

Idaho Chemical Processing Plant

- (See Arco Chemical Plant.)

Incinerators

- cost factors, 62
- design, 11, 58, 281, 284, 294
- performance, 58, 283, 285, 297

Insects

- distribution in air, 107

Iodine I¹³¹

- removal from process gas streams, 41

Knolls Atomic Power Lab.

- air-cleaning activities, 118
- buildings and facilities, 118
- environs monitoring, 126, 335, 348

Limestone

- absorption of halogen gases, 48

Livermore Research Lab.

- air-cleaning activities, 185

Los Alamos Scientific Lab.

- air-cleaning activities, 7

Materials Testing Reactor

- coolant-air processing, 65

Membrane filters

- efficiency, 22, 24, 28, 52, 55, 58, 131, 142, 150, 163, 166, 186, 205, 358, 364, 366, 371

Metallic filters

- efficiency, 14, 356, 362

Microorganisms

- filtration from air, 227

Mineral filter papers

- efficiency, 233

Mound Lab.

- air-cleaning activities, 146

National Reactor Testing Station

- (See also Arco Chemical Plant.)

- air-cleaning activities, 63, 102

Nuclear aircraft power plants

- air-cleaning activities, 86

Oak Ridge National Lab.

- air-cleaning activities, 21, 30, 35

Particle deposition

- effects of electrostatic forces, 374, 377, 382
- effects of particle size, 352, 355
- effects of velocity, 352, 355
- turbulent, measurement, 354
- turbulent, theory, 351,

Perchloric acid gases

- removal from air stream, 57

Process-gas streams

- decontamination, 40, 41, 43

Radiation

- permissible concentrations in air, 339, 342

Radiation Lab., Univ. of Calif.

- air-cleaning activities, 170, 218

Radiochemical processing

- air-cleaning equipment, 28

Radioactive waste disposal

- cost factors, 21
- incineration, 12, 58, 281, 284, 294

Radon

- radiation hazards, 79

Reaction vessels

- silver, efficiency for I¹³¹ removal, 41

Reactor coolant-air

- processing, 65, 143

Rocky Flats Plant

- air-cleaning activities, 161

Sand-bed filters

- efficiency, 158

Savannah River Lab.,

- air-cleaning activities, 155

Serratia indico

- test organism in filter evaluation, 228

Scrubbers

- design, 218, 376
- efficiency, 48, 57, 163, 219

Simon suction filter unit

- (See Dust collectors.)

Smoke penetration meters

- design, 306
- performance, 307, 369

Spray columns

- (See Scrubbers.)

Stack disposal

- of radioactive gases, effectiveness, 28, 44, 122, 143, 159, 173, 191, 335

Stack gases

- particle-size determinations, 338, 345
- radiological monitoring, 11, 44, 58, 60, 101, 143, 150, 191, 337, 340

Thorium production plants

- air-cleaning activities, 167

Uranium

- radiation-hazards, 79, 83

Uranium production plants

- air-cleaning activities, 13, 15, 79, 80, 82

Uranium slurries

- handling, 83

Ventilation systems

- cost factors, 47
- design, 45, 55, 63, 82, 156, 161, 165
- efficiency, 13, 28, 43, 45, 80, 82, 143, 148
- radiological monitoring, 167

Westinghouse Atomic Power Div.

- air-cleaning activities, 99