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TID-7513(Pt. 1)

Subject Category: ENGINEERING

UNITED STATES ATOMIC ENERGY COMMISSION

FOURTH ATOMIC ENERGY COMMISSION AIR CLEANING CONFERENCE HELD AT ARGONNE NATIONAL LABORATORY, NOVEMBER 1955

June 1956
[TISE Issuance Date]

Division of Reactor Development
Washington, D. C.

Technical Information Service Extension, Oak Ridge, Tenn.

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Part 2 (Co. reclassified)
Air Cleaning Problems + Activities at Goodyear (Portsmouth) - Harold Peterson
Special Air Cleaning + Ventilating Eqpt for Spec. Machining Opns - M. D. Thacker
Air Cleaning + Breathing Atmosphere Units Systems for Facility 350 - A. B. Hench, ANL

Part 3 (000)
Fire Considerations in Filter Design - D. J. Keigher

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DIVISION OF REACTOR DEVELOPMENT
Washington, D. C.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

"A Review of Air Cleaning Activities at Argonne National Laboratory"

Presented at
1955 Air Cleaning Conference
by
D. P. O'Neil
Industrial Hygiene and Safety Division

ARGONNE NATIONAL LABORATORY

To facilitate this discussion of the air cleaning setup at Argonne, I'd like to describe the physical layout of the Laboratory by areas and discuss the type of work or operation taking place in these areas, the type of air cleaning equipment utilized and efficiencies realized. The costs of operating and maintaining one of these systems will be dealt with by Mr. R. W. Van Valzah, who follows with a discussion of the costs involved in cleaning exhaust air for this, the Chemistry Building, which is in many ways typical of the research buildings you saw while coming in here this morning.

The Laboratory as it now exists, is divided into four separate areas, only three of which require the cleaning of exhaust air. These areas have been designated as the East Area, the 200 Area, where we are now, and the 300 Area.

East Area

In the East Area are our Central Shops Department and Metallurgy Division which are housed in quonset huts.

The Central Shops Department is separated into two buildings; one for ordinary operations and the other, called the Special Materials Shops, for work with uranium, thorium, beryllium, graphite, etc. Many of the operations are ventilated by elephant trunks or 4" flex duct which is located close to the source of contamination, while other Shop tools are

enclosed or hooded to one degree or another. Those for uranium grinding, graphite work and beryllium work are segregated into three separate rooms off the main Shop area. The machine tools for beryllium work are completely enclosed in sheet steel and safety glass hoods to contain the dust as much as possible.

All the air from the Special Materials Shops area is exhausted through seven systems each with a type N rotoclone followed by an AAF Electro cell electrostatic precipitator. One exception is the graphite room, the air from which is cleaned by a cloth-type bag filter. One of the seven systems exhausts all operations in both the beryllium room and the uranium grinding room. It is interesting to note that efficiencies for this system, determined about once every two or three weeks, (the frequency of our routine stack sampling in this area since 1953) have been consistently high for beryllium, averaging around 99%, while for uranium the average efficiencies have been much lower, approximately 72%. This, we attribute to the fact that all the beryllium operations on machines such as lathes, mills, drills, etc. are exhausted through this system, while for uranium, only the grinding operations are tied into this system. The tremendous difference in the particle size between the chips from a beryllium turning job and the oxidized particles from a uranium grinding job result in much lower efficiencies for uranium collection.

Efficiency studies of other systems exhausting routine uranium machining operations fall between the low of 72% for uranium grinding and the high of 99% for beryllium. This is probably because the chips, unless doused, oxidize rapidly giving off a fine fume. Since this sometimes happens, the

small particles are not collected as efficiently and tend to lower the overall efficiency of the system.

The Metallurgy Division's work in this area runs the gamut from foundry and high temperature ceramic operations to corrosion, metallographic and high purity crystal studies. All these many and varied operations, except the ceramic work, are also exhausted through type N Rotoclones followed by the AAF electro cell electrostatic precipitators. Efficiencies of these systems are comparable to that for the uranium grinding system. This isn't too good, of course, but we're not too concerned since the load on these systems and the subsequent dumping to the outside is extremely light. If the operations in the area should change radically, a re-evaluation of the entire air cleaning setup would, of course, be necessary.

The ceramics building, containing numerous glove boxes, dry presses, vibrators, furnaces, hoods, etc., is exhausted entirely (except for a spray booth and a few pieces of small equipment) through high efficiency AEC filters.

As a somewhat tenuous measure of the efficiency in this, the East Area, or more accurately as a measure of the effectiveness of the air cleaning setup, background samples taken outside the buildings in the immediate area, i. e., within 50 - 1000' of the exhausts at ground level have shown only negligible quantities of either uranium or beryllium.

Maintenance shutdowns of the 21 exhaust systems in the East Area utilizing both electro cells and rotoclones have occurred, on the average, twice a year since early 1952, with the most active systems requiring as many as eight shutdowns in a single year, each requiring from 1 to 10 man-days.

200 Area

The 200-Area research laboratories were designed and constructed from a basic policy that all radioactive work or manipulations would take place in either Blickman or vacuum frame hoods. To implement this policy, a module system has been used wherein each laboratory may consist of one or more 10-foot modules, each module having a normal exhaust of 1000 CFM and a maximum of three hoods. Since each hood at maximum opening could exhaust 1000 CFM, Johnson Service controls are used to control the face velocity through the hood to 135 LFM, plus or minus 25 LFM, and to cut in extra exhaust when the normal 1000 CFM must be exceeded. All the air exhausted from these laboratories is filtered first through pre-filters and then finally through AEC high efficiency filters. A more thorough explanation of the entire supply and exhaust system for Building 200 was made at the 1953 Air Cleaning Conference by Mr. Van Valzah and can be found in the published record of that meeting so I'll not go into it any further; suffice to say it represents the Argonne philosophy and is typical of the situation in the 200 Area. There are, of course, variations or complete exceptions to the typical system and I'd like to mention briefly two of these now. You may have noticed that there is a small building just to the north of this building. That is the Reactor Engineering Division's liquid metals building wherein there are numerous experimental heat transfer loops containing NaK or liquid sodium. Of course, when either of these comes in contact with air or water, copious caustic fumes result, i. e., sodium or potassium oxide, or both, and these not only irritate the eyes and respiratory

tract, but also have a peculiar affinity for late model automobiles in the parking lot and a number of older models that are in dire need of refinishing jobs. As a result of this startling information, and numerous insurance difficulties, disposal operations which had originally been carried out just to the north of the building had to be relocated. And, consideration had to be given to an exhaust system which could be used to vent and clean the air from normal disposal operations. In addition, it was desirable to be able to cut in the exhaust system during fires within the building to both clean the fumes from the fire and keep a negative pressure on the building, thereby eliminating the possibility of fumes leaking from the building. With this setup, the building could be evacuated and the scrubber kept on to clean the fumes generated by the fire.

As a result of the investigation of Mr. F. A. Smith of the Reactor Engineering Division, the installation of a Pease-Anthony venturi scrubber followed by noncombustible high efficiency filters is nearing completion. This is none too soon, since on one occasion recently it became necessary to evacuate the parking lot when a leak occurred in one of the loops and it was thought as many as 50 gallons of sodium might burn and drift over the parked cars.

We, of course, don't have any data on the operation of our unit as yet but do know that the *Ethyl Corporation, in a pilot plant project using a venturi scrubber, removed over 99% of the sodium oxide smoke from an airstream of approximately 1200 CFM. If we can do as well scrubbing approximately 3000 CFM at a maximum disposal rate of 50 lbs. per hour, I think everyone will be satisfied.

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* Letter from Donald Debacher, Technical Service Section, Ethyl Corp., to F. A. Smith, Argonne National Laboratory 7-19-54.

The second exception to the typical air cleaning system is the interhalogen scrubber in the Chemical Engineering Building. The test model for this unit was discussed two years ago at Los Alamos. Since then, the final unit has been installed and tested. It has been designed to scrub continually, using a concurrent flow of caustic, all the air from a cell containing up to 500 pounds of interhologens and in so doing, guard against the possibility of a break in a line and the subsequent dumping of the gases to the outside.

Efficiencies of this system with a loading of 250 PPM Br F_5 and 800 PPM Br F_3 were 98 and 100% respectively with a flow through the scrubber of approximately 6000 CFM. If anyone would like further information on this scrubber, ANL Report No. 5429 covers it completely or if you are interested, I could arrange for a discussion with Messrs. R. C. Liimatainen or W. J. Mechan of the Chemical Engineering Division who designed and tested this unit.

300 Area

In the 300 Area is located the Argonne incinerator, now inoperative, which W. A. Rodgers and D. C. Hampson discussed in a paper incorporated in the record of the 1953 Air Cleaning Conference. The caves for studies of highly active materials are also located in the 300 Area. Exhaust from these caves is cleaned by pre-filters and AEC filters much the same as the exhaust from the hoods in this, the Chemistry Building.

Of particular interest as far as air cleaning is concerned is Facility 350 which is now under construction and which will be discussed by Mr. A. B. Shuck of our Metallurgy Division.

AIR CLEANING COST FOR CHEMISTRY BUILDING 200

By R. W. Van Valzah
Argonne National Laboratory

In order to present air cleaning cost trend data for the Chemistry Building 200, which is considered representative of other 200 Area buildings, a brief description of the ventilating systems appears in order. There are six main laboratory wings to the building interconnected by transverse corridors at the front and rear of the wings. Each laboratory wing is provided with a separate supply system delivering a minimum and maximum of approximately 17000 and 22000 cfm of air respectively. The supply air systems for all six wings with the exception of E Wing normally operate during the eight hour work day at maximum capacity while E Wing operates at near minimum capacity. All supply air is taken into the building through fresh air intakes and filtered with primary and secondary filters. The primary filters are Airmat Type P1-24 with five ply paper and the secondary filters are the same type with ten ply paper, both papers being fire resistant. The static pressure characteristics of the supply systems limit the total pressure drop across both banks of filters to .75" w.g. which in turn limits the maximum pressure drop across each bank of filters to approximately .5" w.g. When this limit is reached the bank of filters having the highest pressure drop is due for a change. The supply system is shut off, the dirty filters are removed, the plenum is thoroughly cleaned and spare filters with new media are put back into the filter frames. The dirty filters are then cleaned, rethreaded with new media and made ready for reinstallation in the supply systems.

One roll of five ply paper which will make up into twelve filters costs $7.25 and one roll of ten ply paper which will make up into nine filters costs $6.80. According to the maintenance records the average life of the primary filters is three months and the average life of the secondary filters is ten months. There are twenty-four filters in each bank per wing. The filter material cost per year per wing amounts to the following:

$$\frac{24 \times 4 \times 7.25}{12} = \$58.00 - 5 \text{ ply material}$$

$$\frac{24 \times 1.2 \times 6.80}{9} = \underline{\$21.80} - 10 \text{ ply material}$$

$$\$79.80 \text{ Total}$$

Supply filters are changed by the building maintenance crews. The labor required for a complete change of one bank of filters per wing is sixteen (16) man hours. On a yearly basis the primary filters are changed four times and the secondary filters are changed 1.2 times making a total of 5.2 changes. The man hours required per year are therefore 5.2×16 or 83.2 total hours. Assuming a labor charge of $4.00 per hour, the labor cost per year is calculated to be $332.80. Adding the material cost to the assumed labor cost, the total air cleaning cost of supply air per wing per year is $412.60. The above computations are based on an air flow

of 830 cfm per filter and an average maximum resistance drop of .5" w.g. This in terms of maintenance cost per 1000 cfm per year for supply air cleaning is (412.60/24) × (1000/830) = $20.70.

It is realized that increased life of these filters could be obtained with a greater pressure drop allowance. The present modifications to the ventilation systems in the building will provide for this. The procedure to be followed in changing filters also has a bearing on the life of the filters particularly when design limitations are imposed. Instead of changing an entire bank of filters as has been the practice, changing only portions of the bank on a staggered schedule basis is being developed. By following such a procedure it is hoped to reduce the total pressure drop across the entire bank of filters while allowing the loading of the individual filters to increase therby increasing the over-all life of the entire bank of filters.

The next phase of the air cleaning cost deals with the exhaust ventilation. All the hoods as well as the laboratory by-passes and the vacuum frame hood runouts are equipped with prefilters. The vacuum frame hoods have dust stop intake filters in addition to the prefilters. All of the prefiltered exhaust air taken from the laboratories is passed through the final AEC filters. Since the final filter costs may be considered of foremost interest, the analysis will start with them.

The original design of the exhaust ventilation systems was based on the use of 24" × 24" × 12" CWS filters with a rated air flow of 500 cfm at 1" w.g. resistance clean and 2" w.g. resistance dirty. CWS filters were used at the start of operations and then replaced with the same size AEC filters having a rated capacity of 800 cfm at 1" w.g. resistance clean and 2" w.g. resistance dirty. Some CWS filters are still in use as a quantity of them were received from surplus.

The exhaust systems are intalled on a modular basis serving the number of hoods operating in each laboratory. Not more than three hoods are connected to a runout which is exhausted through one fan at a rated capacity of 1000 cfm. The number of hoods per laboratory vary as do the number of fans. In one-fan modules all of the air is exhausted through the AEC filters so that the flow rate per filter is established at 500 cfm. In two-fan modules the minimum exhaust is 1000 cfm and the maximum exhaust is 2000 cfm making an average of 1500 cfm. With four AEC filters installed, the flow for each filter would be 375 cfm. In three-fan modules the minimum exhaust is 1400 cfm and the maximum exhaust is 3000 cfm with an average of 2200 cfm. With six AEC filters installed the flow for each filter would be 366 cfm. In accordance with the above flow rates per filter, the average life of the filters taken over a period of four years was found to be as follows:

	Flow Rate	Average Life
CWS	500 cfm	12 months
	375 cfm	16 months
	360 cfm	17 months
AEC	500 cfm	22 months
	375 cfm	30 months
	360 cfm	32 months

Inasmuch as CWS filters are considered obsolete, only a cost analysis will be made for the AEC filters. The cost per AEC filter in 1952 was $44.50 but it is understood the latest bid on these filters was $40.00 each. On the basis of the average life shown above the cost of AEC filters per year per 1000 cfm amounts to 40 × (1000/500) × (12/22) = $43.63.

The exhaust filters are changed by the Reclamation group. The man hours required to change each filter is 1.6 hours with an additional charge for materials and trucking. On an assumed labor rate of $4.50 per hour plus other miscellaneous charges the changing cost may be considered to be approximately $8.50. The total material and labor cost is therefore indicated to by $52.13 per 1000 cfm per year.

The life of the AEC filters indicates that for general scientific operations, there is not much variation between system applications. The prefilters do a good service in prolonging the life of the final filters. The exception to the above is where a large amount of acid fuming is done in the hoods. The final filters in these instances become saturated with acid fume condensation and have to be changed oftener than the average indicates. Fume hoods are being given special study for the treatment of the exhaust air which offers not only an air cleaning but a duct corrosion problem.

The prefilters generally used are 16″ × 20″ in size with steel frame and pleated wire backing which is covered with 25 FG media. The rated capacity is 250 cfm at a clean maximum pressure drop of .2″ w.g. The static pressure characteristics of the exhaust system necessitate changing them at a maximum pressure drop of .8″ w.g. These prefilters are located in three positions in the exhaust systems namely; in the hoods, in the laboratory by-passes, and in the vacuum frame hood runouts. A cost analysis of prefilters for each location will be given.

The laboratory by-pass prefilters take air only from the laboratory and the quantity varies from a minimum of 150 cfm to a maximum of 1000 cfm. There are four prefilters for each laboratory by-pass, four prefilters for each vacuum frame hood runout, and four prefilters for each hood. All hoods are set to exhaust a minimum of 150 cfm. All air removed from the laboratory is either taken out through the hoods or through the laboratory by-passes.

On the basis of the average operating conditions and the tabulated average life of individual prefilters, the life of all laboratory by-pass prefilters checks out to be approximately four months at the rated air flow and maximum resistance. The cost of these prefilters is $3.92 each so that the laboratory by-pass prefilters cost per 1000 cfm per year amounts to $12/4 \times 4 \times 3.92 = \$48.04$. The man hours required to change each filter is .4 hour with an additional charge for material and trucking. At an assumed labor rate of $4.50 per hour plus the other miscellaneous charges the changing cost may be considered to be approximately $1.83. The total material and labor cost may therfore be considered to be $49.87 per 1000 cfm per year.

The above filtration cost is obviously high for laboratory air where the possibilities of contamination are rather remote. This air is passed through the AEC filters anyway so that the primary purpose of the prefilters is to remove the room dust and prolong the life of the final prefilter. There is some doubt as to how effective this prefilter may be because of the particle size of the room dust. In view of this fact a type G fiberglas media, cardboard frame filter having a rated capacity of 500 cfm and a clean resistance of .2″ w.g. is being used to replace the present 25 FG laboratory by-pass prefilter. This change represents a considerable savings to the Laboratory particularly since the air flow to the laboratories is now being increased.

The maintenance records for the vacuum frame hood prefilters which are also the 25 FG type disclosed that the average life is eight (8) months. This longer life can be attributed to the fact that when the vacuum frame hood doors are closed the air is taken in through Dust Stop filters. The cost of the vacuum frame hood prefilters per 1000 cfm per year therefore amounts to $12/8 \times 4 \times 3.92 = \$23.52$. The labor cost is the same as for the laboratory by-pass prefilters so that the total indicated cost for the vacuum frame hood prefilters adds up to be $25.35 per 1000 cfm per year.

The survey of the laboratory hood prefilters which are also type 25 FG discloses that the average life at the rated air flow and maximum resistance is four months. Moderate use of various chemicals with the exception of perchloric acid and the interhalogens does not seem to materially affect the prefilters. A-Lum-O-Aire prefilters are used for the interhalogens and hand packed fiberglas with no binder prefilters are used for perchloric acid. These filters have to be changed at about the same time interval as the type 25 FG apparently due to the resistance drop which indicates similar dust loadings. The cost of the A-Lum-O-Aire prefilters is $6.95 each and the cost of the perchloric prefilters is $6.03.

The cost of the type 25 FG hood prefilters per 1000 cfm per year amounts to $12/4 \times 4 \times 3.92 = \$48.04$ which is the same as for the laboratory by pass prefilters. The labor and miscellaneous charges are also the same so that the total indicated cost is $49.87. This filtration

cost is also high and an attempt has been made to evaluate this cost in terms of prolonging the life of the final filters. This project is under consideration at the present time. It may be stated that the hood prefilters are removing most of the contamination inasmuch as a very few of the final filters have been found hot while a certain number of the prefilters have had to be removed because of activity.

Time does not permit going into the disposal of the above mentioned filters. The disposal costs for each of the three types of prefilters as described above is about $1.73 each.

The above figure includes storing, baling and handling costs. All of the prefilters can normally be baled with the exception of those from a high alpha area or those having a surface radiation greater than 200mr/2" H & S.

Disposition of the final filters when not active is accomplished by burying them in the ground. At one time they were burned in the incinerator but this has been discontinued. The miscellaneous charges previously shown for the AEC filters also include disposition.

In summation there are a number of factors which influence the cost of air cleaning by means of filtration. Some of these have been pointed out but here is the list:

1. System design
2. Fume or dust characteristics, particle size, activity
3. Air flow
4. Efficiency requirements
5. Dust holding capacity
6. Break point in dust loading
7. Operating conditions
8. Allowable pressure drop
9. Testing procedure
10. Changing procedure
11. Initial cost
12. Maintenance cost

It may be stated in conclusion that in order to compare air cleaning costs all of the above factors should be taken into consideration.

Knolls Atomic Power Laboratory
AIR CLEANING PROGRAM
November 2, 1955

by

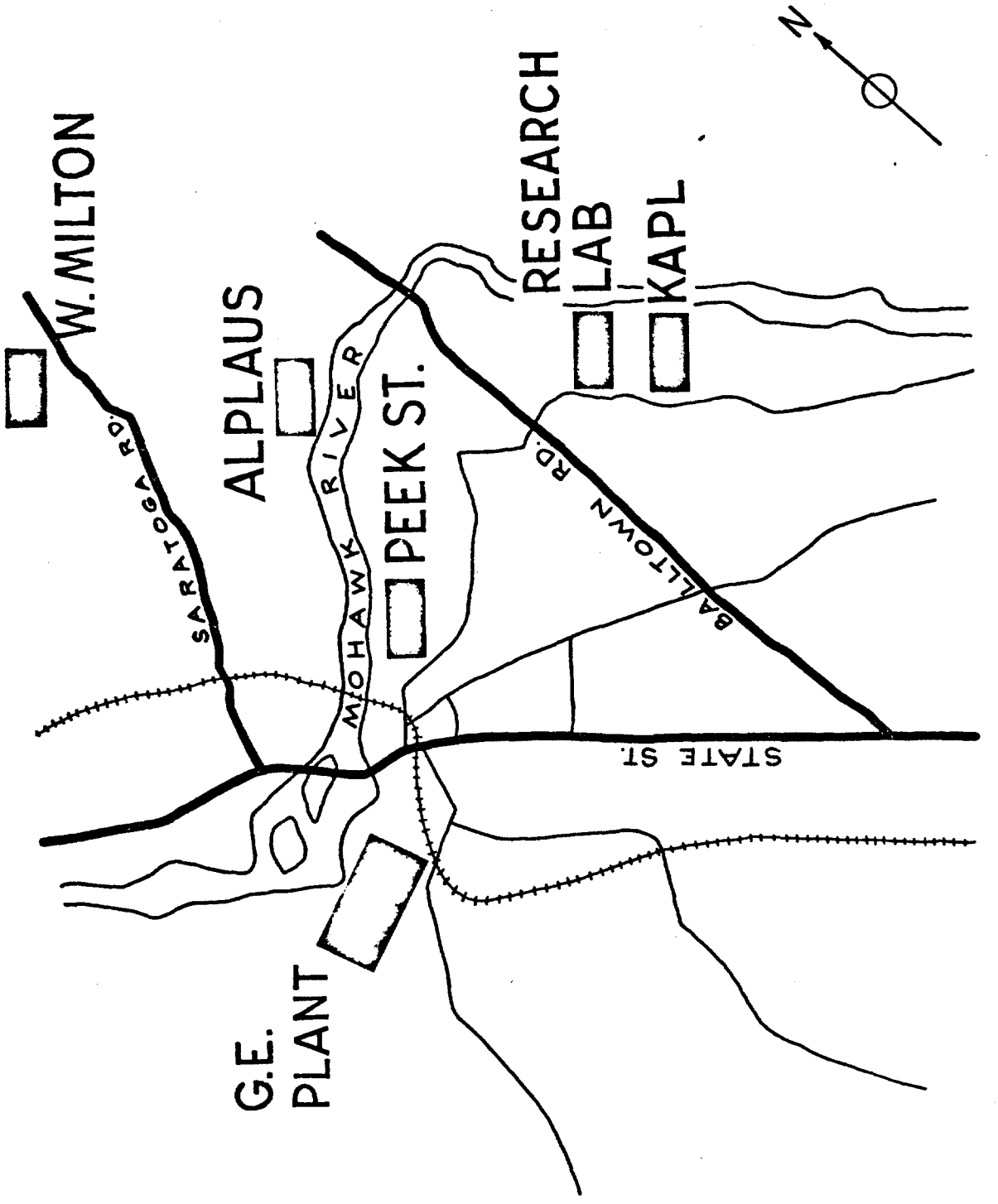
W. H. Truran

INTRODUCTION

The Knolls Atomic Power Laboratory has been principally engaged in the development of a sodium cooled, intermediate power reactor for submarine propulsion. In addition, KAPL has been responsible for assisting Hanford and Savannah River operations offices in their efforts to improve production facilities. More recently the Laboratory has undertaken the development of an advanced, naval propulsion reactor.

In Figure 1122015 the location of the Laboratory is shown near Schenectady, New York. The Mohawk River flows generally from west to east past the General Electric Company's Main Plant, the City of Schenectady, New York, the new General Electric Research Laboratory and the Knolls Atomic Power Laboratory. The location identified as Peek Street was the early home of the Laboratory. It is no longer in use. Likewise the Alplus Site, formerly employed in sodium coolant Test work, is no longer required. The facilities of both sites have been moved to the $28,000,000 Laboratory located on approximately 170 acres of land in the Town of Niskayuna, New York, about 5 miles east of the center of Schenectady and about 1/2 mile from the General Electric Company Research Laboratory. The West Milton Site, containing the prototype submarine intermediate reactor, is located to the north approximately 18 miles from Schenectady on about 4000 acres in Saratoga County.

The Knolls Site (KS-6012) consists of a main group of 9 interconnecting buildings providing space for administration, cafeteria, physics and metallurgical laboratories, manufacturing shops and engineering laboratories,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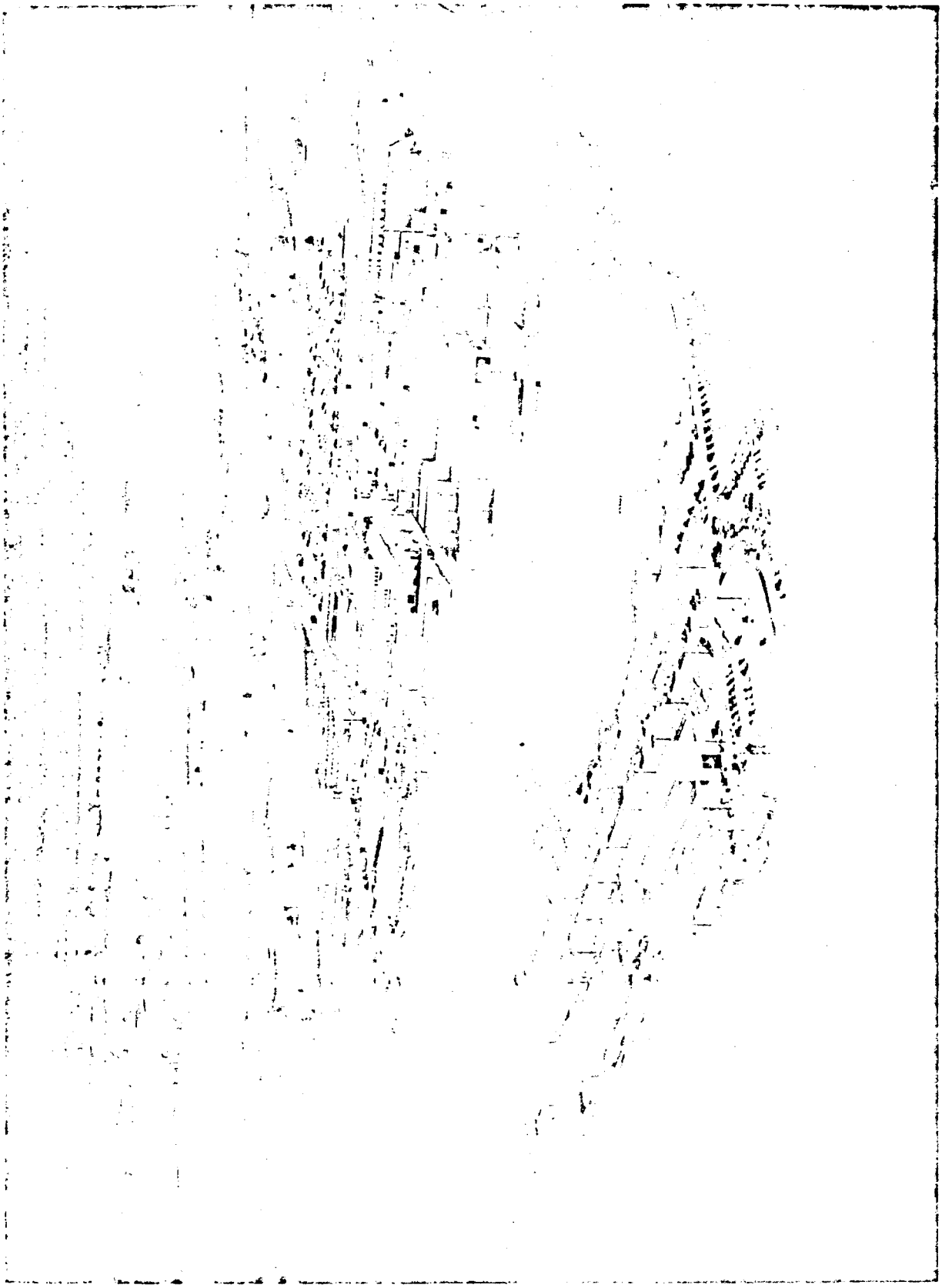

KS-6012

chemical laboratories, chemical separations process units and test cells for the examination of reactor materials. Additional site facilities include 4 critical assembly test facilities, a fuel element fabrication and reactor manufacturing area, facilities for processing liquid and solid radioactive waste and a laundry for laboratory clothing. Approximately 2000 persons are employed at the Knolls and West Milton Sites, 1800 of these being employed at the Knolls Site.

AIR CLEANING SYSTEMS - Knolls Site*

Buildings requiring processing of exhaust ventilation include approximately 2,800,000 cubic feet of space which are ventilated at a total rate of 475,000 cubic feet per minute for an average of approximately 10 air changes per hour. Design figures have ranged from six air changes per hour in laboratories to 20 air changes per hour in chemical separations process cells.

Buildings containing physical, metallurgical and chemical laboratories, and chemical separations pilot plant facilities have been provided with forced air supply, the air being prepared by self-cleaning oil filters and electrostatic precipitators in Raisler Air Conditioning Systems. These ventilating systems are non-recirculating and, together with exhaust systems, control the spread of air-borne contamination by maintaining air pressures in personnel access areas high with respect to process cells and hooded facilities.

Figure 1087050 shows ventilation exhaust applied at cutting tools in the Special Materials Machine Shop. Figure 1086998 shows a ventilation hood over a centerless grinder. Metallurgical laboratories are included in this area. Operations involve solid and powdered uranium and beryllium. The exhaust system for this area is two systems in one: a low velocity system providing air velocities of 100 feet per minute at the face of bench hoods, and a high velocity system providing exhaust velocities of from 3000 to 5000 feet per minute at cutting tools. All exhaust air passes through a roughing mat filter and an electrostatic precipitator supplied by the American Air Filter Company. The high velocity exhaust air also passes through a multi-cyclone separator provided by the Western Precipitator Company prior to filtration and precipitation. During present reduced shop

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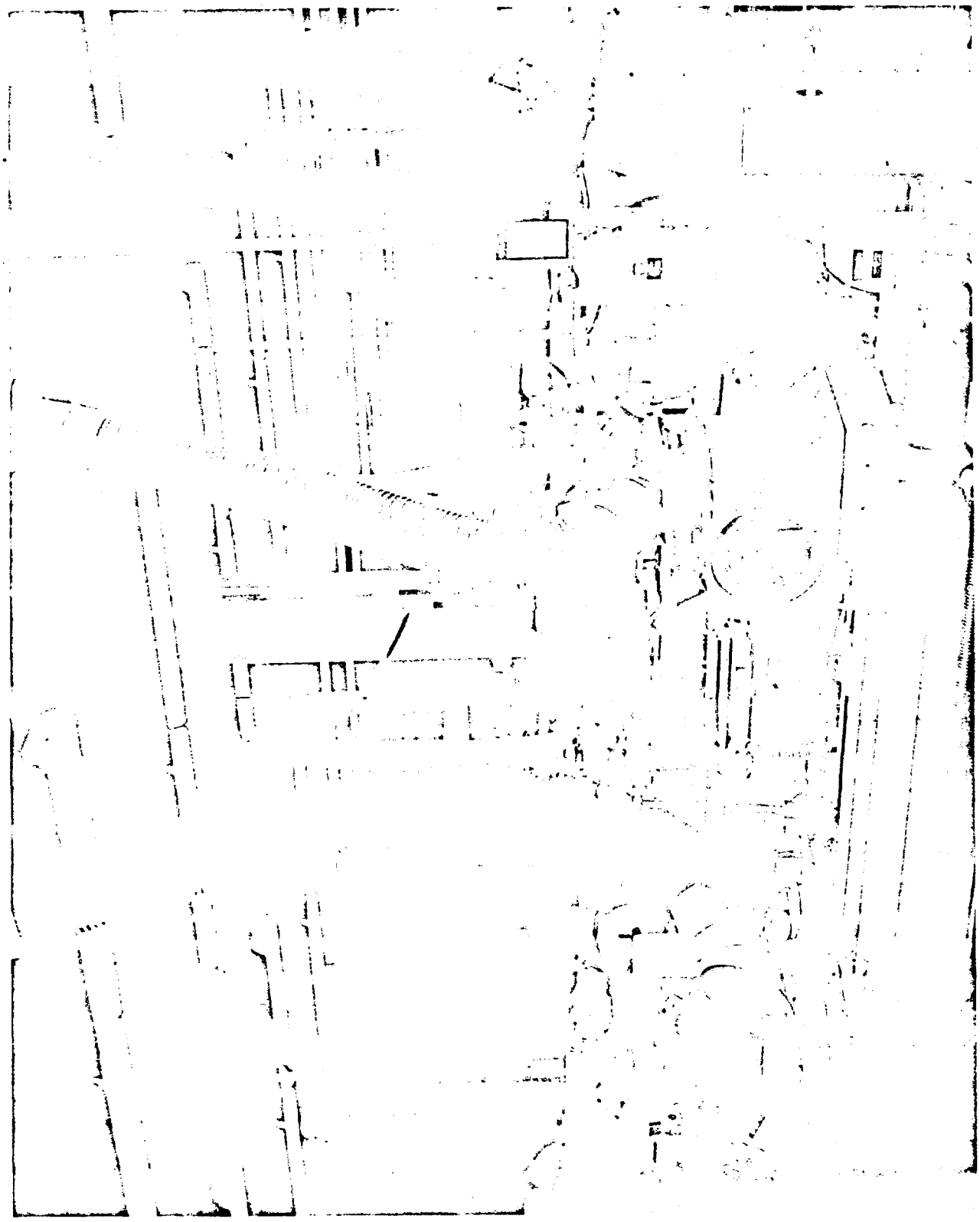
* KAPL 1014, KAPL Air Cleaning Program, L. J. Cherubin, J. J. Fitzgerald.



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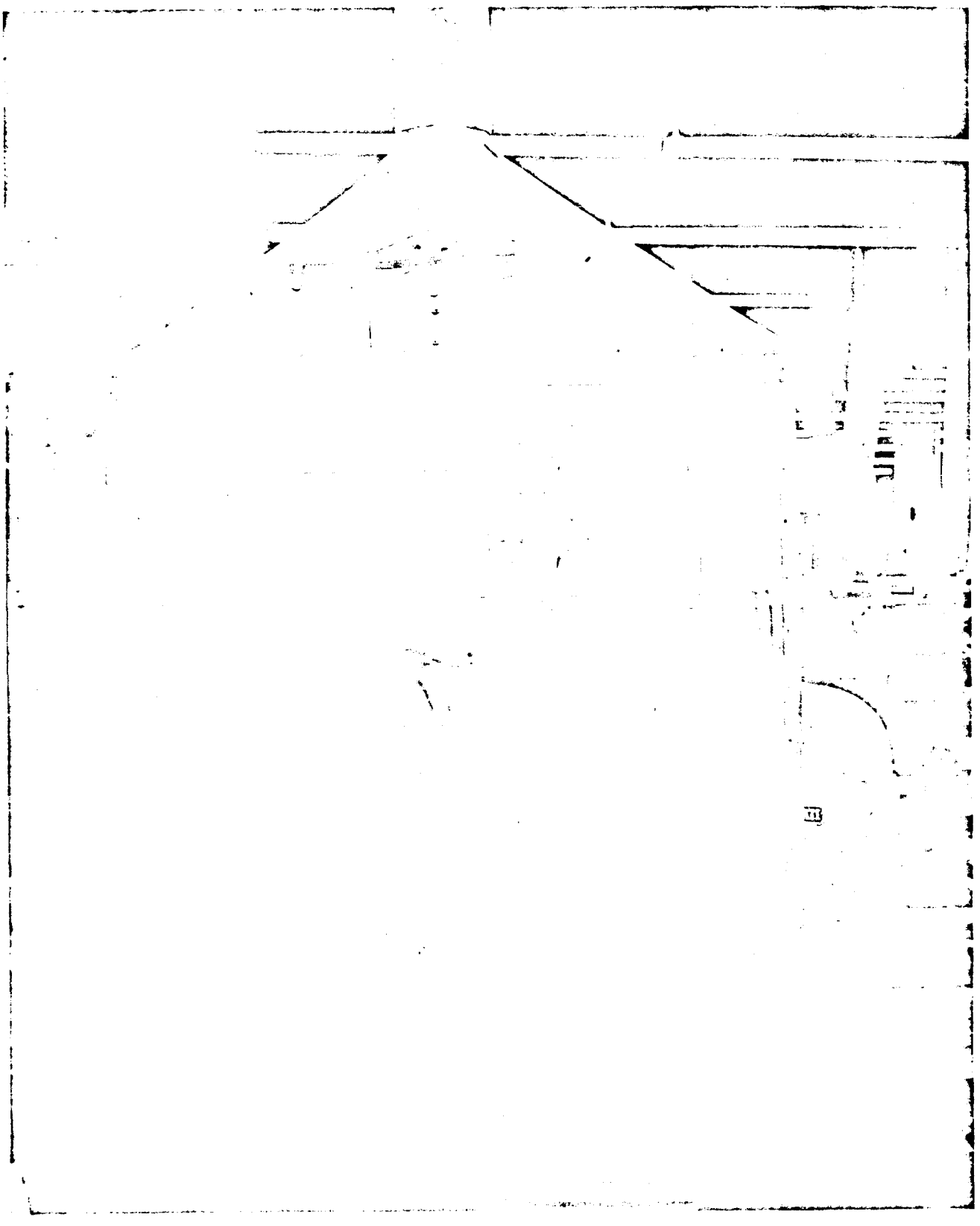
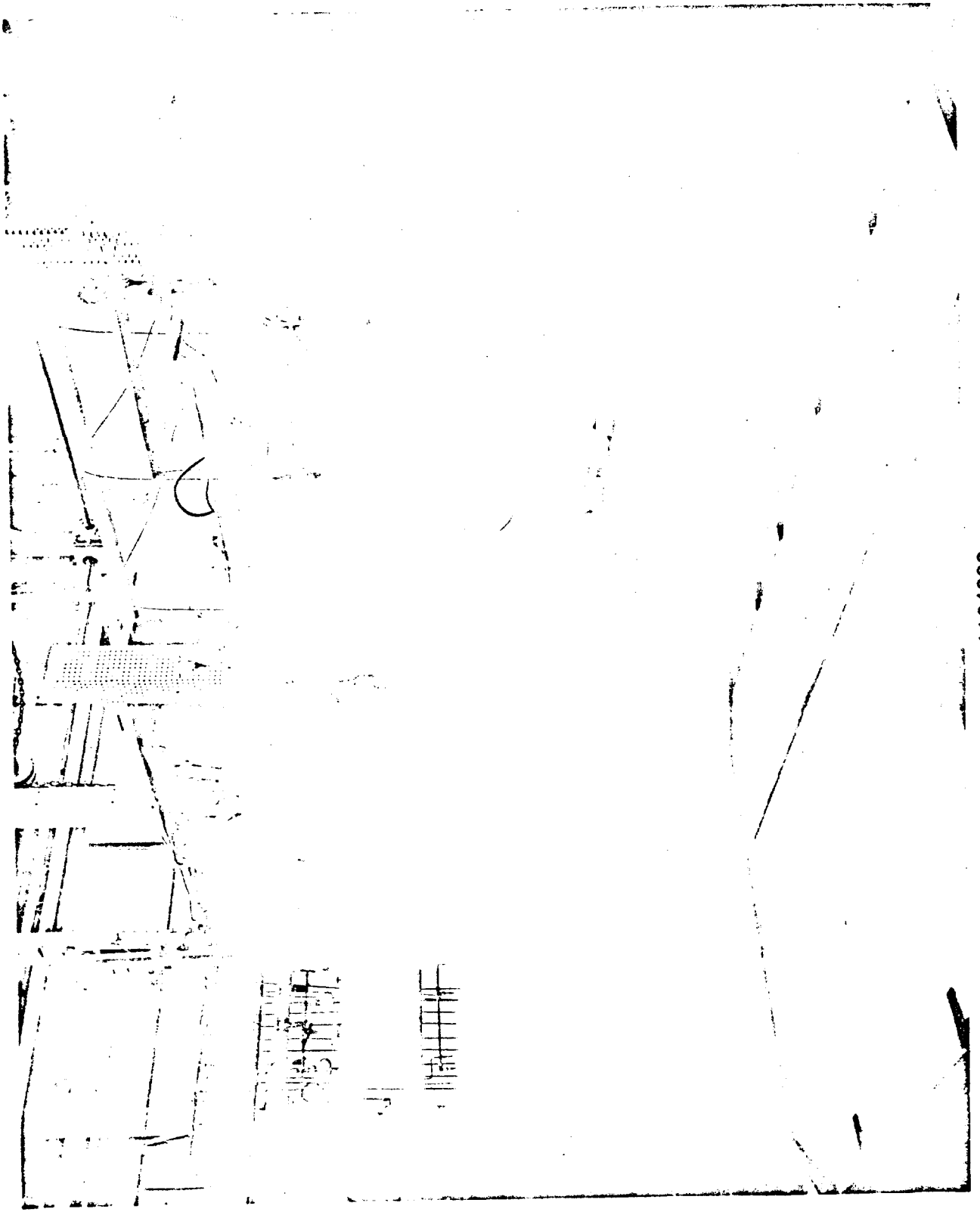


operations, the need for the electrostatic precipitator was investigated and found lacking and so is not now operated.

Figure 1104392 shows a type of hooded cell facility provided for chemistry separations process research. From all areas for which a need of reducing concentrations of plutonium, enriched uranium, or fission products in exhaust air exists, the series of glass wool and CWS or Cambridge Absolute filtration is provided (Figure 1120929). With normal laboratory dust loading, the absolute filter has lasted a year when glass wool filters are changed as often as once a month. Figure (KS-6231) shows a type of CWS filter installation used on a liquid waste process vent with the filter held in place by springs. Jack spreaders on top and bottom facilitate filter removal. The process vent system for Separations Process Research Unit in addition to filters contains a 13 foot caustic spray column for reducing radioactive iodine concentrations. This Research Unit has not been operated since February 1954.

Figure 1100607 shows a cell provided for the examination of radioactive material. It may be looked upon as a cell within a cell in that all examinations are performed within an isolation box seen hanging on rails running the length of the cell. Exhaust is applied to the isolation box as well as to the cell. Figure 1092930 shows the cell exhaust systems. Figure KS-6230 shows the glass wool and CWS Filter unit servicing the cell. The filter frame forms a part of the duct work and the filter is equipped with a handle for easy removal.

Unlike systems just considered, ventilation air is recirculated in the fuel element manufacturing areas, critical assembly buildings and the laundry. In the fuel element manufacturing areas, solid fuel material, when not sealed in



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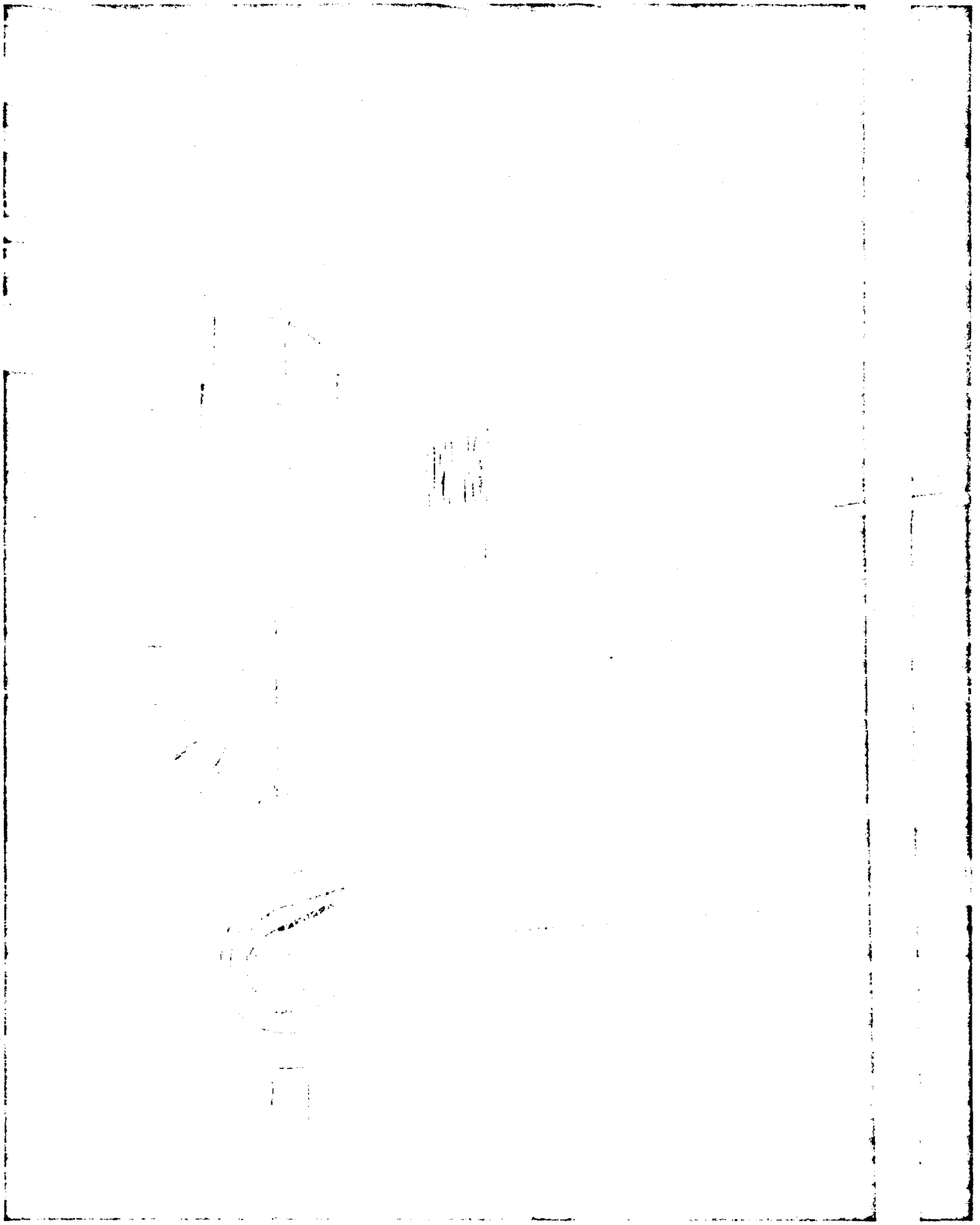

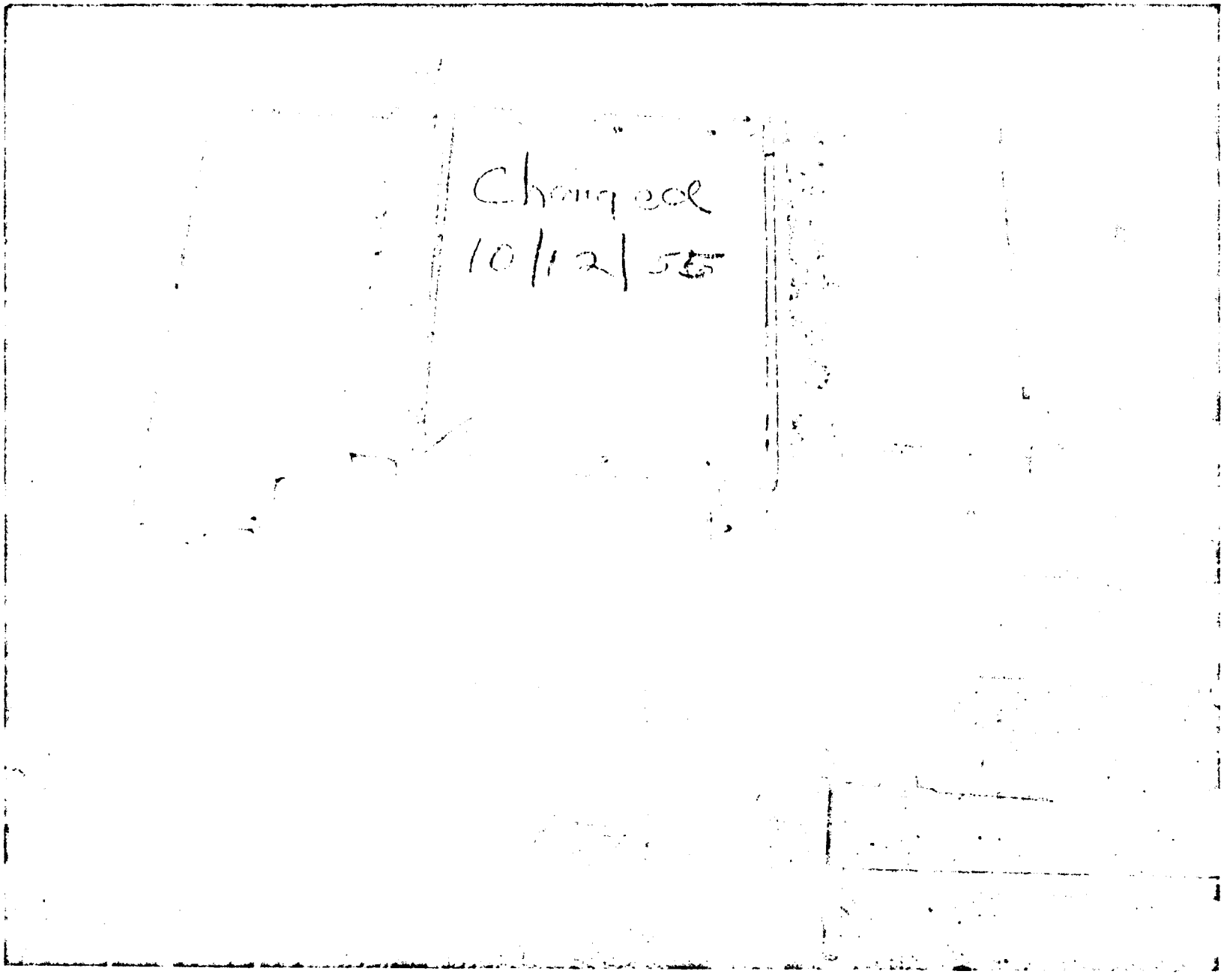
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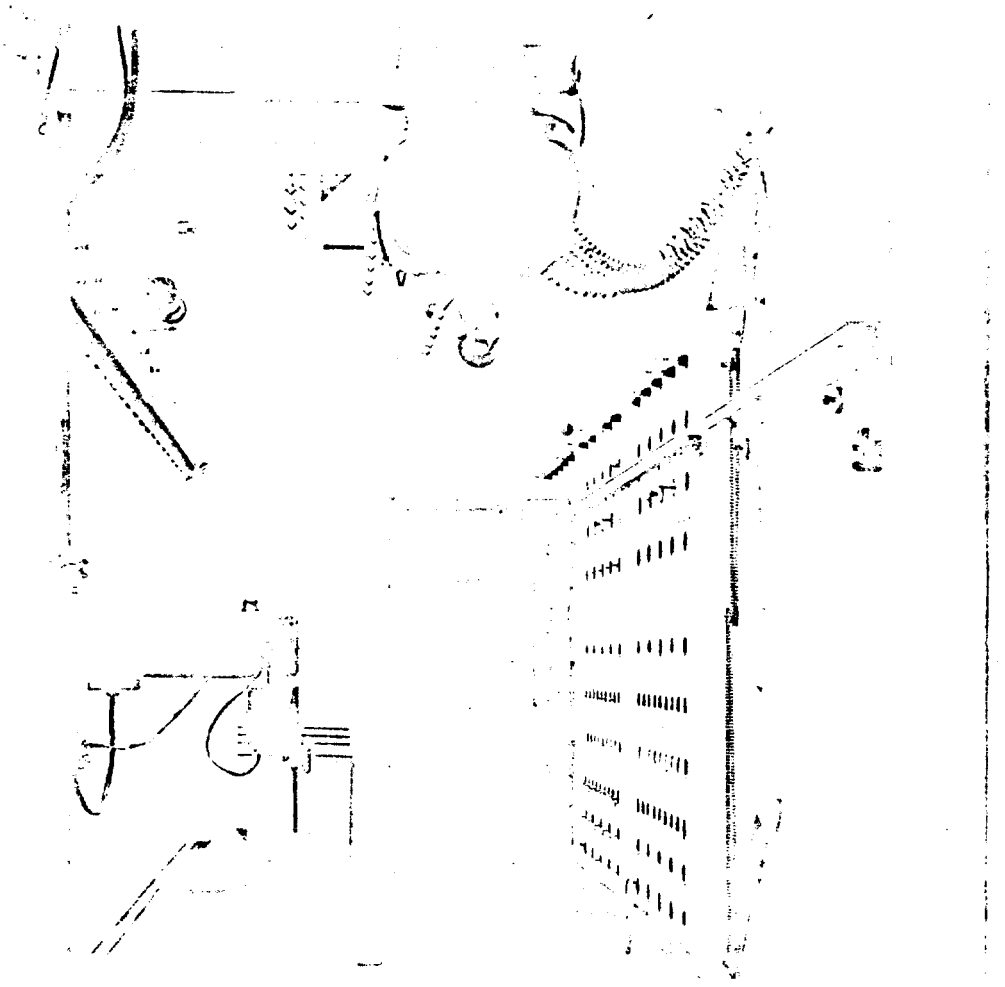
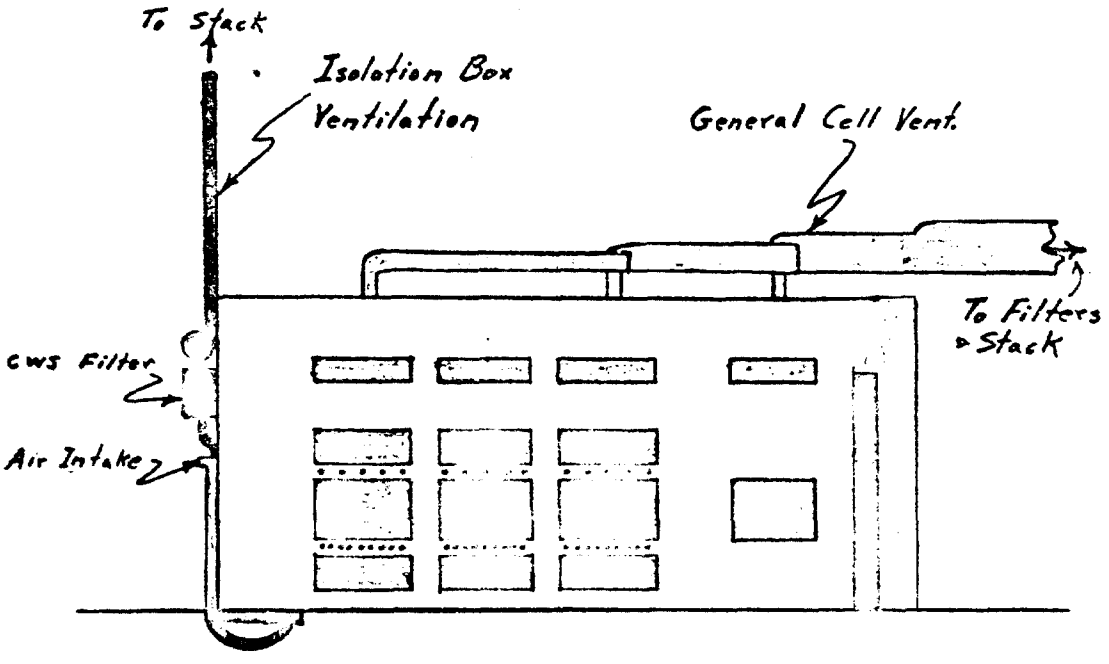


1100607

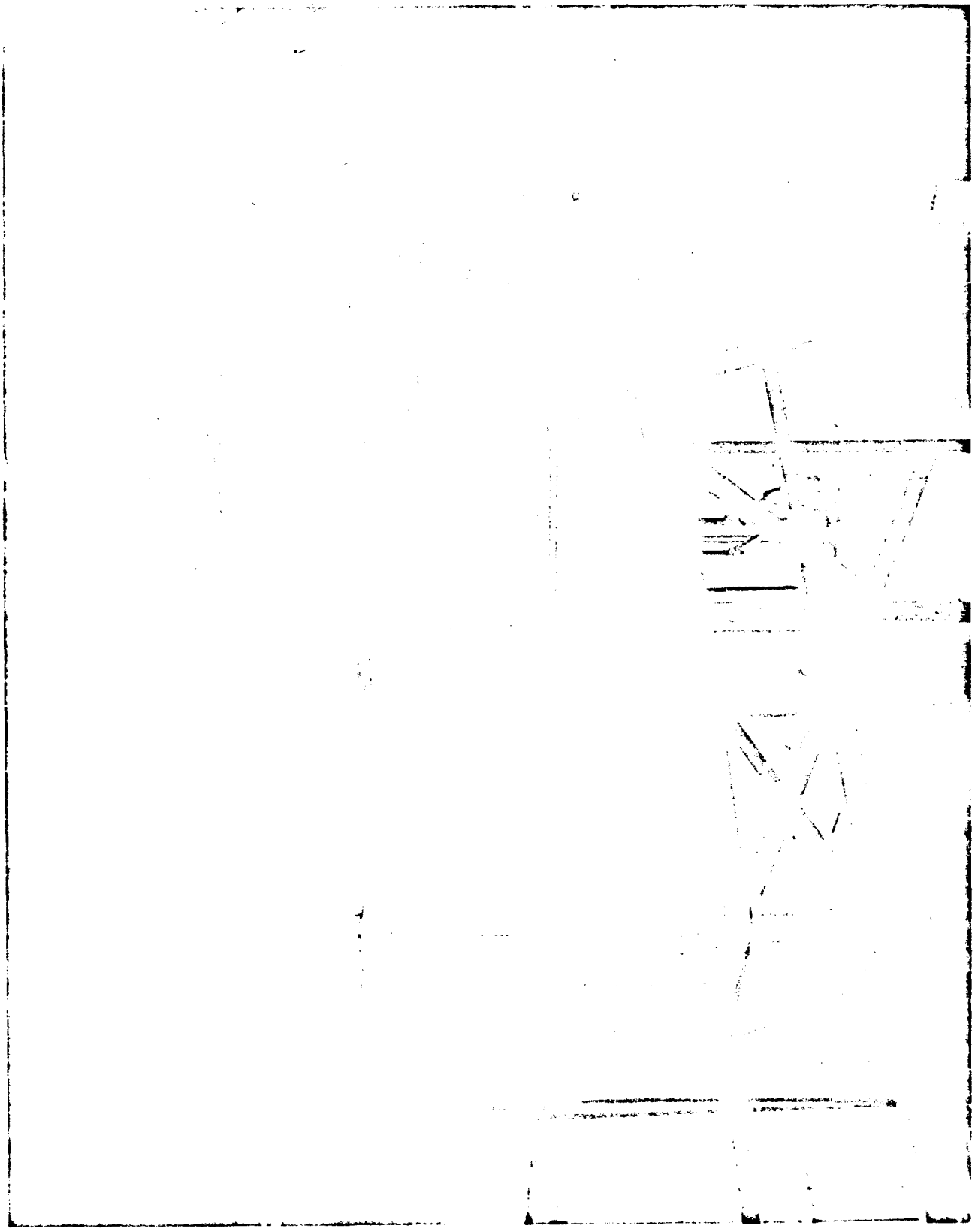
KAPL, RML, General Cell View, Isolation Box In Place



CELL VENTILATION SYSTEMS

RML

1092930



KS-6230

containers, is handled in dry boxes on a non-recirculating filter exhaust system. The remaining area exhaust air is passed through glass wool and absolute filters before being recirculated.

In critical assembly areas where reactor operating levels do not exceed a few watts, recirculated air is processed only by Kathabar or Chill Coil humidity limiting equipment.

The laundry exhaust air has been no problem when passed through paper filters provided to remove lint.

Galvanized iron and stainless steel are the two materials used in exhaust duct work, the latter employed whenever corrosive chemicals are considered a problem, such as in chemical laboratories and the Separations Process Research Unit. Periodically, filter boxes in stainless exhaust systems, which are made of soft iron are inspected and replaced, if necessary.

Stack heights for laboratories, special machine shops and reactor assembly areas range from roof vents to 25 feet above roof level. The exhaust ventilation from the liquid waste processing building is discharged at a stack height 50 feet above ground level, 25 feet above the adjacent roof. The stack associated with the area and process vents of the Separations Process Research Unit is 105 feet above ground level, 65 and 75 feet above adjacent roofs.

Table 1 shows a comparison of the nature and amounts of toxic elements emitted from laboratory stacks in 1952 and 1954 to indicate a reduction over the period reported at the previous Air Cleaning Conference. These reductions are due to changes in the nature of operations, not changes in types of ventilation processing equipment and are typical of present operations. The drastic reduction in alpha activity discharged is attributed to the elimination of the sole contributor when the Separating Process Research Unit was shut down; plus the fact that

the final runs of this Unit did not involve second cycle plutonium purification steps.

Table 1

Annual Amounts of Toxic Elements Discharged into Atmosphere

Year	Beryllium, milligrams	Nonvolatile Fission Products, curies	I-131, millicuries	Radioactive Gases, curies	Alpha Activity, curies
1952	121	40	113	591	7×10^{-1}
1954	44	2	- - -	73	7×10^{-5}

With the shutdown of SPRU, the Radioactive Materials Laboratory in the Materials Metallurgy Section became the most important factor in the contamination of the atmosphere with fission products. The stack effluent from the Special Materials Machine Shop of the Manufacturing Sub-Section continued to be the potential source of beryllium contamination in the environment. The data indicate that the need for atmospheric dilution of stack exhaust air, though never great, has been substantially reduced.

Air Monitoring Surveys - 1954
Stack Air Effluent

		Materials and Metallurgy Section	Project Physics Section	Chemistry and Chemical Engineering Section	Manufacturing Sub-Section	Maintenance and Utilities Sub-Section
General Alpha	Total Number	563	---	408	---	693
	No. $>4\times10^{-12}$ µc/cc	0	---	1	---	0
	Maximum (µc/cc)	---	---	6.8×10^{-12}	---	---
Fission Products	Total Number	563	---	408	---	693
	No. $>2\times10^{-10}$ µc/cc	5	---	32	---	0
	Maximum (µc/cc)	8×10^{-9}	---	5.6×10^{-7}	---	---
Natural Uranium	Total Number	---	---	---	246	---
	No. $>5\times10^{-5}$ µg/cc	---	---	---	0	---
	Maximum (µg/cc)	---	---	---	---	---
Enriched Uranium	Total Number	---	---	---	386	---
	No. $>3\times10^{-11}$ µc/cc	---	---	---	0	---
	Maximum (µc/cc)	---	---	---	---	---
Beryllium	Total Number	---	---	---	456	179
	No. >0.01 µg/M^3	---	---	---	9	0
	Maximum (µg/M^3)	---	---	---	0.04	---
Tritium	Number of Indications $>1\times10^{-5}$ µc/cc	---	---	395	---	---
	Maximum (µc/cc)	---	---	6.5×10^{-3}	---	---

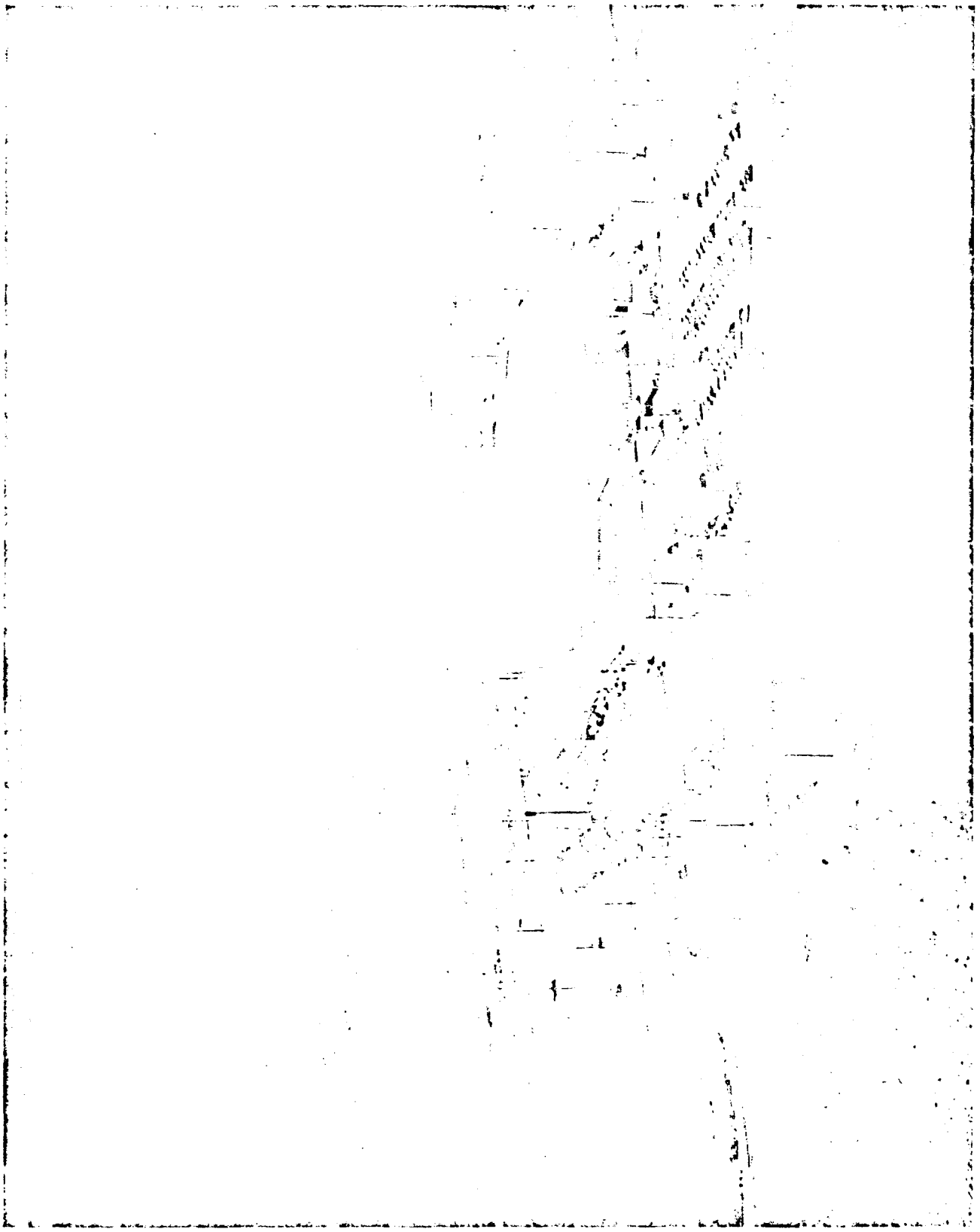
No concentration of beryllium above the prescribed limit of 0.01 $\mu g/M^3$ was detected in the environs and no significant alpha concentrations in environmental air were detected. Although fission product air-borne concentrations, a distance approximately equal to 10 stack heights downwind of the SPRU stack, were significant on a monthly average for the last two months of SPRU operations, a peak concentration of 6.0×10^{-10} $\mu c/cc$ did not exceed the maximum permissible concentrations in air of 2×10^{-9} $\mu c/cc$. This MPC was determined by J.J. Fitzgerald for the quality of radioisotopes in SPRU stack effluent and reported at the Third AEC Air Cleaning Conference.* During the remainder of 1954, a single significant environmental fission product concentration attributable to laboratory operations was related to Radioactive Materials Laboratory operations involving the examination of irradiated samples.

AIR CLEANING SYSTEMS - West Milton Site

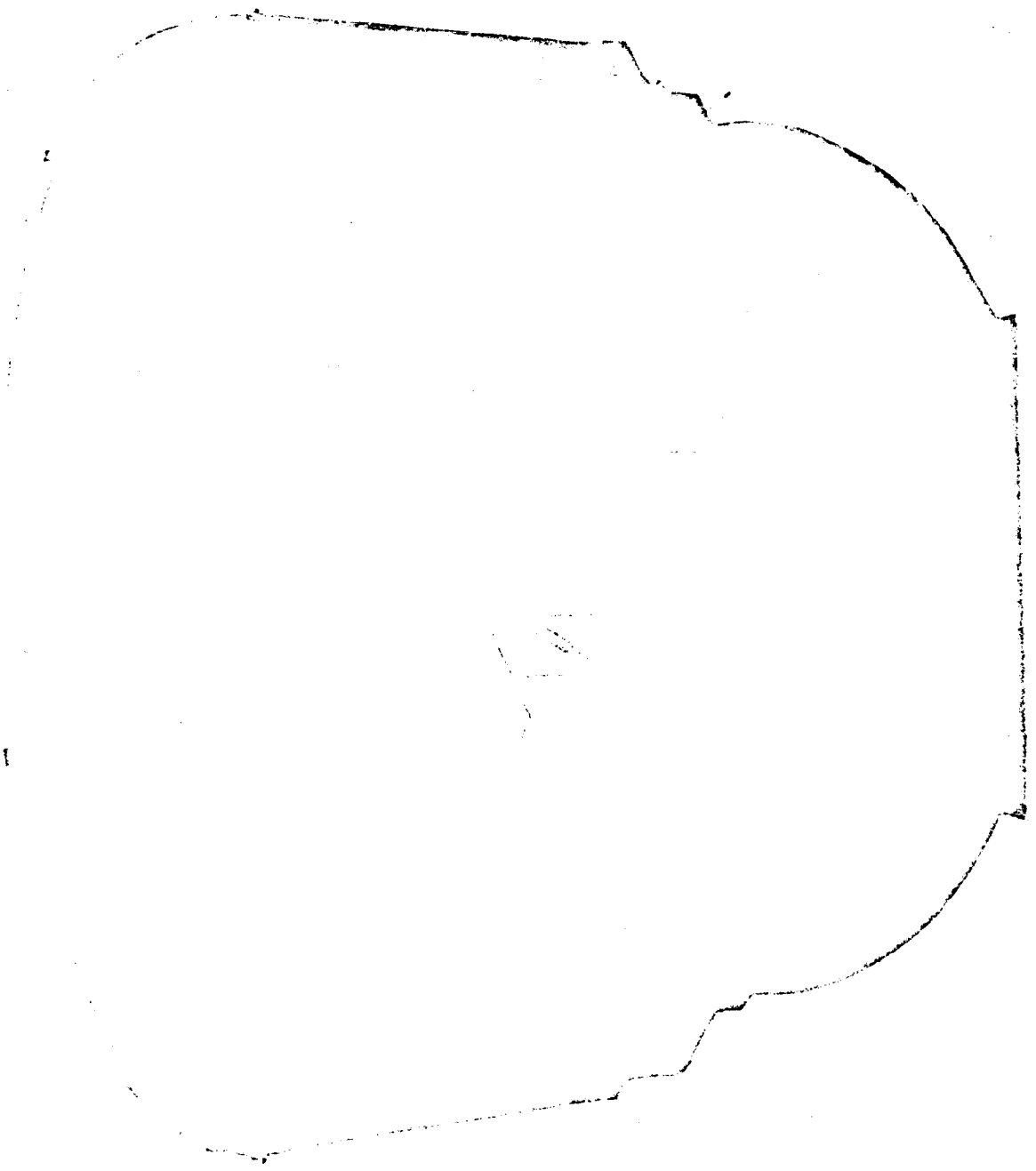
The West Milton Site consists of a main group of three interconnecting buildings providing space for engineering and operations offices, health physics and chemistry laboratories, change area, fuel element service cells and the Power Plant Building (Figure KS-6013). The Power Plant Building is a steel sphere 225 feet in diameter. Figure 1121193 is a cut-a-way view of the sphere showing the liquid metal cells and the submarine hull section containing the power reactor.

Facilities at West Milton requiring control of radioactive concentrations in exhaust air are the reactor compartment of the submarine hull and the liquid metal cells within the sphere, and the laboratories and fuel element service cells in adjoining buildings. The ventilation system supplies and exhausts 22,000 cubic feet of air per minute, of which 83% provides approximately 10 air changes per hour to the

* KAPL 1015, Evaluation of KAPL Separations Process Stack Effluent, J. J. Fitzgerald.



KS-6013



laboratories and the Fuel Element Service Building. Figure KS-6234 shows the filter room servicing the Fuel Element Service Building. Again the filter media is CWS or equivalent preceded by a glass wool filter.

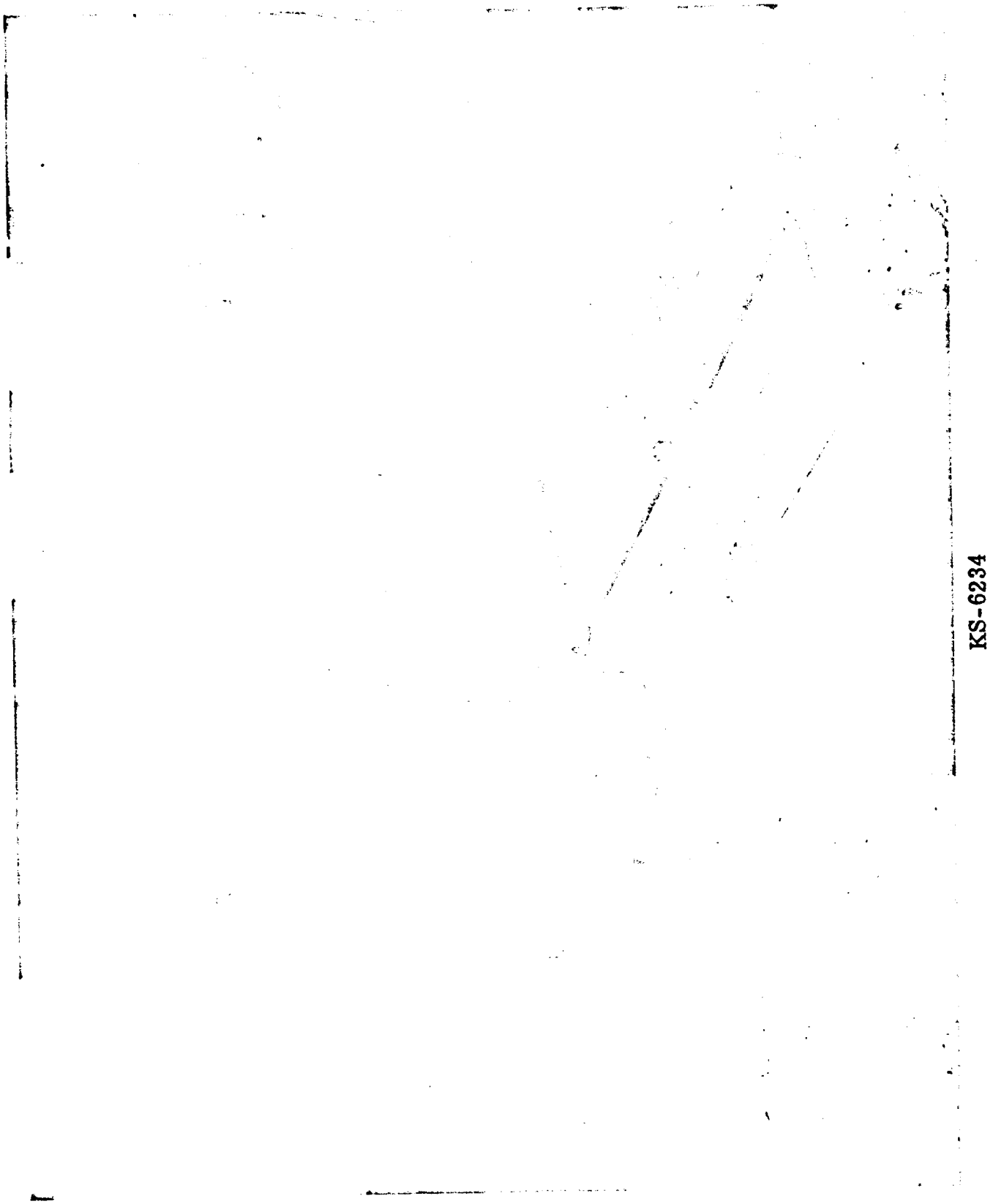
Figure KS-6233 shows the filter installation servicing atmosphere exhaust from the Liquid Metal Cells. The filter media in this case is a Cambridge B-Series high temperature Absolute Filter preceded by a glass wool filter.

The reactor compartment is normally vented to the exhaust stack without processing. However, in the event that radioactive gas monitors indicate the need, the vent gases are compressed by equipment in a shielded concrete cell shown in Figure KS-6235. The gas release can then be adequately regulated.

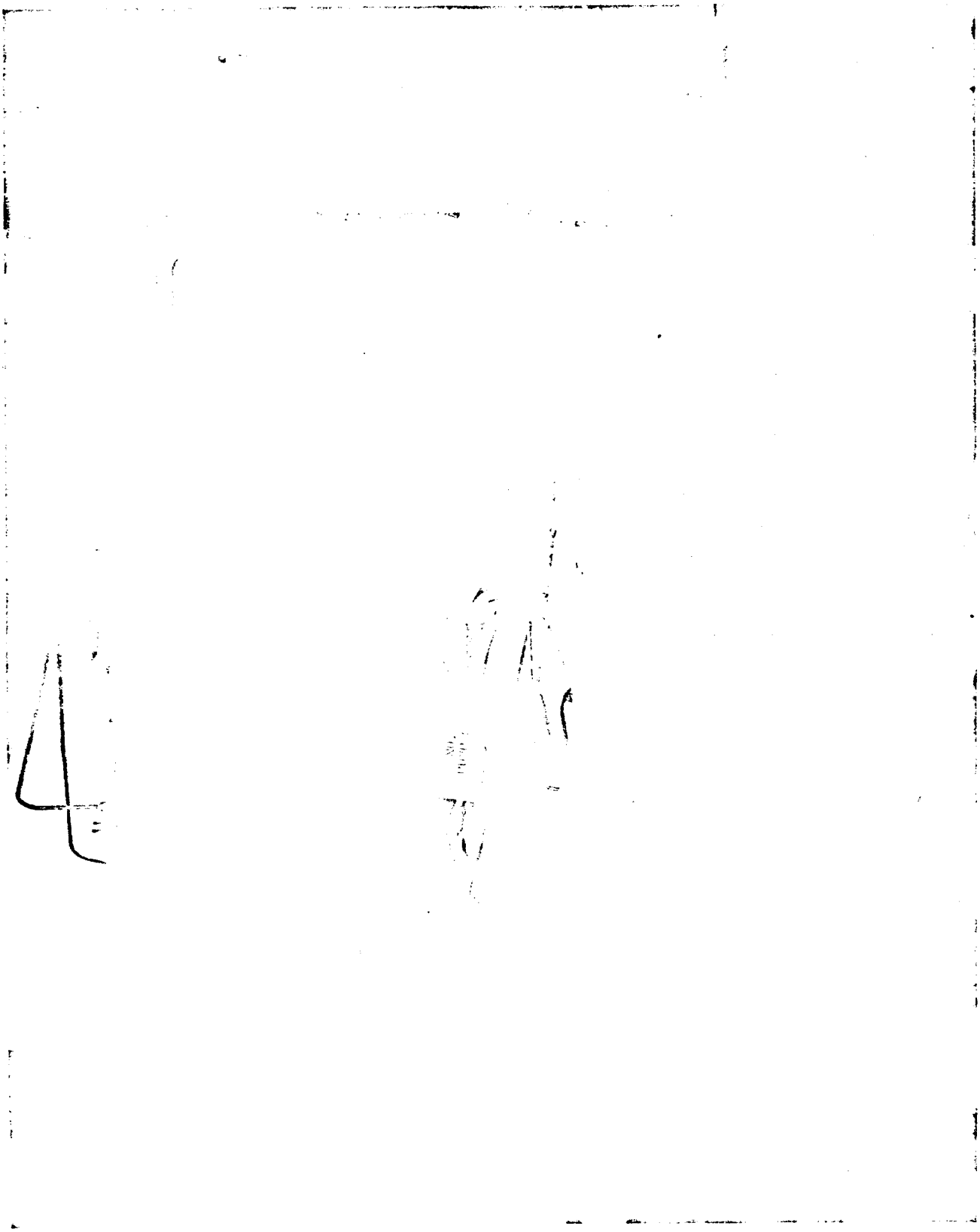
Air in the Power Plant Building is changed about once a day at the rate of 4,000 cubic feet per minute. Twenty-five percent of this air is taken from the liquid metal cells in order to maintain a negative pressure in the cells with respect to the rest of the sphere. Sphere air is filtered through glass wool filters and conditioned once each hour and a half by 10 unit air conditioners located symmetrically around the floor of the sphere (Figure KS-6232). Also, when required to prevent cloud formation and precipitation within the sphere, five blowers with a total capacity of 80,000 cfm are located in the upper section of the sphere to provide good mixing of air throughout the sphere.

Figure KS-6236 shows the base at the exhaust stack and two 25,000 cfm exhaust blowers, one in standby. The standby blower is available for stack dilution. Figure KS-6229 shows the top of the stack through which air exhausted from the Power Plant Building, laboratories, and the Fuel Element Service Building is discharged.

Although there has been no need to rely on atmospheric dilution of stack effluent, in an incident involving a sodium fire in the Liquid Metal Cell, concentrations of beta gamma activity in stack effluent approached 10% of the maximum permissible concentration of Sodium-24 in air. The maximum concentration detected at ground level indicated an atmospheric dilution factor of 500.



KS-6234



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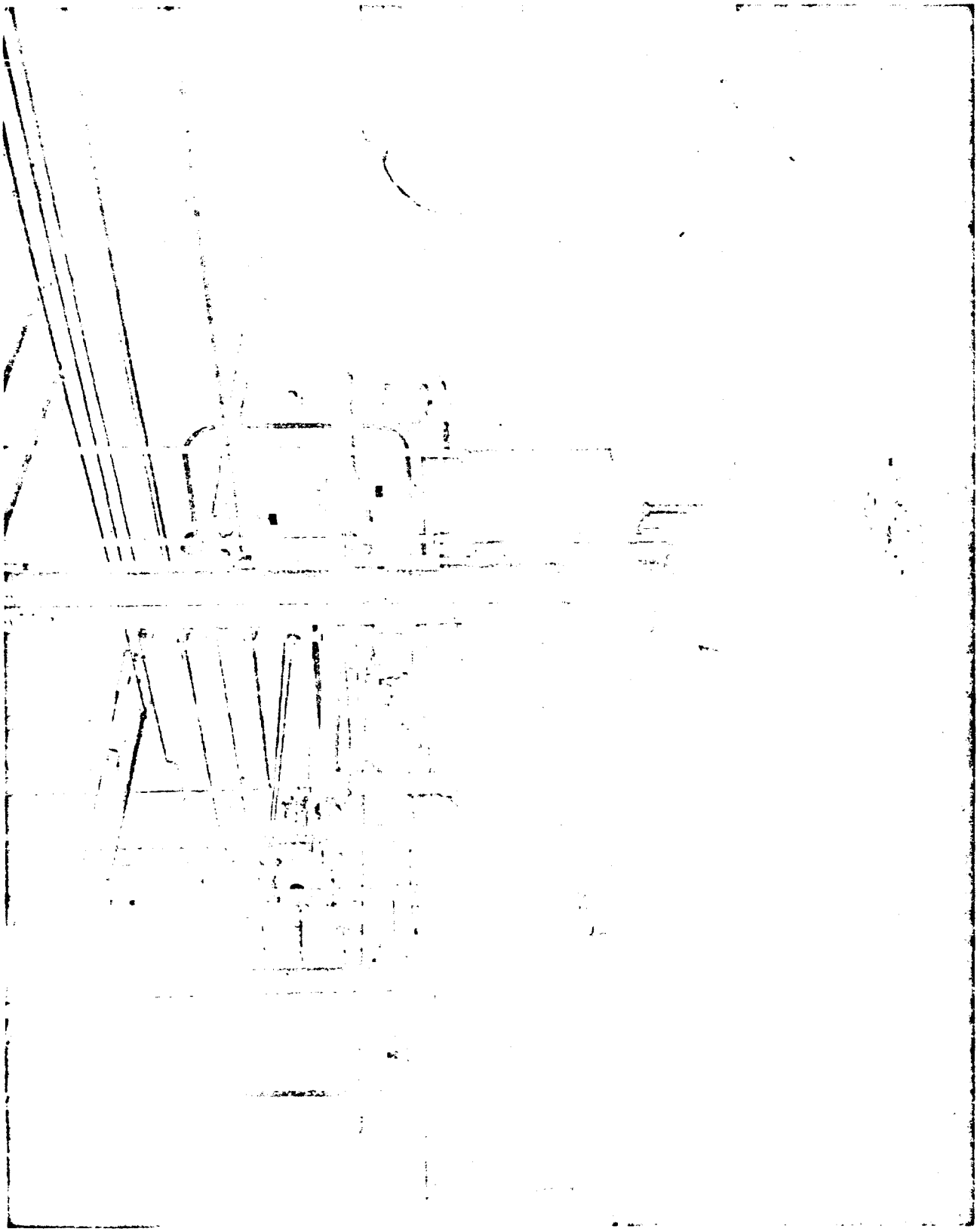

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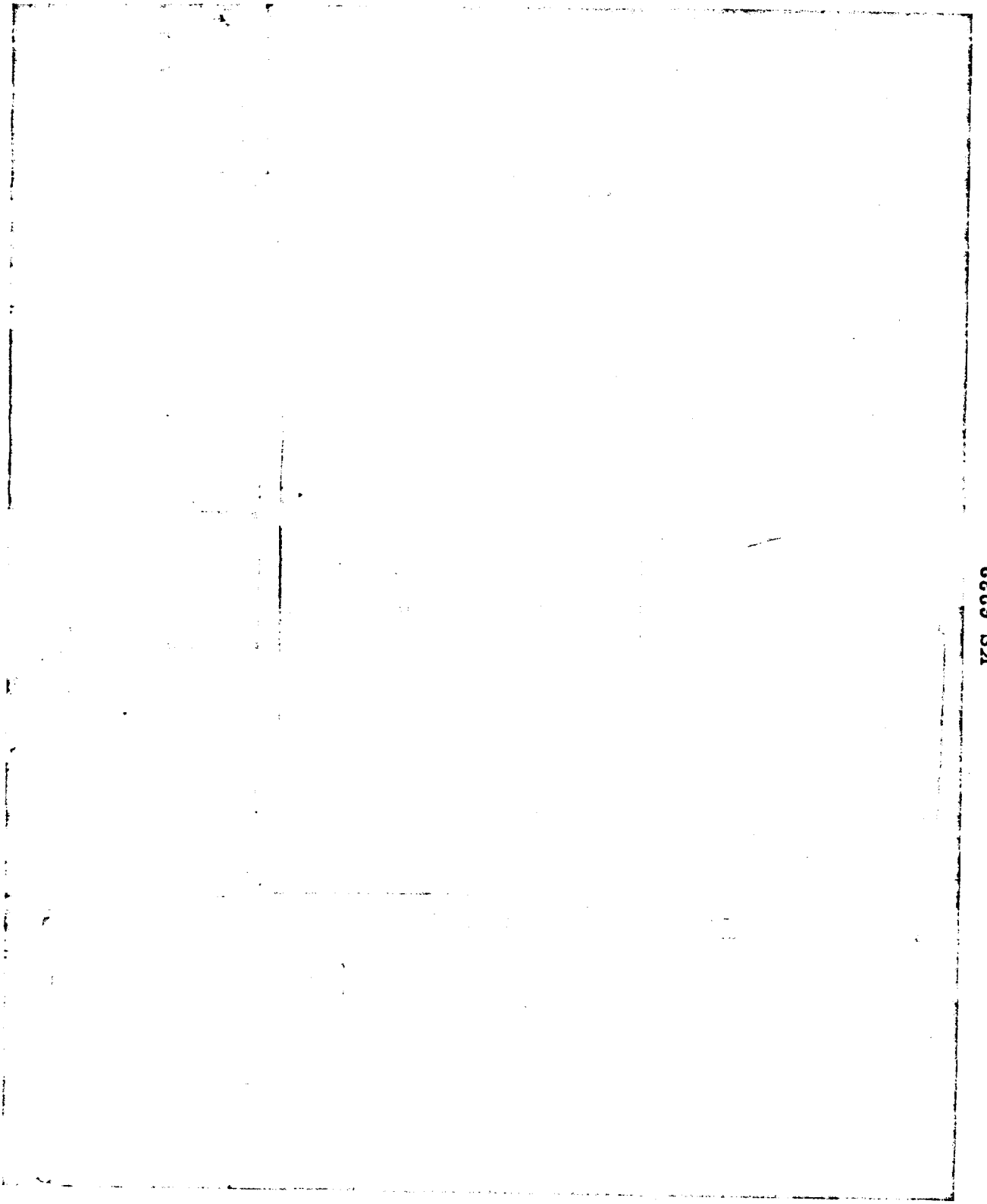
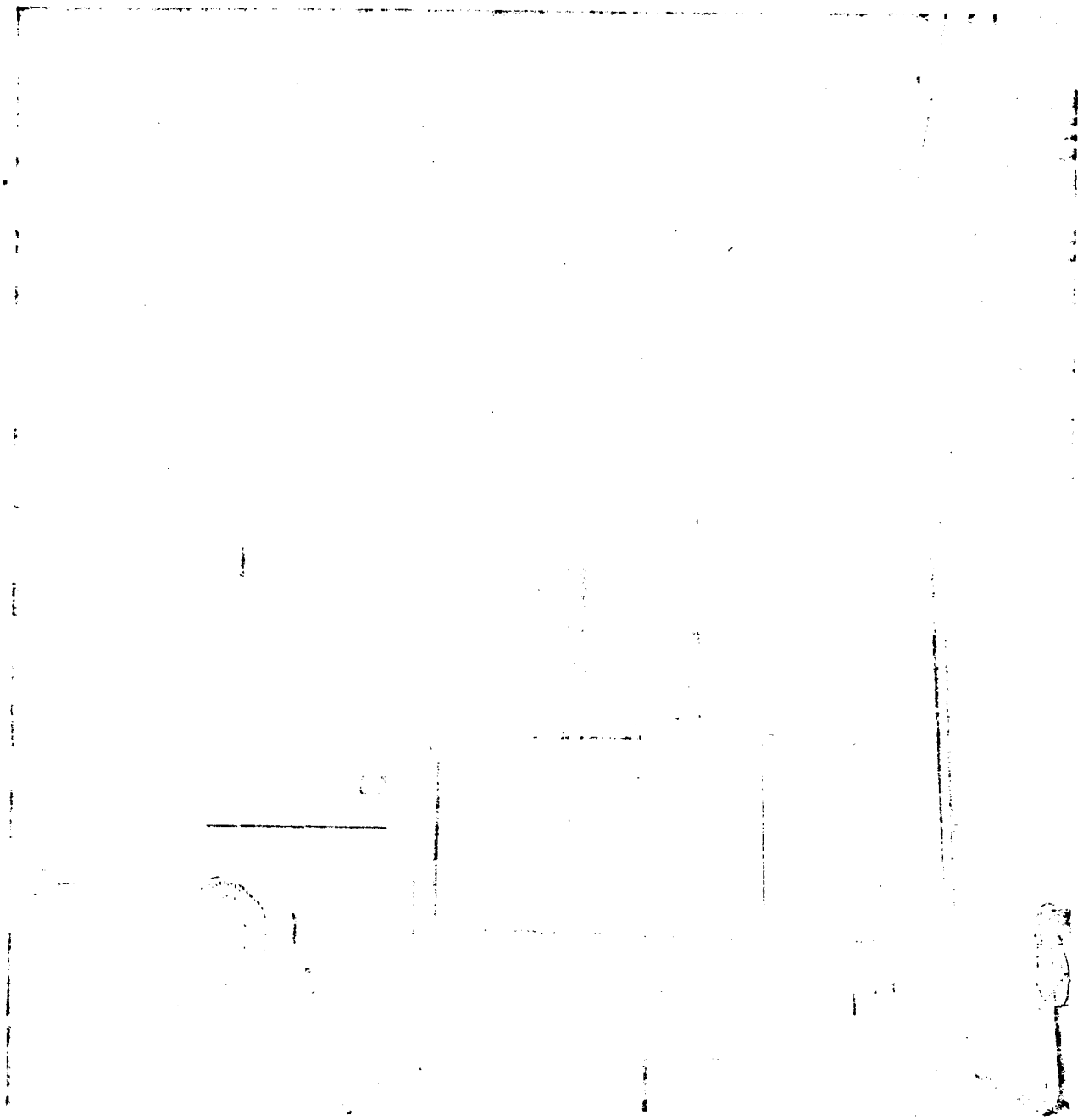
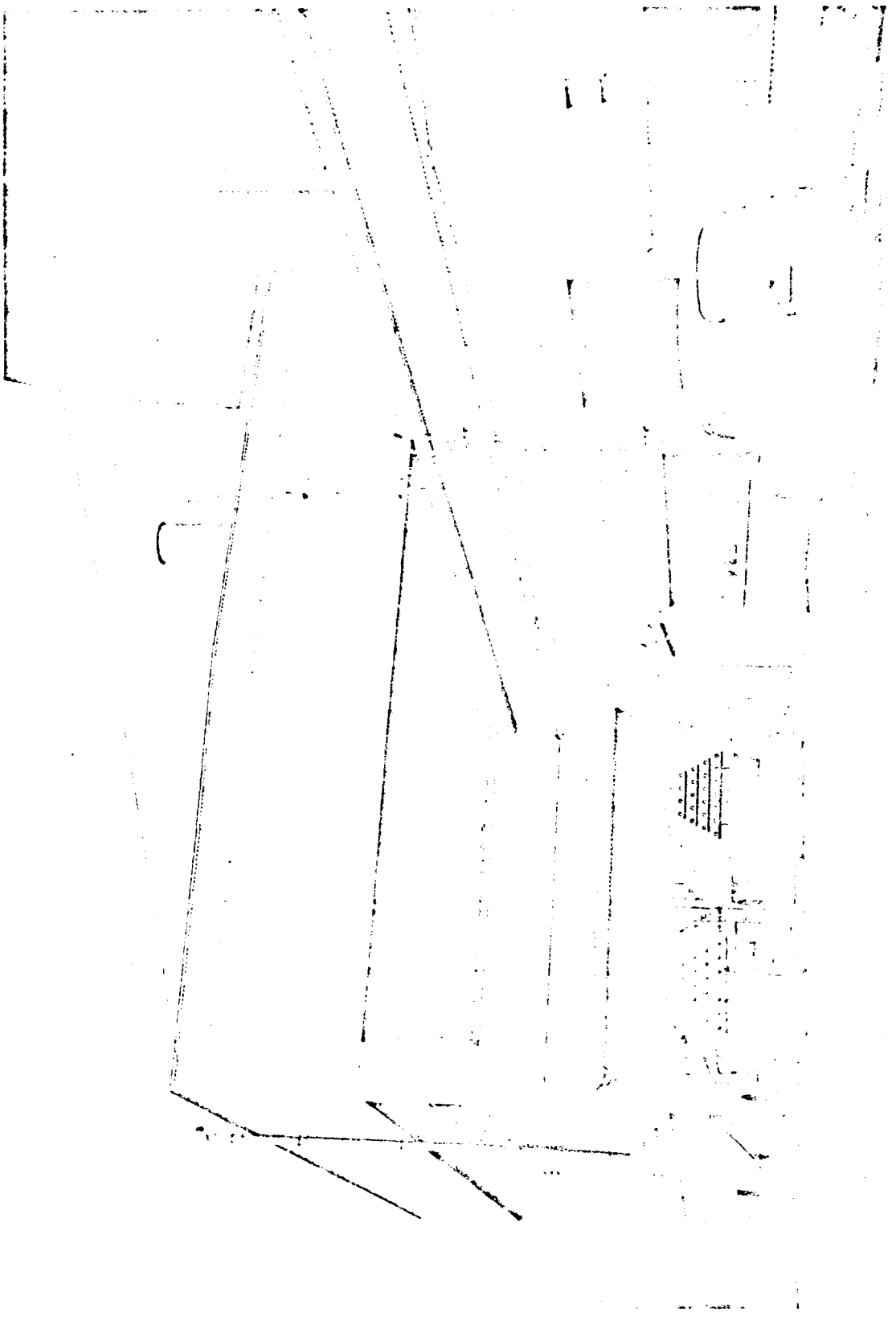


KS-6232





KS-6229

The efforts to combat the fire had caused the Liquid Metal cell to become pressurized with respect to the Power Plant Building and cell atmosphere was exhausted largely with the unfiltered Building atmosphere. The exhaust system has been modified to assure negative atmospheric pressures in the liquid metal cell during the use of sodium fire fighting equipment and to provide standby filtration for Power Plant Building exhaust air.

In summary, although the amounts of toxic elements released to the atmosphere at the Knolls Site have not been a problem in the past, the potential has been further reduced by changes in programs including shutdown of SPRU. The exhaust system for the Power Plant Building at the West Milton Site is now considered adequate for normal operations and for fires involving primary coolant in the Liquid Metal Cell.

AEC BETTIS PLANT AIR CLEANING ACTIVITIES

P. R. Bolton
Westinghouse Electric Corporation
Pittsburgh, Pa.

The Atomic Energy Commission's Bettis Plant, operated by Westinghouse, has certain air cleaning problems which consist chiefly of the removal of radioactive particles and acid fumes and mists from process air. Quite often, both types of contaminants are common to the process air. For this reason, the work horse of our air cleaners is a wet collector. We have in use the American Air Filter, Type "N" Rotoclone and the Schmeig Centri-merge, utility-type wet collector.

These collectors are constructed of stainless steel for use where the exhaust air is highly corrosive, such as in acid pickling operations, and of carbon steel where corrosion conditions are not severe.

The wet collector is in general use for pickling operations, in chemical laboratories, and for metal working operations where exhaust gases are hot or where pyrophoric metals are used. It is also used in some special applications as a precleaner for dry collectors to remove corrosive fumes or heavy dust loadings before the exhaust air enters the dry collector. In these special applications the collection efficiency required is greater than that which is provided by the wet collector alone.

The advantages of this type of collector for our operations are as follows:

a. Its collection efficiency is greater than 90% for particulate matter, and high for mists and fumes.

b. It can be used where there is a variety of contaminants to be removed, such as acid fumes, mists, particulate matter, and when exhaust air is at a relatively high temperature.

c. The maintenance cost is low because there are no filters to change. Waste water is piped to suitable disposal facilities depending upon the nature of the material collected. Where hazardous materials, such as radioactive isotopes, are collected the water can be changed and disposed of with a minimum of personnel exposure.

d. The exhaust rate is constant. Because the resistance of the water does not increase with dust loading, the pressure drop of the system remains constant, resulting in a constant exhaust rate. The exhaust fan does not have to be sized to provide for an increase in system static pressure due to loading of the filter medium. Resistance of the collector changes only with water level which is controlled within close limits by the automatic water-level control.

Among the other collectors in use is a deep-bed type dry collector. This is a special design which consists of a dirty plenum chamber and a clean plenum chamber separated by the filter medium supported in a horizontal plane by an expanded metal plate. The filter medium consists

of two layers of FG50 Fiberglass. The media mat is held in place by a rectangular rod frame which lies on top of the mat around its perihery and by the greater negative pressure drop through clean filters of about 4 inches W. G. This high initial resistance is a compromise between the physical size of the unit and the horsepower required to provide a given exhaust rate. Needless to say, a 5000 cfm unit occupies considerable floor space, approximately 65 square feet. The filter is changed by removing the cover of the top plenum chamber and rolling up the filter, retaining the collected material inside the roll. To catch any material which might fall off during filter change a tray is inserted beneath the expanded metal filter support prior to rolling up the filter. The change is effected with a minimum loss of valuable collected material and minimum dust exposure for personnel. The filter chamber is easily cleaned, if necessary, to reclaim the material adhering to its walls.

Several deep-bed units of 500 cfm capacity are used on various uranium alloy metal working operations, such as shearing, rolling and melting charge preparations. Each of these units contains its own blower and motor in the bottom (clean) plenum chamber. They discharge into a common header wherein a constant negative pressure is maintained by an auxiliary fan to prevent blow-back through units which are not operating. These are very versatile units in that they are semi-portable, permitting greater flexibility of the exhaust ventilation equipment, a distinct advantage in a development laboratory. We also have some of these units mounted on casters and backed up

by high efficiency AEC filters which permit discharge of the exhaust air back to the room, thus eliminating duct work. These units are used in a new development lab where work with powdered UO_2 is being conducted. Flexible hose on the inlet permits quick hook-up to different equipment. The collectors can be shifted to intermittent operations as required. The filters are changed when their resistance is twice that of clean filters or at the end of an accountability run, whichever occurs first.

Bag filters of the Hersey reverse-jet type are in use on powder metallurgy operations using UO_2. At present, the reverse-jet is operated manually at periodic intervals but we plan to install a differential pressure mechanism to actuate the jet. Dust loadings have been low, requiring infrequent operation of the blow ring. The lab employing these collectors is in a state of development at this time and we do not have much information on the performance of these collectors.

Electrostatic precipitators are used as the final cleaner in our hot lab operations. The air from the hot lab cells passes through a wet collector (Rotoclone) for removal of heavy dust, fumes, etc., and then through the precipitator before being discharged out the stacks. Fiberglass filters follow the precipitator to catch any blow-off from the collecting plates. The precipitators are cleaned periodically by washing the plates with a built-in water spray with an adhesive. The adhesive provides better retention of the collected material, and because it is water soluble the plates are easier to

clean. The contaminated water from the precipitator is piped to the radioactive liquid waste disposal system. Continuous monitoring of the stacks has shown that performance of the precipitators has been good. In the new hot lab facilities now being constructed the air cleaning facilities will be the same with the exception that precipitators will be followed by high efficiency filters to provide adequate cleaning for the high level radioactive samples to be handled. A distinct advantage in using the precipitators for radioactive work is that they can be cleaned remotely and the waste is in a liquid form, thus minimizing direct contact by personnel. We also have some precipitators for supplying clean air to "clean" rooms. These remove only atmospheric dirt and do not handle process air.

High efficiency filters of the AEC type are in use in the hot lab for local exhaust of operations where very high levels of airborne radioactivity are contemplated. This system consists of Rotoclone followed by the high efficiency filter. The master slave cell (or shielded hood) exhaust system consists of roughing filters of FG50 Fiberglass followed by a high efficiency filter as a final filter on small portable deep-bed type collectors permitting discharge of cleaned air to the room. In installations employing the high efficiency filters upstream to prolong the life of the high efficiency filters.

DEVELOPMENTS IN AIR CLEANING AT LOS ALAMOS

By R. N. Mitchell
Health Division, Los Alamos Scientific Laboratory

Since the last air cleaning conference at Los Alamos in September 1953, there have been no major changes or additions to the air cleaning equipment on the project. At present, no basic research on air cleaning is being done.

Radio-Chemistry Building

The Radio-Chemistry Building at Los Alamos is now under construction. A portion of the air exhausted from one section of the building will require cleaning.

The process involved is the dissolving of the samples using fuming nitric and perchloric acids. A maximum of 400 ml. of fuming nitric and 100 ml. of 70% perchloric acids are used per sample. A maximum of 8 hours and a minimum of 3 hours are required for dissolving the samples. In addition to the acid fumes, volatile radioactive materials, principally iodine, are evolved. The total activity per sample varies from 0.3 curie to 1.0 curie. Hood stack samples indicated that approximately 9% of this is volatilized.

In the present building, there are facilities for dissolving 16 samples at one time. Each dissolving unit is in a separate hood with a face opening of 20 x 18 inches. A total of 5000 c.f.m. of air is exhausted for the 16 hoods. The air cleaning consists of a water spray in the duct in back of each hood. Of the 9% of the sample that is volatilized, 35% is collected in the water spray and 65% goes out the stack. The mass median size of the material as determined by the cascade impactor is 0.5 to 1.0 micron. A total of 200 to 700 millicuries is exhausted to the atmosphere during a run of several samples.

The new building plans have stations for 16 dissolving setups in eight standard laboratory fume hoods. Instead of attempting to clean all the air exhausted through the hoods, a separate exhaust system provides local exhaust directly over the dissolving beaker. By this method, 320 c.f.m. of air requires cleaning instead of 5000 c.f.m.

A description of the air cleaning equipment as written into the building specifications is as follows: "The Venturi scrubber and cyclone separator in the dissolving room absorption system shall be manufactured by the Chemical Construction Corporation, New York, N. Y. or approved equal, and shall be installed in accordance with the manufacturer's recommendations. Unit shall be constructed of stainless steel in such a manner as to facilitate easy dismantling for cleaning and service.

The scrubber shall be designed to remove fuming nitric acid, perchloric acid and other solvents and dissolve material from 320 c.f.m. of 80°F. fume hood exhaust air with an efficiency of not less than 98%. Cleaned air shall be discharged to the atmosphere.

A caustic solution shall be supplied to the scrubber at a rate of 10 g./m. and a pressure of 15 p.s.i."

The feasibility of this type of air cleaning was checked by testing the Venturi scrubber of the incinerator at Los Alamos built for the disposal of contaminated trash. Fumes from boiling nitric acid containing radioactive iodine were passed through the scrubber. Duct samples taken before and after the scrubber indicated an efficiency of at least 98% and above.

Beryllium Shop Air Cleaning

Cleaning of air contaminated with beryllium at Los Alamos is done on the air exhausted from the hoods in the beryllium machine shop. The only work done in this shop is machining of metallic beryllium. The types of machines used are lathes, mills, drill press and surface grinder. Each machine, with the exception of the drill press, has an enclosing hood.

The amount of air to be cleaned varies between 1500 c.f.m. and 2500 c.f.m., depending on the number of machines operating. The air cleaning equipment consists of an American Air Filter Rotoclone, Type D, Size 10, followed by an American Wheelabrator and Equipment Corporation Dustube Collector.

The seventy-two orlon filter bags in the Dustube Collector are 5 inches in diameter and 70 inches in length. Total filtering area is 550 square feet; filtration velocity varies from 2-1/2 to 4-1/2 f.p.m. The filter is divided into two sections, to be used alternately under heavy loading conditions. As used at Los Alamos, the loading is extremely light so that both sections are used at all times.

The Beryllium Shop was moved to its present location and machining started in October 1953. New orlon bags were installed at that time. The initial pressure drop across the filter bags was 0.05 inch of water. After two years of operation, the pressure drop across the bags has risen to 0.35 inch of water.

With the new bags, the concentration of beryllium in the air exhausted to the atmosphere at start up varied from 0.5 to 1.0 microgram of beryllium per cubic meter. At the end of two years' operation, the beryllium concentration averages 0.05 microgram per cubic meter.

Sigma Portable Filtering Unit

One ventilating and air cleaning problem at Los Alamos is the result of the predilection of various groups to work with radioactive material for short-term experiments in areas that have no exhaust ventilation or insufficient ventilation for the process involved. This problem has been solved to some extent by the construction of portable blower and filter units. The first unit, has a roughing filter, one 24 x 24 x 11-1/2 CWS-6 filter, and a blower capable of

exhausting 1000 c.f.m. through the filter. A suitable hood or slot exhaust is made for each job. This unit worked satisfactorily at Los Alamos and at a Kokomo, Indiana mill that was doing contract rolling of uranium.

Air samples taken at the blower exhaust showed no activity when the unit was being used to ventilate work with radioactive material.

D.P. West Air Cleaning

The plutonium contaminated air exhausted from dry boxes at DP West is filtered through CWS-6 type filters installed in the room or nearby outside the room. Efficiency tests on one set of filters ranged from 70 to 99%. Particle size measurements made on particles collected in ducts downstream from the filters ranged from a mass median of 0.4 to 1.3 microns in diameter. The median size passing through a CWS-6 filter should be less than 0.3 micron. The results indicate leakage around the filter or improper filter installation.

Changing CWS-6 filters contaminated with plutonium presents a serious potential hazard to the craftsmen. Ingenious designs have incorporated safe handling in the filter holders. Plastic bags enclose the holder in such a manner that the workmen never touch the CWS-6 filter when removing or replacing it. Perhaps these elaborate safeguards make it impossible to properly seal a new filter in place. Whatever the cause, it is believed that improved air cleaning will result if the filters can be sealed more tightly.

The method of installing CWS-6 filters for plutonium filtration will be studied and an improved method devised. In addition, a ventilation engineer should be present during the filter change to inspect the job.

Miscellaneous Installations

The reverse jet-type bag filter has been installed in two locations at Los Alamos. One is for graphite dust where a cyclone has proven inadequate. This nuisance dust will be removed by passing through the cyclone and then into the reverse jet-type filter. In the second location, it is used to remove chemical dust from sizing and loading operations.

LOS ALAMOS AIR CLEANING ACTIVITIES

S. H. Glassmire
CMR Division
Los Alamos Scientific Laboratory

At the last Air Cleaning Seminar, Mr. Barrie Graham saw fit to comment on the organization of various departments concerned with air cleaning at Los Alamos. Since we have many people concerned with various aspects of air cleaning and since we have had some organizational changes it might be desirable to review our organization.

So, to bring the record up to date -- The three (3) major organizations at Los Alamos has remained unchanged. The technical work is under the University of California which operates the Los Alamos Scientific Laboratory (L.A.S.L.). The Zia Company is the maintenance contractor for both the townsite and the Laboratory. The third organization is the Atomic Energy Commission.

The Industrial Waste Treatment Section under Mr. C. W. Christenson was reported last time as functioning under the Health and Safety Branch of the A.E.C. This group has now been transferred to the operational jurisdiction of Health (H) Division of the Los Alamos Scientific Laboratory. The function of this group remains the same and is charged with the treatment of industrial and radioactive waste.

In the Laboratory's Engineering Division, Mr. Charles Wherrit heads the Mechanical Design Section. This group is charged with the over-all design and specifications of all ventilation and filtration systems of the Laboratory. Mr. Raymond McDonald represents the Engineering Division at this meeting and any specific questions concerning the general systems and filters at Los Alamos may be directed to him. Recently another Engineering group (ENG-4 under

Mr. C. A. Reynolds) has undertaken the operation and responsibility for the main building filtration systems of the CMR Building which handles and filters some 600,000 cubic feet of air per minute. (All air entering the building and passing through the laboratories and equipment is 100% fresh make-up and, before discharging to atmosphere, it is filtered to give below tolerance stack counts.) Mr. Les Pagd and Mr. Roy Merryman have direct responsibility for the operation of these main filter towers. This group is now using various combinations of filtering media. These combinations include such media as: PF 334, 335, 336, and 105 manufactured by Fiberglass Corporation; Cambridge Aerosolve #95; and capillary air washers. Each combination of these materials cleanses with different efficiency and are still being studied. Mr. Reynolds has indicated to me that his group will advise the industry via a report sometime in the future when more data is accumulated to substantiate such reporting.

Group H-5 of the Health Division of the L.A.S.L. handles the Industrial Hydiene activities of Los Alamos and is under the direction of Mr. Harry Schulte. Mr. Schulte's group is represented at this seminar by Mr. Robert Mitchell. Mr. Mitchell is reporting separately here today and will summarize the over-all air cleaning and stack gas situation at Los Alamos. My remarks will be confined to the "process" air cleaning interest of the Chemistry and Metallurgical Research Division (CMR) of the Laboratory. CMR's research and and production lines discharge the bulk of the radioactive effluent at Los Alamos. CMR's process laboratories also discharge many varieties and types of radioactive aerosols into the air streams which obviously presents many filtration problems. Therefore, CMR Division maintains people on their staff interested in air cleaning

ventilation and radioactive handling.

CMR's ventilation and air cleaning was formerly carried out by CMR-AE. However, this group has recently merged with CMR-7 under the direction of Mr. James R. Lilienthal. I represent this group here today. Our group is charged with the responsibility of "process air flow" which concerns proper air balance, quantity, and flow pattern through the individual laboratories and equipment, and local or source filtering where necessary. We now maintain filtered air flow through all our dry boxes at rates ranging from 10 - 30 cfm with a 0.5" w.g. negative pressure inside the dry boxes maintained by an inlet type edge filter. The edge type filter that we have developed for this application is shown on Drawing 11Y-31674, copy enclosed with this report. Various media have been used in this edge filter depending upon the pressure drop and efficiency desired. The media that has proven satisfactory for over-all enclosure operation is 1" thick dynel with #2 dinier with blend of #6, #12, and #24 fibers manufactured by the Fiber Bond Corporation. Discs 6" O.D. by 2-1/2" I.D. are placed in the holder, cemented together, cemented to top and bottom plate, and stretched or compressed to give the desired pressure drop.

Local exhaust filtering at the source of "hot spots" is sometimes necessary in order to facilitate recovery operations and to prevent undue contamination of the main systems. Where necessary, local exhaust filters are incorporated in the original hood or dry box design or filters are installed in the exhaust line near the enclosure. Cambridge absolute filters are generally used for this application. Types of filter boxes that we have developed for line filtration are shown on enclosed drawings 11Y-31978 and 11Y-31789.

This design permits filtration of all air discharging through a single branch line. It also facilitates changing filters through the standard plastic bag and ring arrangement with a minimum spread of contamination. The design has proven very satisfactory to us if care is taken to assure a good seal around the gasketed surface of the filter.

CMR Division also operates experimental test duct sections where we test efficiencies and air flow characteristics of various media. Drawying 11Y-31798 shows one of our test ducts, the design of which is standard. The sampling ports and mechanism are not shown on the drawing. The CMR laboratory scientific personnel report to us the probable physical properties (size, shape, adhesion characteristics, etc.) of the effluent issuing from their particular operation. Similar, or sometimes idential aerosols, are then generated in our test ducts. We have found it difficult to simulate test material that exactly duplicates our radioactive effluent actually discharged into our air streams. Therefore, as far as is economically feasible, we are testing with the same aerosols that the media will ultimately be expected to filter. High efficiencies of a media using charged lead, copper, etc., and other such aerosols, ordinarily used for testing, cannot be assumed to apply nor to be equally effective on submicron plutonium, uranium, or other particles. Substitute aerosols in general do not have the same filterable characteristics as our small radioactive contaminants.

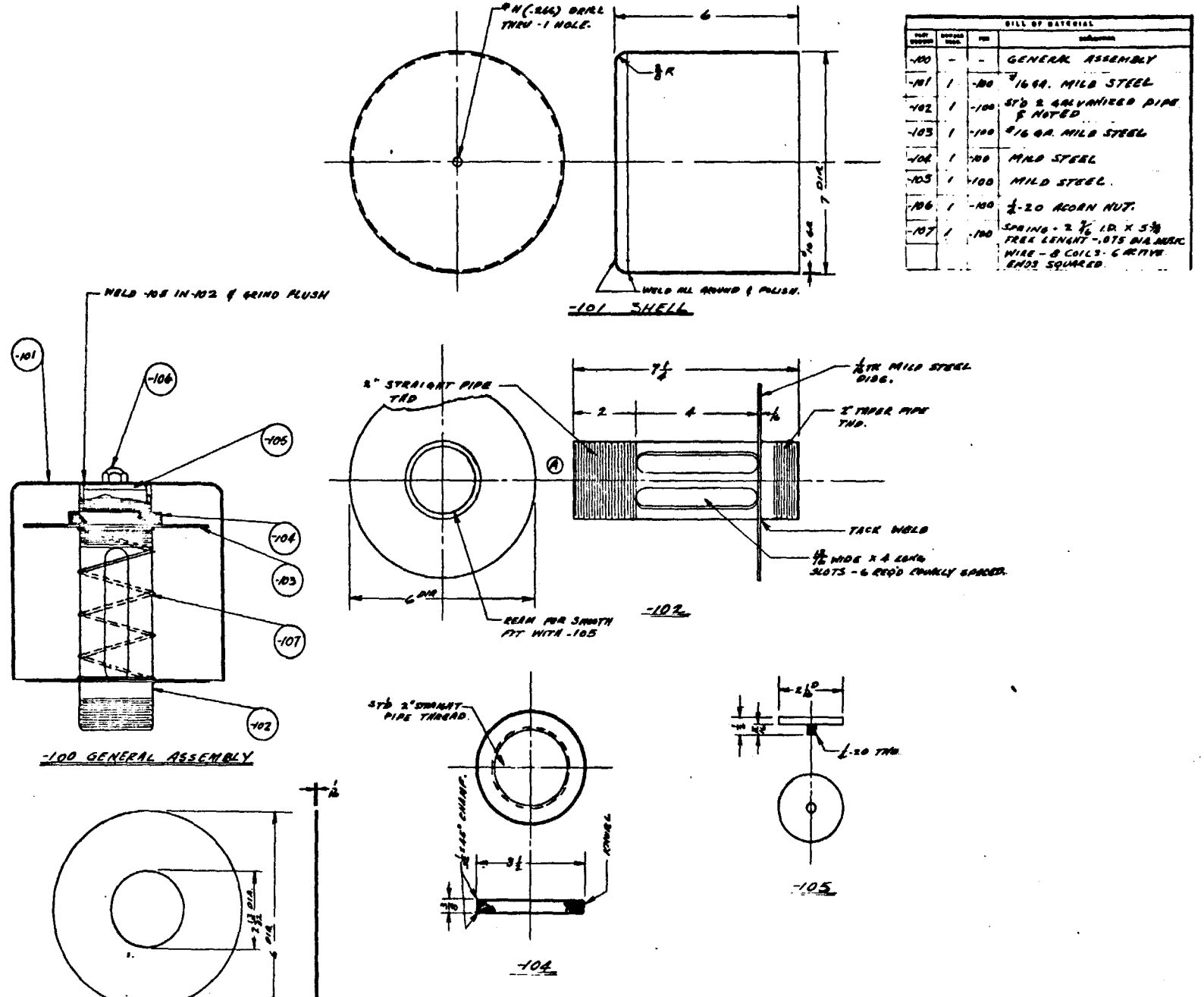
Cambridge Absolute, Cambridge Aerosolve, F.G. 50, and Fiber Glass PF 105 have performed well under out test conditions and have been adopted and operated by Engineering Division in our main filter towers. PF 334, 335, and capillary air washers are often used in series with

one of the above medias. Our capillaries cleanse the air of corrosive fumed and acid mist but must be followed by efficient moisture climinators if the capillary is operating ahead of the above medias. (Engineering Division has minimized the build up of solid concentration of the capillary spray water by proper blow down.)

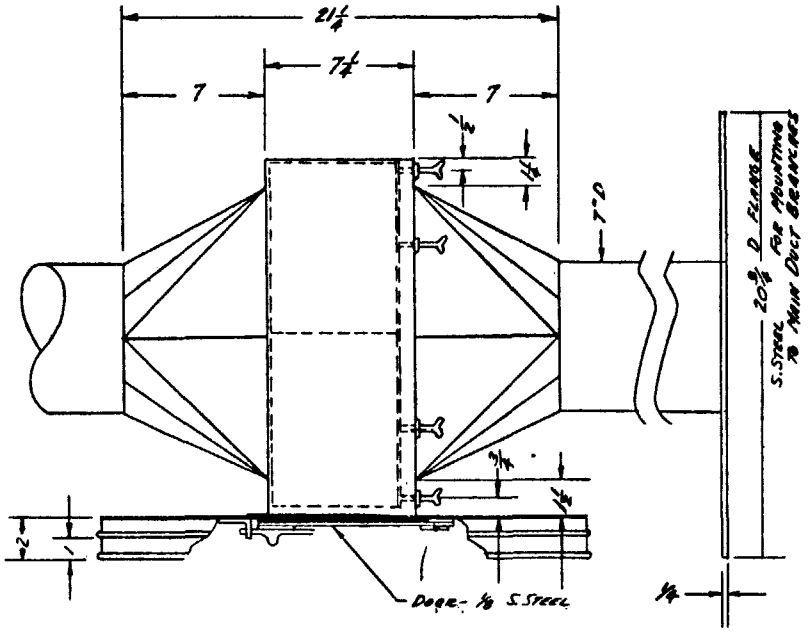
It might be of interest to this seminar to know that we have recently experimented with small capacity sand filters and have obtained good results. We are constantly searching for economical, as well as efficient, filtering media. In our effort to utilize economical and available material, we have ground volcanic tuff and used it for media. Tuff composes the bed rock at Los Alamos and is minutely vesicular in texture with apparent high adhesion properties. We have packed 8" square filters to a thickness ranging between 1" and 4" with ground tuff retained between #12 and #20 U.S. mesh wire screen. Excellent efficiencies have been obtained on particles ranging from 5 to 40 microns in size at flows up to 30 cfm across this face area. The efficiency decreases as aerosol size decreases to about 2 or 3 micron. However, from preliminary studies, the efficiency curve appears to start back up (better efficiency) somewhere in the submicron range. These sand filters probably filter on the principle of inpaction and their efficiency is probably due to the high adhesion characteristic of the tuff. They warrant further study for possible application as an ecomomical, efficient, low pressure drop, roughing filter. These sand filters were also tested with heavy metallic contaminants and were operated both wet and dry.

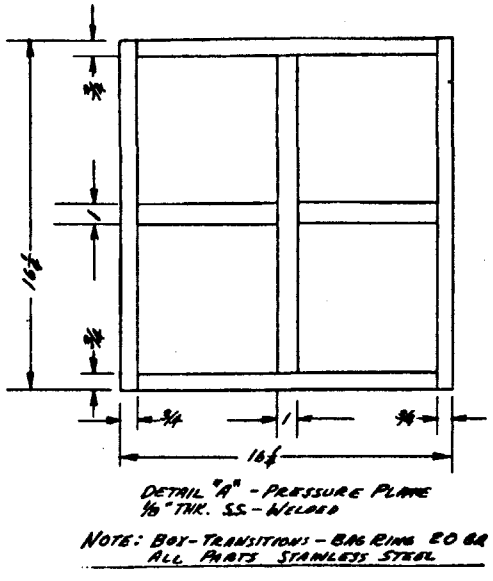
In connection with sand filters, I would like to mention a research problem that I started last year at the University of Kansas

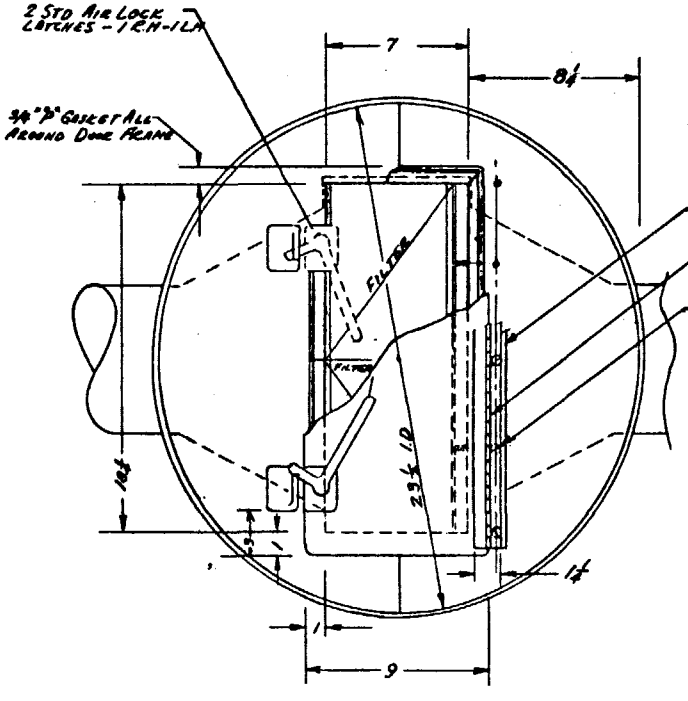
while on leave from the L.A.S.L. My problem concerned the vertical and horizontal travel or migration of air born radioactive contaminants after fall out on the earth's surface. Unfortunately, I had to leave before accumulating sufficient test data to warrent publication. However, I would like to take this opportunity to report that my preliminary studies suggest that once such a particle falls out on the earth's surface it tends to remain in place. Very little horizontal or vertical migration was noted. The soil covering tends to be a very effective filter in itself and there is little chance of downward washing and subsequent spread of contamination. Since I am not directly connected with such matters at Los Alamos, I am turning my data over to others that are, for further study and future reporting.

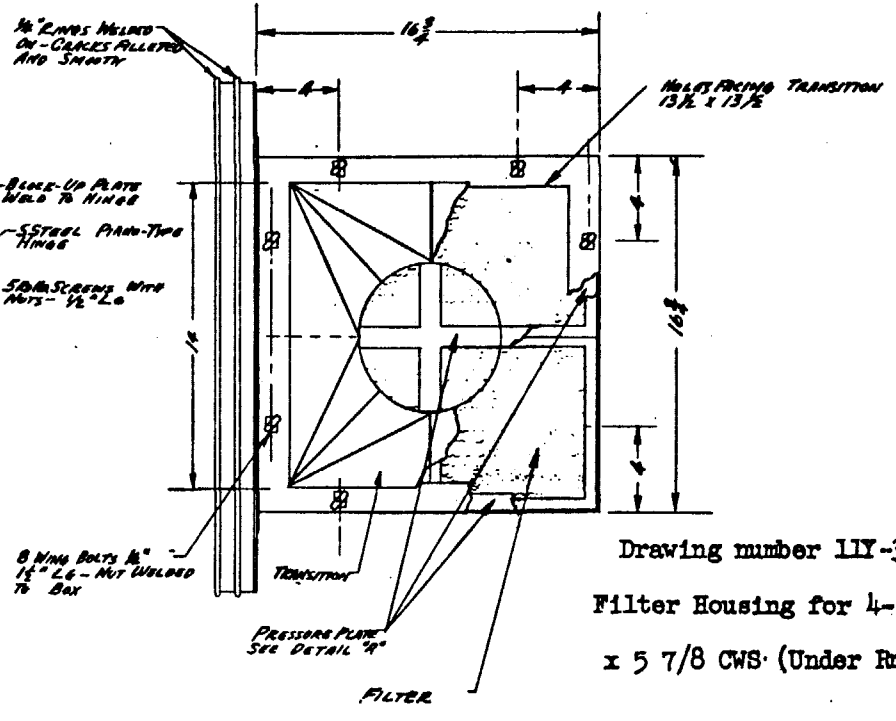


Drawing number 11Y-31674. Edge Filter (Assembly & Details).



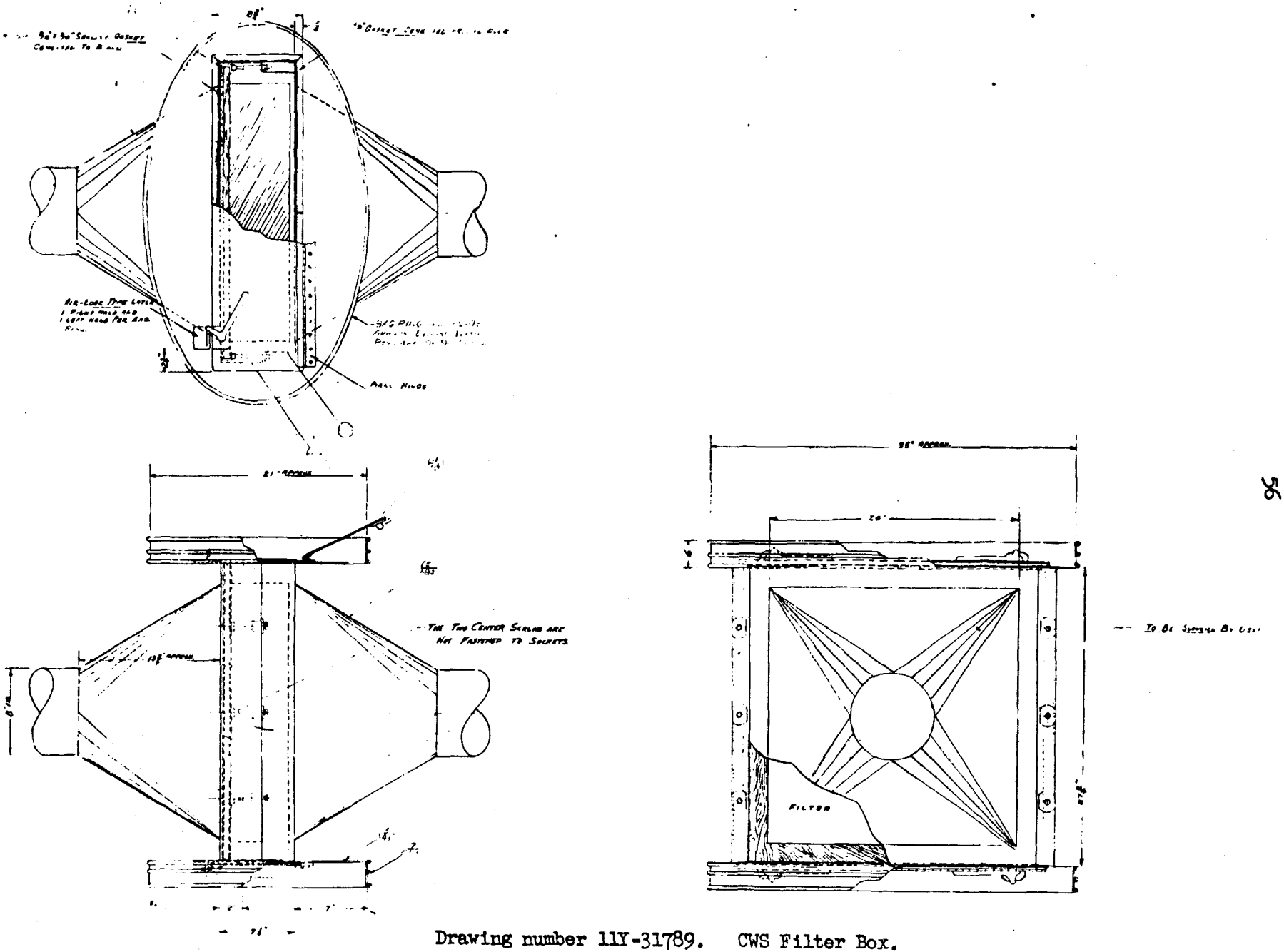




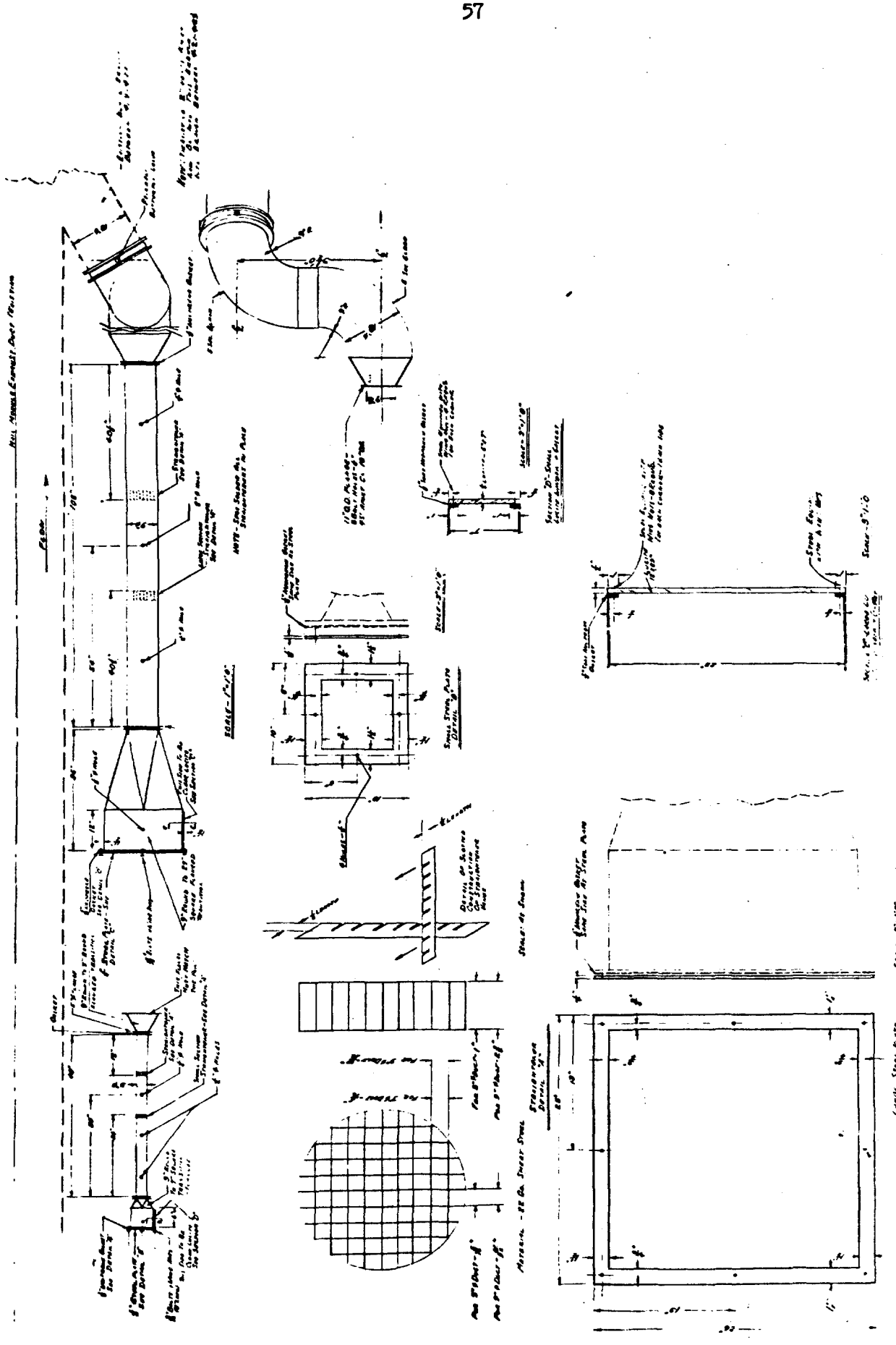


Drawing number 11Y-31978.

Filter Housing for 4- 8" x 8" x 5 7/8 CWS (Under Rm 4123).



Drawing number 11Y-31789. CWS Filter Box.



Drawing number 11Y-31798. Test Duct Section New CMR Bldg. Basement Wing #4.

SPECIAL AIR MONITORING PROGRAM AT THE BROOKHAVEN REACTOR*

By Lee Gemmell
Health Physics Division
Brookhaven National Laboratory

Whenever the BNL Reactor shield is opened up for the purpose of charging or discharging fuel, or when certain isotopes are made in a non-routine fashion in the pneumatic tube facilities, airborne contamination may accidentally escape into the reactor building in varying quantities. Most jobs can be done with a minimum of contamination. However, experience has shown that even with the greatest care in planning an operation, accidents or unforeseen problems can still happen.

To remove fuel elements from the reactor, it is necessary to reach in with long handling tools through the biological shield, across the plenum and into the reactor graphite itself. The fuel cartridges are pulled out of the graphite holes into a supporting tube suspended across the plenum and then lowered into the canal. The manipulation of items in the plenum is all done through the narrow scanner slots opening from the top of the pile into the plenum.

Even though there is supposedly negative pressure in the pile at all times (i.e. air always moving into the pile) there have been occasions during pile shutdowns when puff-backs or backdrafts have occurred and spread considerable contamination into the building by way of the scanner slots and open experimental facilities. As the handling tools are removed from the pile they are thoroughly wiped and scrubbed, however, even under the most exacting requirements for cleanliness, some contamination may get out onto the charging platform and become airborne.

The reactor building is air conditioned with only part of the air being recirculated. Air movement in the building was studied using smoke with the air conditioning both on and off. There is some mixing between the air in the north and south portions of the building (see Figure 1). However, during certain operating conditions, there is a tendency for it to circulate mostly in the part of the building from which it entered. Two air sampling systems were necessary in order to sample each part of the building promptly. Air is drawn through the sampling tubes and then through the filter paper strip at about 2 cu.ft./minute. The particles are stopped by the paper (H & V #7 – 9 mils thick) and counted by the mica-window GM counter that sees the dust as it is collected. The counter feeds into a ratemeter which displays the results on a recorder located in the Health Physics office. If contamination shows up on the filter-paper, an associated alarm circuit lights a red light on the charging elevator showing the operators that airborne contamination is present and that the prompt use of respiratory equipment is required.

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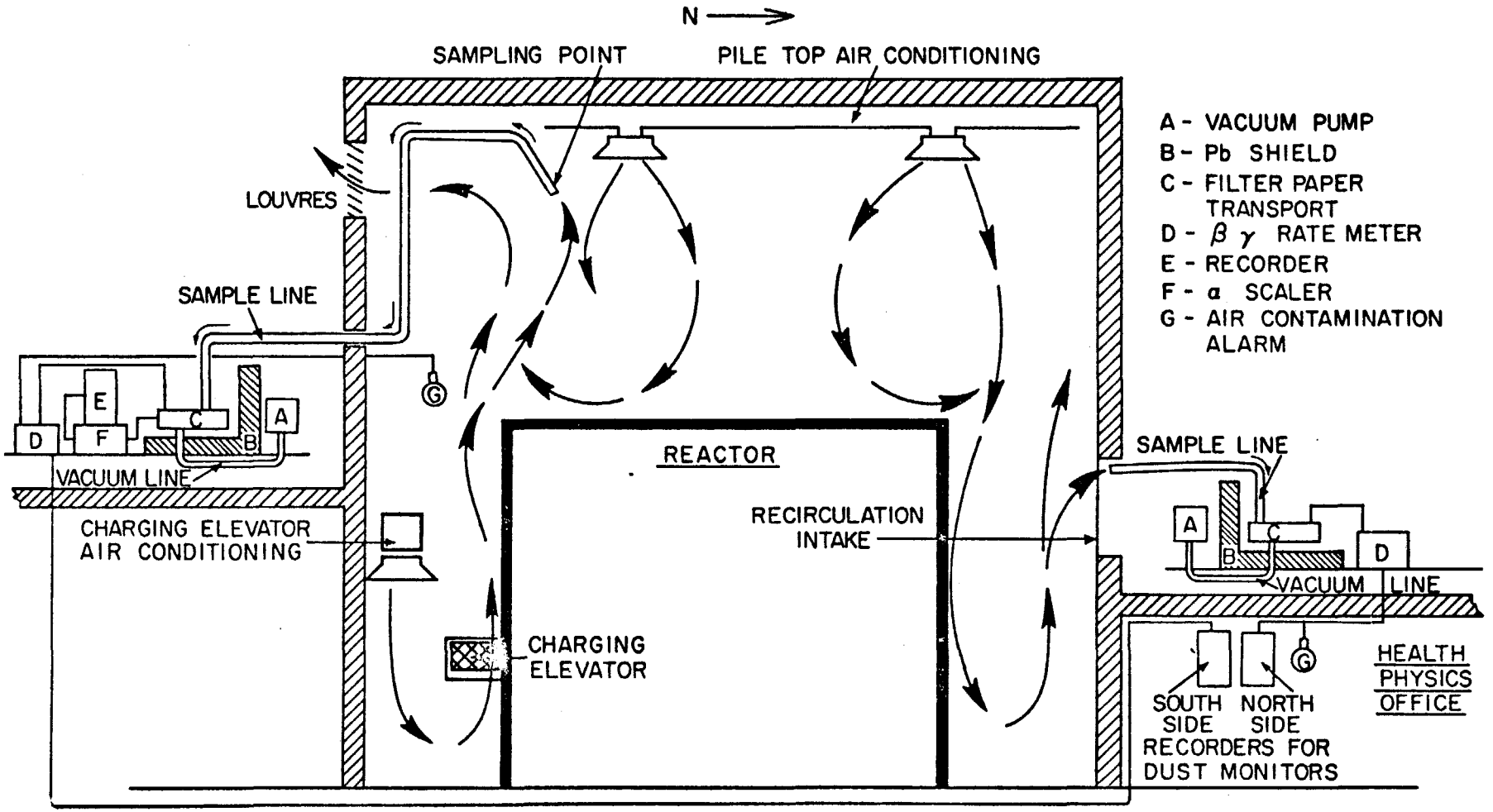
* Paper given at Air Cleaning Seminar at Argonne National Laboratory, November 2, 3, 4, 1955.

The dust collector and electronic counting equipment are surrounded by lead and are located in a room far removed from the contaminated air that is being sampled (see Figure 2). The only radiation the counter sees is the radioactive particulate matter that is pulled in from the pile room through the sampling tube and deposited on the filter paper. Because of the low background, it is possible to detect extremely low levels of airborne contamination. Increases in radiation background due to the naturally occurring radium and thorium products brought into the building during inversion conditions show clearly. Calibrations have been worked out showing concentrations of airborne activity due mostly to escaped fission products in the pile room vs recorder readings.

To carry off the more than 25 million watts of heat per hour from the Brookhaven Reactor, a tremendous amount of cooling air is needed. Approximately one million pounds of air per hour is pumped through it by four 1500-horsepower fans. The air is filtered before it enters the pile by American Air Filter FG-100 deep-pocket filters and again before it leaves the pile by Dollinger Glasstex deep-pocket filters. Most of the activity discharged up the stack is due to the radioargon. However, there is a small amount of unavoidable particulate activity.

To monitor this particulate activity, a dust collecting probe has been inserted in the air stream at the base of the stack (see Figures 3 and 4). This tremendous quantity of cooling air is sampled as nearly isokinetically as possible with the sample being pulled through a 3-inch flexible tube from the sampling nozzle and then through a flow meter and filter paper. The sampling rate is about 1.5 cu.ft./minute. Five minutes after collection, a scintillation counter sees the collected particulate activity on the filter paper, feeds the signal through a logarithmic rate meter circuit (range from $10-10^5$ counts/sec) and into a recorder.

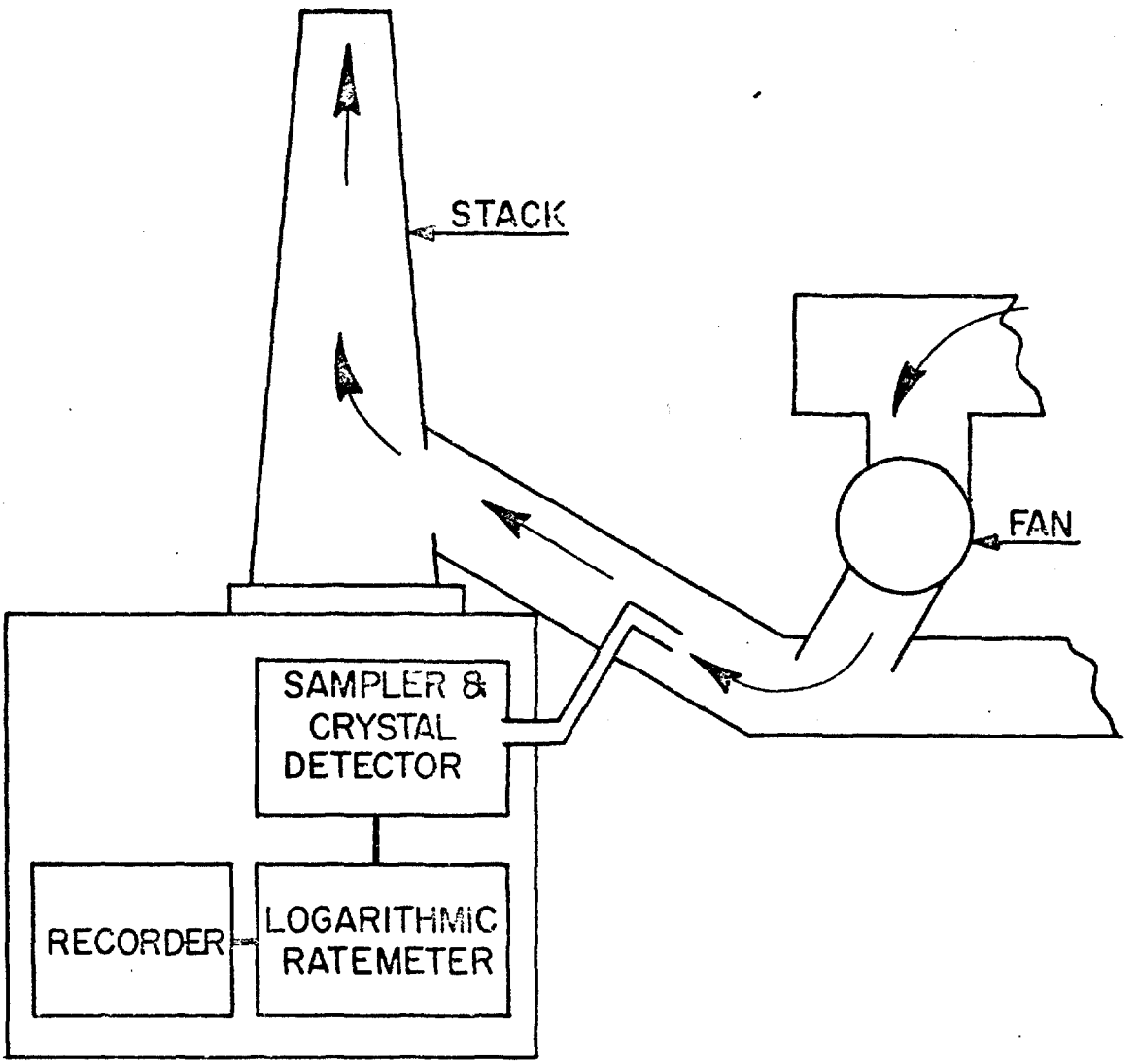
The usual air sampling and quantitative assay problems are present in both of these installations. However, both are continuous monitors, they each have good sensitivity and prompt response, so are effective as survey detectors during unusual or emergency conditions.



HEALTH PHYSICS AIR MONITORING SYSTEM
SCHEMATIC ARRANGEMENT

Figure 1

Figure 2



STACK AIR MONITORING SYSTEM
SCHEMATIC ARRANGEMENT

Figure 3

Figure 4

A REVIEW OF AIR CLEANING EXPERIENCES IN VARIOUS FACILITIES AT THE HANFORD PLANT

By J. H. Palmer, Projects & Personnel
Development Sub-Section
Separations Division
General Electric Company
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The types of filtration and the maintenance, including replacement of filters used in supply and exhaust systems, is of a direct concern to the engineer in charge of maintaining ventilation balance at the Hanford plants.

In order that his problems be appreciated, it is perhaps necessary to follow the air movement through a typical building from the supply fan intake to the final discharge at the stack to the atmosphere.

First, the air is drawn into a supply unit or series of supply units, passing successively through a bank of dry filters (usually pleated media or wire maze filters), preheaters, spray washer (which may or may not include a bank of wet filters), and reheater, from which it is discharged by the fan either to a plenum or directly into a distributing duct system to various parts of a building.

As our interest at this session is mainly concerned with filtration, let us pause and discuss the filter media used for the dry filters.

When the Hanford plant first commenced operations, a commercial type filter paper airmat was used, which, although it supplied the necessary filtration, was easily torn in handling or when being pleated in the machine used for forming the replacement. Considerable fog is experienced during the fall and winter months and the paper media being very absorbent, would load up with moisture, causing the pressure drop across the filter to increase, which in turn would cause the filter media to rupture. Freezing of filters would add to this problem.

The maintenance of these filters (as many as twenty fan units in some buildings) was time consuming, inconvenient, and costly.

It was practically impossible to maintain a regular supply of ventilation air under these conditions so the ventilation balance suffered as a result. In latter years, a fiberglas media has been in use which has reduced the maintenance costs and shutdowns of the equipment approximately 75%, greatly facilitating the maintenance of ventilation balance.

The possibilities of using an electrostatic attraction filter has been investigated to some extent. It is a good dust collector, is fairly rugged, and can be rinsed out and reused indefinitely. Unfortunately, to use them, the filter bank frames of our present units would need a great deal of remodification. Another reason why we cannot use them is that all our supply fan intakes are classified as radioactively contaminated zones, and the rinse water used would have to be routed to a process sewer. It could not be turned into the sanitary floor drain within the unit.

The replacement of the filter media now in use is a nuisance job, and because of its possibly contaminated condition, has to be performed under "Special Work Permit" conditions (hereafter in this discussion will be termed SWP). This permit describes the type and number of items of protective clothing required, type of mask to be worn, and time exposure limit per man, etc. Great care must be taken to prevent the spread of dust when replacing these filters.

In some Hanford buildings, a room with a good source of exhaust has been set aside for this purpose. A layer of airmat filter is placed over the exhaust grill to prevent dust being borne to the exhaust system. This airmat has to be changed frequently as it builds up rapidly.

The filter frames are carefully removed from the filter bank, placed in fiber-board cartons, and moved to the filter changing room where the frames are refilled and the dust contained within this room.

The wet filters, where used, are fiberglas packs placed in frames and are easily replaced.

The replacement of these wet filters would be less frequent were it not for the calcium deposits picked up from the spray water. There are various additives which can be used to prevent this build up. Our experience has been such that the additives are expensive to use, and, if manually applied, not too effective.

We have found that most of the build up first occurs around the edges of the filter and gradually spreads to the center, eventually covering the entire filter. By test, we have found that this is caused by the spray nozzles only partially covering the filter and that if the nozzles are adjusted to overlap each filter, that the build up is much slower and in some cases eliminated. The entire filter must be kept wet as long as air movement is through it. Frequent inspection of the nozzles is necessary as they plug easily, resulting in a distorted spray.

Another method tried at Hanford is to proportion condensate from heating coils into the spray water. This is effective not only in preventing build up, but also to remove the deposit after it has formed. The pH value of the resultant spray water must be watched closely to maintain it slightly below neutral. A pH of 6.5 is recommended. If the pH is maintained too low, corrosion of the filter frames, spray water tank, etc., will result. Alternately lowering and raising the pH value has been found to maintain the internals in good condition.

Let us again follow the air movement. After the supply air has been filtered, washed, and tempered, it is discharged either to a plenum or directly into a distributing duct system and is delivered to the various building spaces, proportioned to requirements.

So far we have discussed problems with which ventilation engineers in all industries are familiar.

In nucleonics buildings we have to zone each area and each space within an area. The direction of air flow must always be from the clean, or noncontaminated zones towards the potentially or positively contaminated zones. This is accomplished by maintaining carefully calculated static pressure differentials between the zones. Often, as little as 0.005" w.g. is sufficient to accomplish this. It can readily be seen that careful and absolute control of the ventilation balance is necessary so that flow reversals will not occur.

The air is exhausted from the spaces, either through hoods or exhaust grills. There are usually three types of hoods: open face, sliding door face, and closed hoods. The open face and the sliding door face hoods are exhausted usually through a C.W.S. type filter at the transition between the hood and the exhaust duct system, or several hoods may exhaust into a filter box containing a series of C.W.S. type filters. A flow of from 100' to 150'/M is usually required for openings into these hoods, dependent on hood function. Most hoods receive their supply from the room spaces, through either the adjustable sliding door or other openings to the hoods.

The closed hoods as the term implies, are totally enclosed, receiving their supply through C.W.S. type filters or a regulated duct system as in the remote line systems. The filters are placed over small openings in the hood casings and are actually used to prevent or alleviate contamination spread in case of a flow reversal from the hood into the surrounding space. These hoods require very little air flow, the pressure differential between the hood and the space being the important factor.

Throw-away filters (Dustops) are in some cases placed over the faces of expensive filters to catch lint, Kleenex, etc.

Many types and designs of controllers are in use to control the quantity of air flow through these hoods and to make up for the build up of filters. We will not attempt to cover them at this time.

It can readily be seen that exhaust filters play a very important part in maintaining ventilation balance in addition to the filtration they provide. The high degree of filter efficiency demanded (up to 99.95% for submicron particles) requires a filter that is compact and capable of high collection. Thus, the filter is dense and closely woven and is easily plugged. This plugging increases the pressure drop across the filters, reduces the flow, and upsets the balance.

To give some idea of the extent to which the C.W.S. type filters are used, in one building, over a thousand of these filters of various dimensions are in constant use. Some of them have been in service for over five years and others are replaced frequently, dependent on location, usage, and durability. The condition of these filters has a direct influence on the ventilation balance of the building.

It is obvious from the foregoing that the ease of replacement, durability, and condition of filters are items of great interest to the ventilation engineer. Each time a filter is changed, or a piece of equipment is out of service, the engineer usually has to make some counteractive adjustment.

Owing to their usually highly contaminated condition, very careful methods must be employed when changing these exhaust filters. At Hanford we use the plastic bag method wherever possible. The filters are removed from their frames and, with as little movement as possible, are sealed in plastic bags. Sometimes it is necessary to erect temporary enclosures around a filter box before the plastic bags are used. In each case, the spread of contaminated dust is contained within small areas. Most filter changes are made under S.W.P. conditions, sometimes under extremely short time limits. In one case, as short as thirty seconds. The multiplicity of man power and labor cost required to cover this kind of work is terrific. The need for a filter capable of withstanding high pressure drops and still maintaining its filtration and flow characteristics is urgent. The C.W.S. filter, because of its excellent filtering qualities, was thought to be the ideal filter for our use until the inflammable nature of the media was realized.

Tests under simulated conditions were conducted which proved that, although the filters appeared hard to ignite from sparks (during the tests), once fired by direct flame were extremely hard to extinguish. Application of CO_2 and then water applied to one side of the filter failed to extinguish the fire. Water had to be applied at both sides of the filter bank and then the filters had to be torn apart before the fire was completely extinguished.

As a result of these tests, the search for an all-purpose filter was instigated. After a very short functional test because of the urgency, an absolute filter was selected because of its apparent ruggedness and fireproof qualities.

This filter, although possessing the filtration and fireproof qualities desired, was soon found to be unsuitable for our particular needs. In one building, all C.W.S. filters were discarded and replaced by the absolute filters. After a short time of service, it was noted that contamination in the stack emission had increased. Careful inspection of the exhaust systems revealed that under normal ventilation conditions, with an average relative humidity of 50%, the cement used to bind the filter media and separators to the frames, had disintegrated, permitting separation of the components, thus allowing contamination to by-pass the media. Efforts have been made by the manufacturer to overcome this difficulty by treating the frames and outside edges of the binder with a waterproof mixture. But, within the filter itself, the binder is still subject to decomposition. It was also noted that the corners of the metal frames were not airtight and that the cement would break away from the perforated sides of the frames, providing additional sources of by-pass air. It was also noted that the aluminum separators erroded rapidly under minor acid fume concentrations and if used in the horizontal position, the filter would collapse at loss of the support provided by the separators.

Since these difficulties were noted, the use of the absolute filter has been discontinued and the use of C.W.S. filters resumed, until a supplier can be found who can provide a filter that will meet with our requirements.

As moisture appeared to be the main cause of filter breakdown, several moisture tests have been conducted on various manufacturer's products which were available, using an apparatus designed for this purpose (include reports, photos, etc.).

Much of the discussion so far has been about primary filters. After the ventilation air has passed through the primary filters it is again subjected, in most cases, to further filtration before being discharged through stacks to the atmosphere. This is accomplished by several methods at the Hanford plant, including sand filters, fixed bed filters, and specially designed filter rooms containing banks of C.W.S. type filters.

No attempt is being made in this paper to discuss the merits of these final filters, however, a brief discussion of their construction and characteristics might not be amiss.

The sand filters are costly in construction, as usually a great deal of excavation and heavy concrete installation is necessary. The sand layers progress from very course at the filter intake, to fine grain at the outlet. The filter bed has to be of large area so that the velocity is kept at a minimum. High velocities would cause fluidization of the layers. The life of the filter bed is not actually predictable and the filtering sand cannot be replaced. When the sand filter has outlived its usefulness, it must be abandoned and a new one constructed. One of the advantages of the sand filter is that it requires no maintenance. Fixed bed filters consist of several layers of fiberglas in bulk of varying diameters and densities, progressing from course at the intakes, to fine at the outlet.

The beds are packed according to calculations. The advantages of this filter are that less area is needed than the sand filter and usually the initial pressure drop across the filter is less for the same amount of flow.

Both the sand and the fixed bed filters have been in use in the Hanford plant for a number of years. In one plant, the fixed bed filter had become plugged, reducing the flow to the point where something had to be done about it. Manually removing the contaminated filter bed is a tremendous job, and owing to the high degree of contamination, the very low time limits per man per day, and the number of men involved, makes it extremely costly. It was found by taking pressure drops across the four layers of varying sized fibers, that the three top layers, because of their finer texture, had collected most of the particles. It was decided to remove these three layers only. This cut the cost of replacement considerably as the time limit per man on the third layer was only three minutes and below that it would be down to seconds. The filter fiber had to be removed manually. Pitchforks were used and the material carefully placed in plastic bags for removal. Owing to the very short exposure time limits, a considerable number of men were required to perform this operation. Work of this nature is extremely costly. Very little is accomplished by each man and when exposed to the daily limit, in this case three minutes, his usefulness in any contaminated zone for the rest of the day is eliminated. In addition to the labor costs, the shutdown cost must be considered.

Prior to the above operation, the ventilation engineer had to take precautions against reversal of flows within the building affected, and also assist in preventing contamination spread in the area in which the work was being done.

The exhaust system in another building includes a set of nine large filter rooms. Each filter room has a bank of 112 or more C.W.S. filters. These filters have been in use for approximately five years. During this time, all filters in two rooms were changed. We have since initiated a program of vacuum cleaning the intake side of the filters, removing the lint collection, and thus prolonging the life of the filters. The replacement of these filters is comparatively easy. Neoprene curtains are provided to cover the intake and discharge openings, thus containing the dust particles loosened in handling in the filter room itself. The filters are removed and carefully placed in paste board boxes, sealed, and removed to the burial grounds.

The possibility of using this type of filtration, instead of sand or fixed bed filters for all final exhaust systems, is being presently investigated at the Hanford plant. This is contingent on finding a suitable fireproof filter. The filter rooms could be constructed above ground level, would be easily accessible, and means could be devised to change banks of filters by use of a crane. Standby rooms could be available so that plant shutdown would be avoided.

The ventilation engineer is vitally concerned with all types of filtration uses, as the plugging of filters, their replacement, and shutdown of systems all affect ventilation balances. Even the most insignificant filter has some effect on ventilation balance. The multitude of small filters used in closed process systems are of direct concern to him as they often control the number of air changes within a ventilated space and the differential pressures between the systems and surrounding areas.

Meanwhile, the search for the ideal filter continues.

A METHOD OF CHANGING ALPHA AND GAMMA CONTAMINATED FILTERS WITHOUT INTERRUPTING EXHAUST

by

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Remote Control Engineering Division

Argonne National Laboratory
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Abstract

This method consists of pushing a filter into its working position in a tunnel as an initial step and then pushing it on through with a new filter. Special gaskets on the filter keep it sealing the openings at all times. The seal is maintained during transfer into the disposal container. The transfer can be accomplished by remote operation using gamma shielding.

Introduction - The need for a simple mechanical method to change highly alpha and gamma contaminated filters is becoming more apparent as fabrication and reprocessing of reactor fuel is required. The possibility of higher gamma activity in the filter due to fire and methods of cutting and fabrication which generate small air-borne particles makes it necessary that the prefilters be highly efficient and possibly shielded. Details of the shielding of the filter housing and filter disposal container are not included in this paper. It is always desirable to maintain a radioactive area under a slight negative pressure which means an uninterrupted exhaust. Filters which can be changed without shutting off the blowers and without losing filtration of the exhaust air are desirable.

The one way push-through method requires a continuous tunnel so that filters are inserted successively on one end only and pushed through the tunnel by the following clean filter to the collecting end (the container). The working position is intermediate between the ends of the tunnel. At the working position, the contaminated air is collected in the filter as the air passes from an upper plenum to a lower plenum. A seal is maintained on the openings of the tunnel by each successive filter. The air is filtered at all times during the transfer.

A mockup was set up, using the 24" x 24" x 12" AEC filters. In most installations the new high efficiency glass media filters of the same size

will be used particularly where a fire hazard exists or chemical elements are injurious to the filter media. Experimental testing of the mockup was required to study the following problems. It was important to observe the physical characteristics of the seal in operation and also to determine the optimum deflection of the seal. The effectiveness of the seal and the force necessary to propel filters through the tunnel was also information desired from the mockup.

Design - The filter with its seal and a typical metal container are shown in Fig. 1. The ring gasket with 1 inch radius corners mounts to the top and bottom of the wooden filter frame. This gasket seals on the upper and lower plates of the tunnel.

The main section of the seal material[a] is a 5/8" diameter neoprene covered sponge rubber core. The round section has a mounting leg of wire and cord mesh covered with neoprene. This mounting leg is 1/16 inch thick and extends about 1-1/8 inches from the center of the 5/8 inch diameter. The wire mesh leading into the sponge rubber center gives the gasket some support. The seal material is very smooth on the outer surfaces.

The wooden frame of the filter was notched on a shaper at the outer edges with 1 inch radius at the corners. The continuous gasket vulcanized at the joint was cemented into the recess and a steel strap tightened over the mounting leg. Wood screws fastened the steel at 4 inch intervals. Aluminum support strips were placed on the leading and trailing edges to support the 5/8 inch diameter section. This support is especially needed while passing the opening at the working position.

Another advantage of this sealing material is the great deformation of the seal without substantial increase in the sealing force. The seals and sliding surfaces are coated with a Silicone Pneumatic grease.[b] The wiping force is thus held to a minimum. The seal due to its flexible neoprene skin seems to conform to irregular surfaces maintaining a seal without ground or honed surfaces. The seals are compressed about 1/8" for best wiping and sealing action.

Figure 2 shows the experimental setup with the clean filter at the left ready to push the dirty filter on through to the right into a container not shown. The hydraulic ram pushing on the clean filter propels the dirty filter into a container attached as shown in Fig. 3.

The container to receive the filter is bolted to the tunnel. The container can be shielded. The bolts to mount the container can be operated by long-handled wrenches through the back end of a shielding pot. The cover to the container would be fastened to the sliding gate of the shielding pot and after loading of the container, it would be lowered in front of the container. The same bolts would then be used to fasten the cover on the container. During this sealing of the container, the filter is sealed by the top and bottom of the container--but there will be suspect contamination in the grease.

[a]Bridgeport Fabrics Company, Bridgeport, Conn. (Catalog #HD-604N-1).
[b]USAF 3515 Spec. MIL-G-4343 Dow Corning Corporation, Midland, Michigan.

The ring gasket, top and bottom mounted to the filter frame, seals on the upper and lower plate of the tunnel. The gasket on the leading edge of the clean filter and the gasket section on the trailing edge of the dirty filter come together to form one wiping seal as they travel over the openings in the upper and lower plates. The air to be filtered enters the filter at the top and is exhausted at the bottom. The contaminated particles on the top side of the filter cannot fall off onto the track during transfer. The wooden sides of the filter are roughly guided just below the center so that the rounded cross section of the gasket riding in the apex of the corner is uniformly deformed. Tests show it required a maximum force of 500 lbs. to move the two filters through the tunnel. The surfaces of contact and the seals are coated with a grease to reduce friction and to fix contamination which is spread by the wiping action of the seals.

Testing - The following experimental tests were conducted: the burning of uranium to test the spread of contamination; fluorescent powder was used to observe the wiping action of the seals; and leakage tests on the seals were attempted.

The filters used in the leakage test are only available with a wooden frame. Testing of the filter seals was attempted in the tunnel but the wooden frame, even after coating with paraffin, was too porous. A metal container inserted in the tunnel, open on the top with a seal similar to the upper seal of the filter, held 42 inches of water pressure for a few hours testing without loss. The seal, compressed 1/8" on the rough ground stainless steel plates, was considered sufficient for the present filters. The filter leakage, of course, will be offset by the negative pressure established by the blower which should be operating during the filter change.

Using the hood to the left of the upper plenum of the mockup (Fig. 2), a test was made burning 150 grams of uranium while drawing 200 to 250 cfm of air through the filter and hood. The background air tests showed a little over one microgram of uranium per cubic meter. The air count during the burning and during the filter push through into the container remained the same as background. The air suction tube for this test was placed under the parting line between the tunnel and the attached container. Smear tests were made on the top leading edge of the test filter gasket before and after the uranium burning. The contamination increased from 2 to 136 micrograms of uranium. A smear test across the top leading edge gasket of a second filter unit, pushed through the working position on out so that a smear could be taken, measured 144 micrograms. The smear test on the bottom front edge of the receiving container showed no gain in contamination when tested before and after the push through. This showed that the filter did a good filtration job and the lower plate was not contaminated. We would conclude that some contamination was spread by the wiping action of the seal but was fixed in the lubricating grease. Contamination did not escape at the joint between the tunnel and the container. Smears made on the inner sides of the container before and after the uranium burning showed no increase as a result of air displacement by the filter insertion.

To further test the efficiency of the wiping seal, a 1" x 24" strip of yellow fluorescent powder was applied to the lower plate of the mockup about 8 inches from the opening toward the clean end. Using a black light detector, after passage of the first filter unit, it was observed that the powder had been spread from the original one-inch wide band to a three-inch wide band about one third the original brilliancy. None of the powder was detected as having fallen into the opening; the powder that was picked up by the wiping action of the seal was retained in the grease. A second filter passed through picked up very little of the powder and did not visibly spread the band. As with the uranium burn test, we conclude that the contamination that was spread by the wiping action of the seal was contained in the grease and would not fall out when passing over joints or openings.

Conclusions - This method of filter changing can be done in a fairly short period of time compared to some of the cover taping and bagging methods now being used. It can be adapted to remote control because of the simple load and push through feature which might have to be done behind gamma shielding. The greased seal contains the contamination during the wiping action. With the exhaust operating at all times during the change, the chance for the spread of contamination in the handling area is kept at a minimum. All leakage is into the exhaust as our wooden filter frames are not well sealed. The filter will, of course, be sealed in the container during transfer to processing or disposal areas.

Acknowledgment - The authors are grateful for the cooperation of members of the Remote Control Engineering Division, especially Hubert Judkins for his work in the assembly and testing of the push-through filter change mockup. The uranium burning experiments were directed by Donald P. O'Neil of the Industrial Hygiene & Safety Division, who also helped in evaluating the merits of the proposed method.

Fig. 1. Container and Filter with Ring Gasket Top and Bottom.

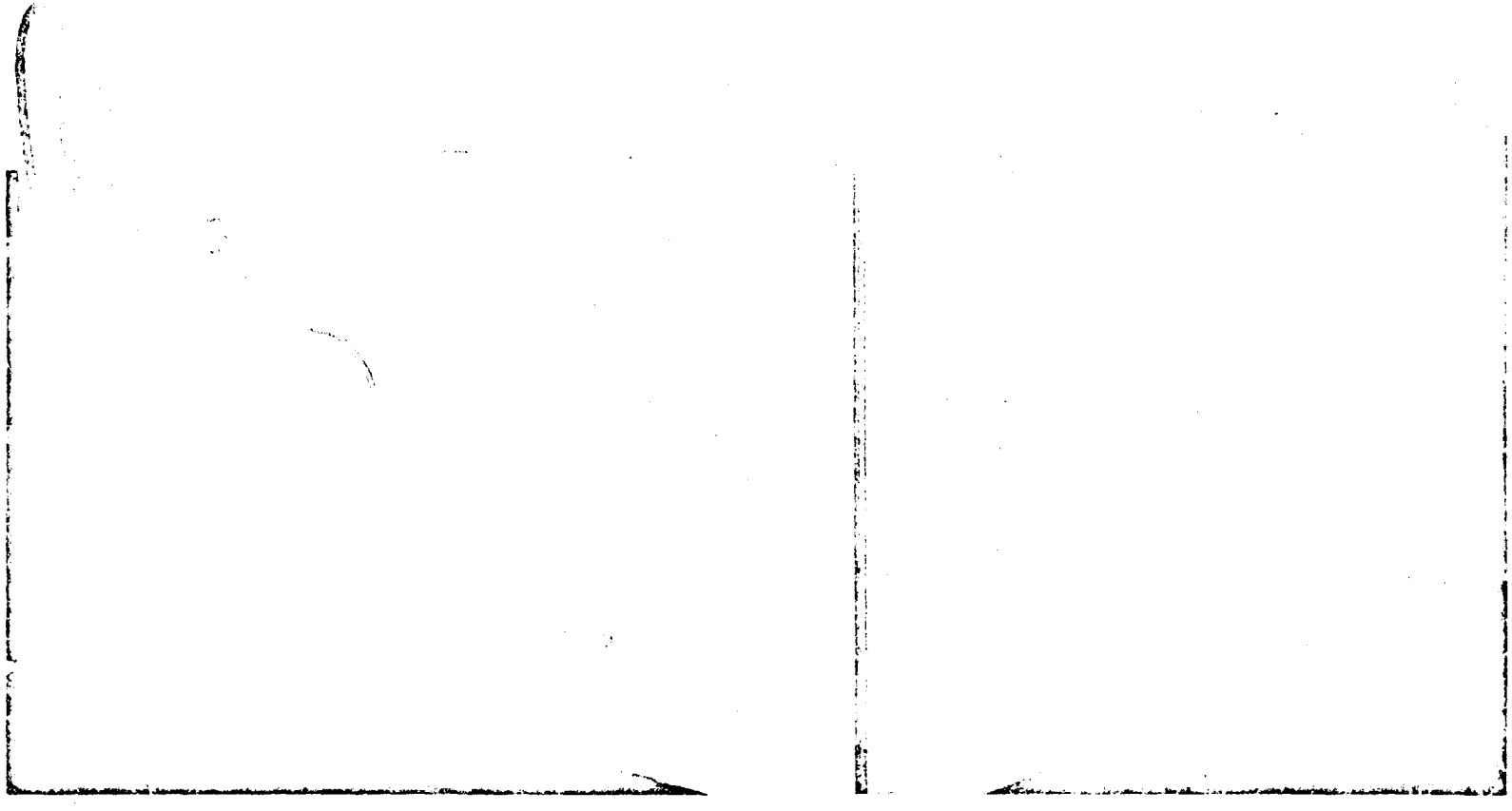

Fig. 2. Mockup of Push Through Filter Change Method for High Level Caves.

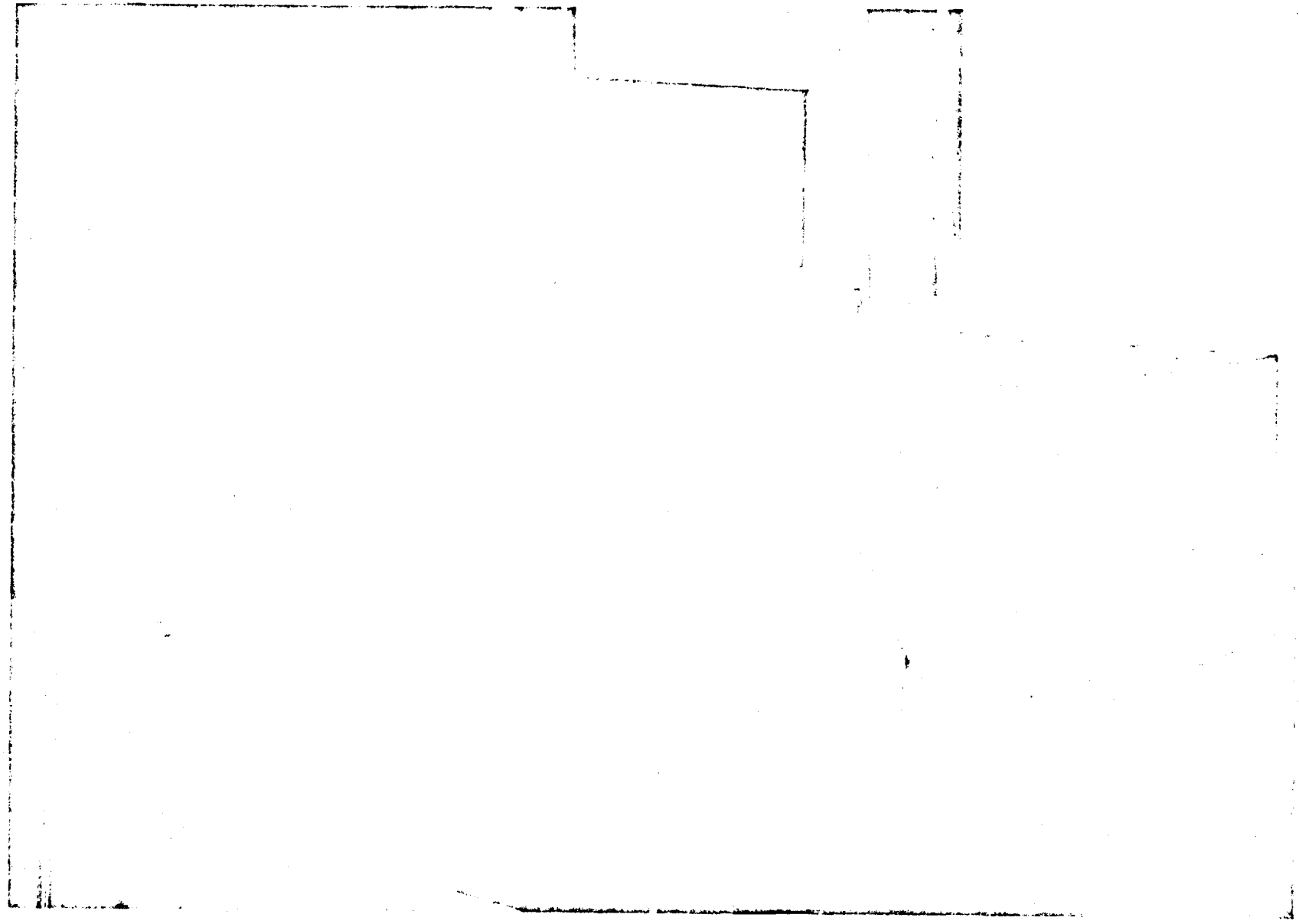

Fig. 3. Container for Contaminated Filter Attached to Mockup for Push Through Filter Change Method.

COLLECTION EFFICIENCY OF AIR CLEANING AND AIR SAMPLING FILTER MEDIA IN THE PARTICLE SIZE RANGE OF 0.005 to 0.1 MICRON

J. J. Fitzgerald

C. G. Detwiler

Abstract

The Hollingsworth and Vose-70 filter medium and the air cleaning filter media, (CC-6, MSA-1106-B, AEC-1) tested in these experiments are significantly more efficient in the collection of submicron particles than the Whatman-40 and 41 filter papers. However, with a proper selection of the face velocity, relatively high collection efficiencies can be achieved even with the use of the Whatman filter papers.

In these filter efficiency studies, all air sampling filter media investigated were more efficient for the collection of liquid $KMnO_4$ particles in the size range of 0.01 to 2.1 microns than for corresponding sizes of solid duraluminum particles.

In the size range of 0.005 to 0.1 micron, the Whatman-40 and 41 filter papers are more efficient in the collection of solid duraluminum particles than in the collection of $KMnO_4$ particles.

The optimum particle size for penetration through air cleaning and air sampling filter media was detected or indicated in each of the studies conducted. The optimum particle sizes for penetration through Whatman-40 and 41 filter papers occurred at approximately 0.03 and 0.02 microns, respectively at a velocity of 150 cm/sec (the minimum efficiency under these conditions was 90%). These results are in good agreement with the theory of Davies and Green.

Introduction

Chemically toxic and radioactive particles and gases may of their very essence emanate from mechanical, chemical and reactor operations in an atomic energy laboratory. At the Knolls Atomic Power Laboratory, an air cleaning and air sampling program* was initiated to provide adequate cleaning of the laboratory air and the air discharged to the environs. Particles emanating from laboratory operations are collected in a variety of air cleaning equipment such as electrostatic and cyclone precipitators, caustic scrubbers, and Dustop and high efficiency filter units. A total of 475,000 cfm of laboratory air is cleaned prior to discharge to the environs. High efficiency air filter units (predominantly CWS-6) clean 80% of the filtered air discharged in the environs. To assure adequate control of air-borne material and the proper operation of air cleaning equipment, 20,000 air samples are taken yearly and analyzed for their chemically toxic and radioactivity content.

Whatman-40 and Hollingsworth and Vose-70 filter papers are used to collect chemically toxic (beryllium) and radioactive particulate material, respectively in the Laboratory and the environs. Cascade impactors, electrostatic and thermal precipitators and Millipore Filters have been used to determine the particle size distribution of materials emanating from operations in the metallurgy, chemistry and physics laboratories at KAPL. These particle size distributions have included analyses of the particles under a light and an electron microscope.** Autoradiographic studies have been conducted using a stripping film technique** to evaluate the size distribution of radioactive particles in a heterogenous mixture of radioactive and non-radioactive particles.

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* KAPL-1014, KAPL Air Cleaning Program, L. J. Cherubin, J. J. Fitzgerald.

** KAPL-1015, Evaluation of the KAPL Separations Process Stack Effluent, J. J. Fitzgerald.

An evaluation of the effectiveness of an air cleaning program requires not only a knowledge of the particle size distribution but also the efficiency of the filter media used to collect these particles. To provide an adequate evaluation, one must know the collection efficiencies of the filter media primarily as a function of the particle size, particle velocity in the air stream and the type of particles used. In an earlier report by Fitzgerald and Detwiler,* collection efficiencies were determined for the H-70, W-40, W-41, CC-6, MSA-1106-B and AEC-1 filter media in the particle size range of 0.1 to 2.1 micron at face velocities of 0.5 to 150 cm/sec using a duraluminum aerosol. This study in itself was not adequate for a complete evaluation of the filter media. A complete evaluation of a filter medium requires a knowledge of the collection efficiency in the size range of 0.005 to 0.1 micron for the following reasons:

1. The majority of the particles in the air, upon which radioactive material may be deposited, are in this size range.**
2. The average particle size emanating from the KAPL separation process operation was 0.05 micron.***
3. The maximum penetration of particles, theoretically, occurs in this particle size range when the particle velocity is greater than 1 cm/sec.****
4. There is no doubt that particles in this size range will be retained with relatively high efficiency in the aveolar from Brownian movement in the respiratory system.*****

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* Fitzgerald, J. J., and Detwiler, C. G., "Collection Efficiency of Air Cleaning and Air Sampling Media", American Industrial Hygiene Association Quarterly, June 1955

** Wilkening, M. H., Natural Radioactivity as a Tracer in Sorting Aerosols According to Mobility. Review of Scientific Instruments, Vol. 23 No. 1, Jan. 1952.

*** KAPL-1015, Evaluation of KAPL Separations Process Stack Effluent, J. J. Fitzgerald

**** Proc. Inst. Mech. Engr. (London), B 1 185 (1952) pg 203, H. L. Green

***** Brit J., Industr. Med., 1952, 9, 120, C. N. Davies, "Dust Sampling and Lung Disease."

In this report the following experimental results will be discussed:

1. The collection efficiencies of air sampling (W-40, W-41 and H-70) and air cleaning (CC-6, AEC-1 and MSA-1106-B) filter media in the particle size range of 0.005 to 0.1 micron will be presented.
2. The theoretical and experimental optimum particle sizes for penetration through the filter media will be discussed.
3. A comparison will be made of the efficiencies obtained using atmospheric dust, solid duraluminum and liquid $KMnO_4$ aerosols.

Discussion of Parameters Affecting Filter Efficiency

Theoretically, aerosols are collected in fiber filter media by several methods; inertia, interception, electrostatic forces, settling, and diffusion. These factors have been discussed in detail in many reports.* For a given fiber radius or standardized filter medium, the filter efficiency is predominantly a function of the particle size and the velocity of the particle in the air stream for a specific aerosol. In some instances, the electrical charge of the fiber and the aerosol may have a significant effect on the collection efficiency. The collection efficiency of a filter medium varies with particle size and face velocity in the manner presented in Table 1.

Table 1. Variation of Collection Efficiency with Particle Size and Face Velocity

Collection Efficiency Parameters	Relationship of Particle Size, Dp and Face Velocity, v with Collection Efficiency E
Inertial Impaction	$E \sim v\, D_p^2$
Direct Interception	$E \sim D_p$
Electrical Attraction by Charges	$E \sim (v\, D_p)^{-1}$
by Induction	$E \sim v^{-1}\, D_p^2$
Diffusion	$E \sim (v\, D_p)^{-1}$
Gravitational	$E \sim v^{-1}\, D_p^2$

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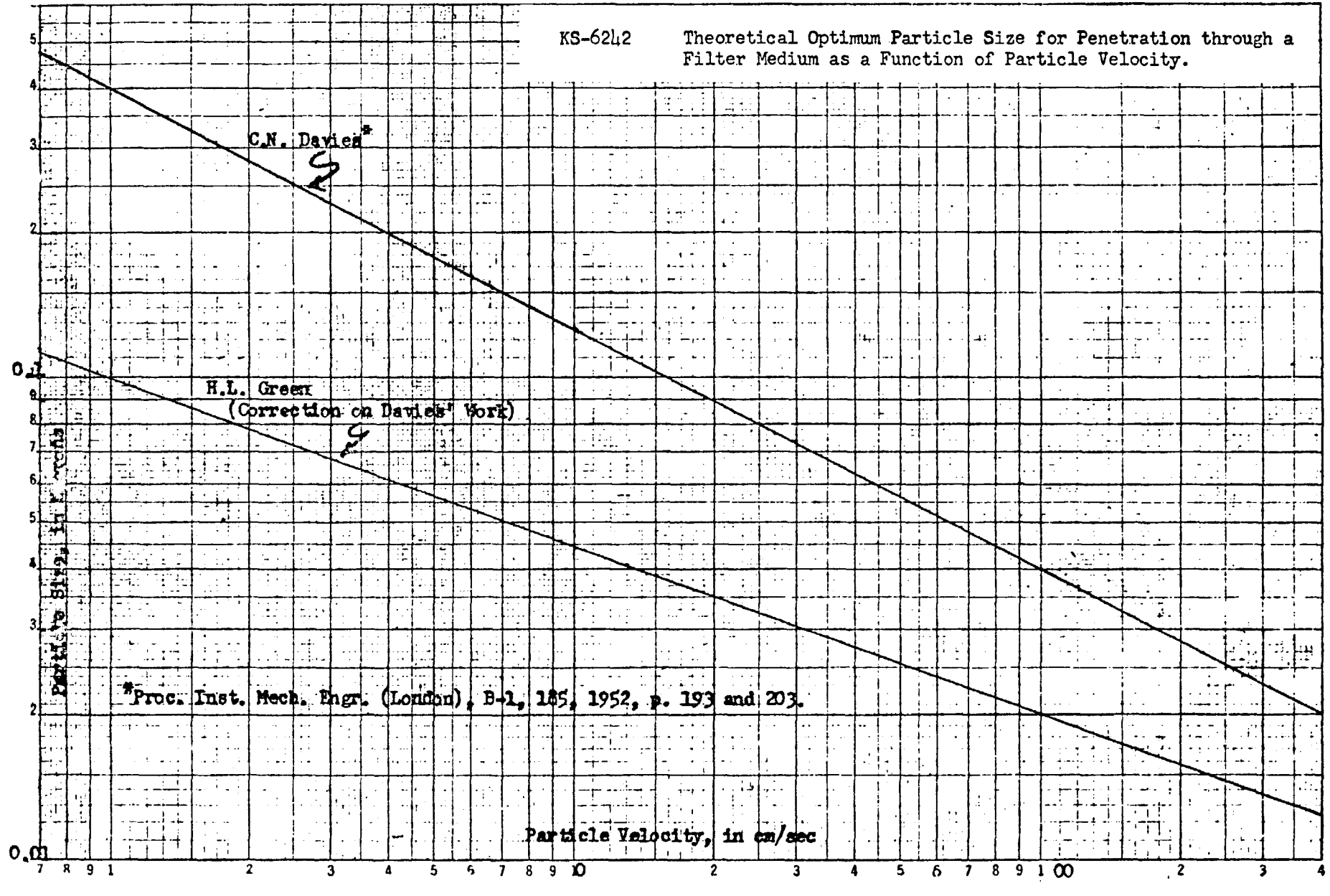
* NYO-512, Studies on Filtration of Mondispersed Aerosols, V. K. La Mer

NYO-1594, Electrostatic Mechanisms in Fiber Filtration of Aerosols, A. T. Rossano, Jr., L. Silverman.

Handbook of Aerosols, U. S. AEC Washington, D. C., 1950, Chapter 9, Filtration of Aerosols, W. H. Rodebush.

SO-1004, The Impaction of Aerosol Particles on Cylindrical and Spherical Collectors, W. E. Ranz.


KS-6242 Theoretical Optimum Particle Size for Penetration through a Filter Medium as a Function of Particle Velocity.
C.N. Davies*
H.L. Green
(Correction on Davies' Work)
*Proc. Inst. Mech. Engr. (London), B-1, 185, 1952, p. 193 and 203.
Particle Size, in Microns
Particle Velocity, in cm/sec
0.01
0.1
1
2
3
4
5
6
7
8
9
10
100

For large particle sizes and high particle velocities, the inertial impaction parameter is an important factor in determining the total efficiency of the filter medium. For small particle sizes and low particle velocities, the diffusion parameter becomes an important factor in determining the total efficiency of the filter unit for the collection of the particles. Collection by direct interception is independent of particle velocity and depends fundamentally on the ratio of the particle size to the filter fiber size. Collection by gravity is important when the particle size is large and the particle velocity is small.

Several theories based on these relationships have indicated that each filter medium will yield a point of maximum penetration for a certain particle size at a given face velocity. This theory of maximum penetration evolves from the fact that for a given particle velocity, fiber size (or filter media) and test aerosol, the efficiency of collection by the diffusion mechanism increases with a decrease in particle size whereas the efficiency for collection by inertial impaction and direct interception decreases with a reduction in particle size. Perhaps, the most recent and complete theory has been promulgated by C. N. Davies. In his theory, the optimum particle size, D_p in cm for a maximum penetration through a given filter medium at a specified velocity of v, cm/sec may be approximated in Equation (1).

$$D_p^2 v = 4 \times 10^{-9.4} \qquad (1)$$

In a review of Davies' Theory, H. L. Green pointed out that using Davies' final equation, the optium penetration sizes did not occur at the above relationship. The optium penetration sizes using Equation (1) and the corrected values of Green are given in Figures KS-(1).

Davies' Theory did not consider the gravitational and electrostatic parameters in the determination of the optimum penetration size. In general, the contribution of these parameters in the total collection of particles is negligible for the particle sized and velocities considered. However, the electrostatic effects of some aerosols and filter medium may be sufficient to alter substantially the optimum penetration sizes as stated by Davies and Green. In the final analysis, the experimental determination of the optimum penetration sizes is of greatest significance at this time until more reliable assumptions can be made with respect to theoretical considerations.

Experimental Procedure

Test Aerosol

In previous studies,* duraluminum was used as the test aerosol for determining filter efficiencies in the particle size range greater than 0.1 micron in diameter. The duraluminum aerosol concentration was too low, however, to permit the production of satisfactory electron micrographs for studies in the particle size range of 0.005 to 0.1 micron in diameter. General atmospheric dust was found sufficiently abundant to use as the test aerosol for some of the less efficient filters. The general atmospheric dust concentration in the particle size range of 0.1 to 2.1 microns was approximately one order of magnitude greater than the duraluminum aerosol concentration but was too low for satisfactory electron micrographs in the air cleaner filter efficiency studies in the lower particle size range.

An effort was then made to produce a highly concentrated and suitable aerosol with respect to particle density, detection under the light microscope, physical state and particle shape. Lauterbach's improved aerosol generator** was modified by increasing the size of his aerosol generation chamber to 13 inches in diameter. With this modification, and with the use of a saturated solution of $KMnO_4$, the aerosol concentration was approximately three orders of magnitude greater than when duraluminum was used. Suitable electromicrographs for the filter efficiency studies in the sub-micron size range were obtained with the $KMnO_4$ aerosol.

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* Fitzgerald, J. J., and Detwiler, C. G., "Collection Efficiency of Air Cleaning and Air Sampling Media," American Industrial Hygiene Association Quarterly, June 1955.

** UR-377, "An Improved Aerosol Generator," by K. E. Lauterbach, et al, July 12, 1955, p. 4-6.

The modified $KMnO_4$ aerosol generator is shown in Figure KS-4911. The letter "A" designates the aspirator and aerosol production chamber. The $KMnO_4$ reservoir is located at "B". The operating principles of this aspirator type aerosol generator are described in detail by Lauterbach, et al, in UR-377*. With a saturated $KMnO_4$ solution, the generator produced 1.1 x 10^9 particles/ft^3, as determined with light microscope. The particle size distribution was characterized by a geometric mean size of 0.3 micron and a geometric standard deviation fo 1.9; based on light microscope particle size measurements.

Standard Filter Sample Collection

The aerosol was released into the test equipment illustrated at "A" in Figure KH-9A 1064. The particles larger than approximately three microns in diameter were collected on the impaction plate at "C", and the particles less than three microns passed into chamber "F". The details of this system were reported in KAPL-1088 and the American Industrial Hygiene Association Quarterly.**

Equal quantities of the test aerosol were taken isokinetically from the aerosol chamber at sampling ports, "H". The fractions of the test aerosol taken at the sampling ports, "H" were shown experimentally to be equal within the statistical limits of the procedure.

Referring to Figure KS-2714, the filter under test was held between flanges at the right of "B". The desired face velocity for each filter efficiency test was obtained by the insertion of retainer rings between the test filter flanges. The retainer rings had aperatures which varied in diameter, (from 0.46 to 6.52 cms) depending on the desired face velocity.

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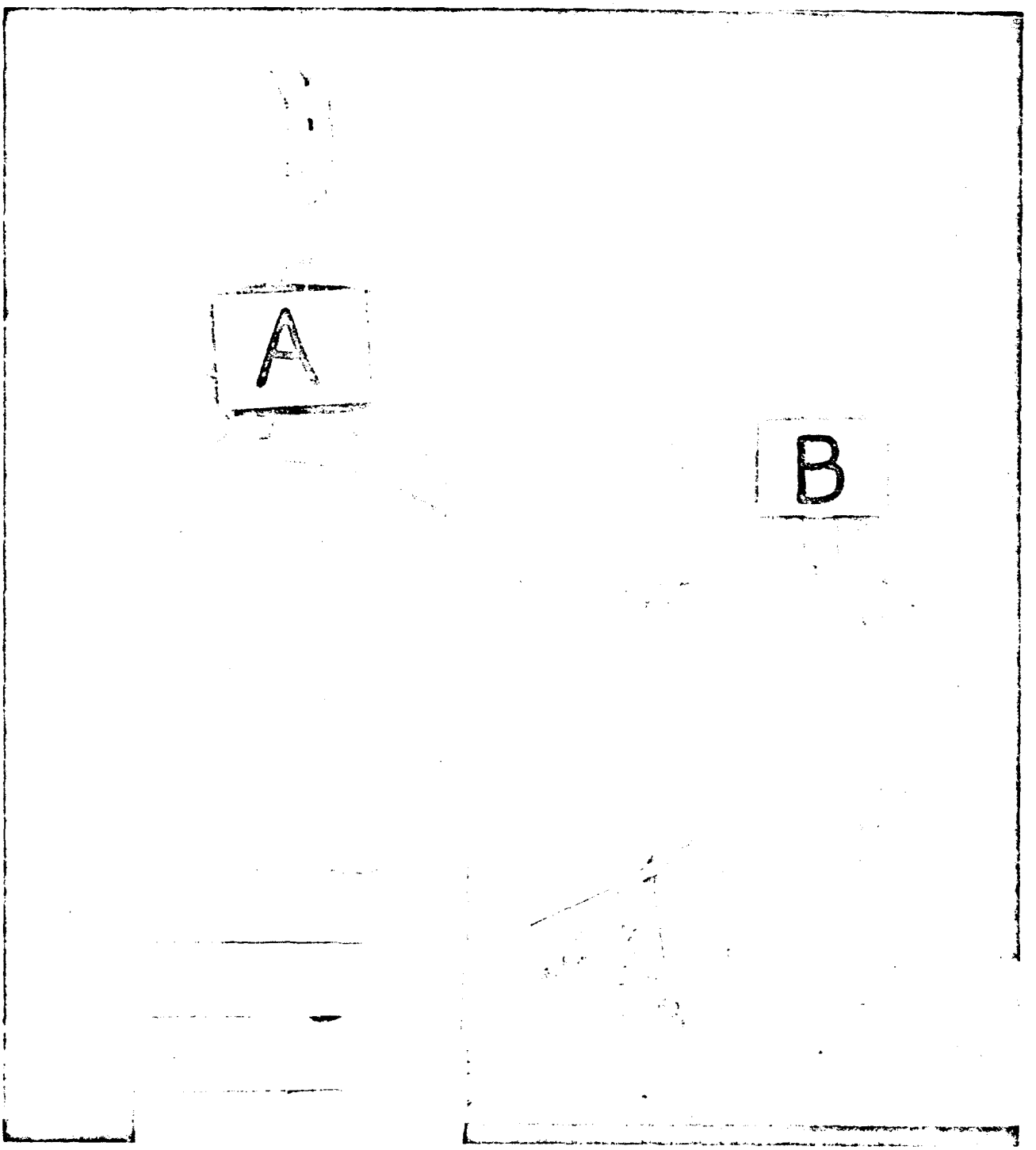
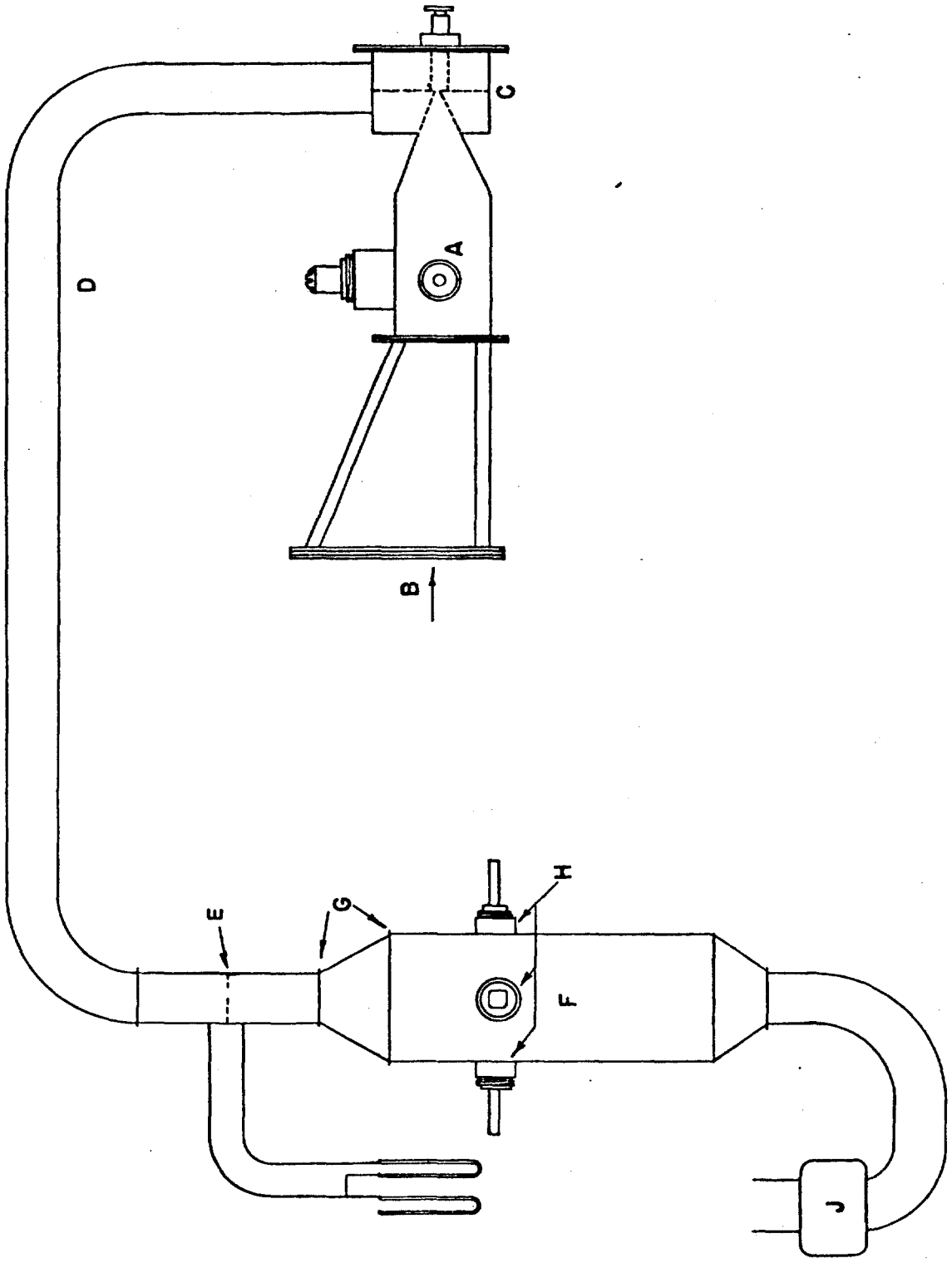
* UR-377, "An Improved Aerosol Generator," by K. E. Lauterbach, et al, July 12, 1955, pg. 4-6.

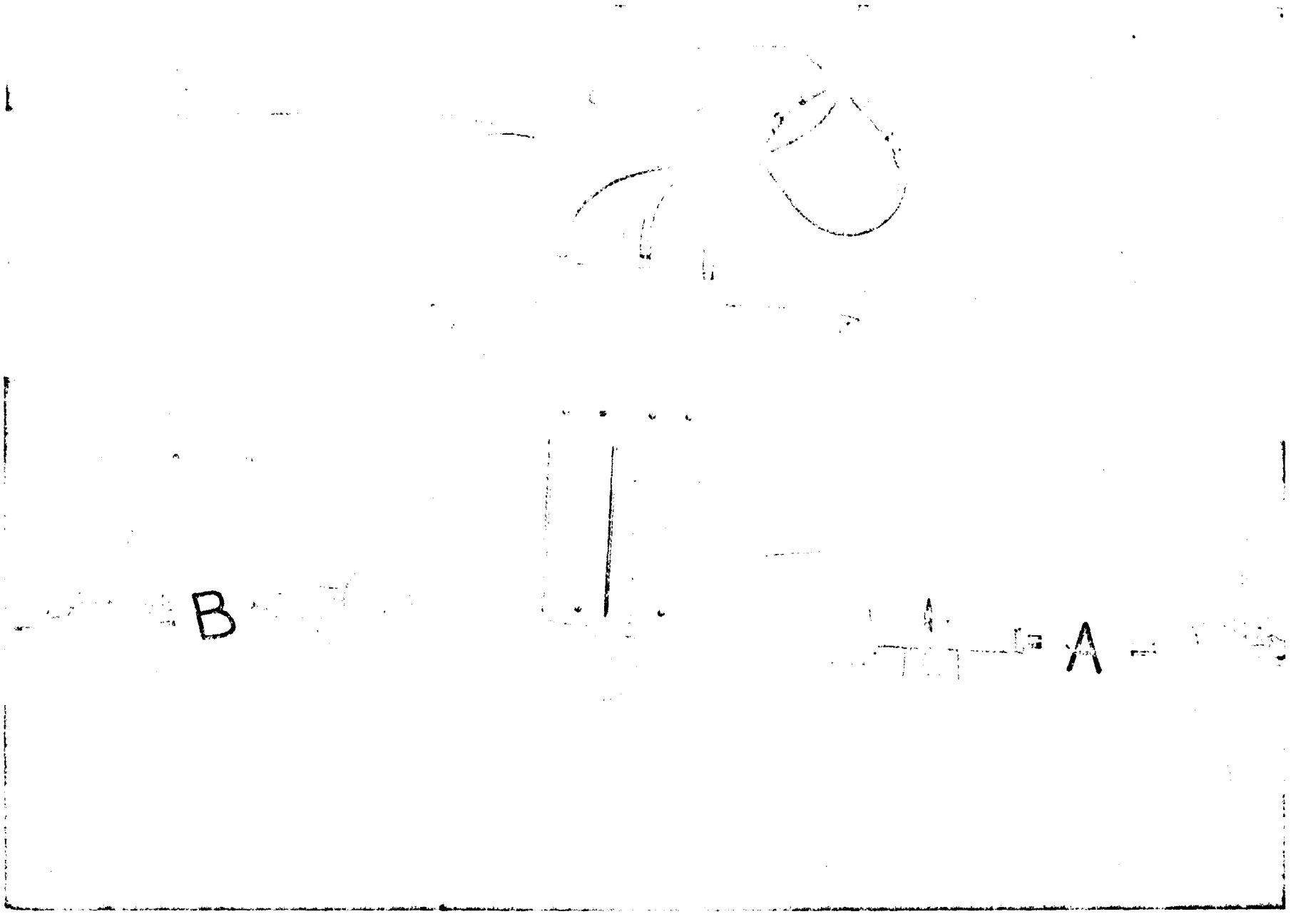
** Fitzgerald, J. J. and Detwiler, C. G., "Collection Efficiency of Air Cleaning and Air Sampling Filter Media," Am. Ind. Hyg. Ass'n. Quarterly, Vol. 16, No. 2, June 1955.



KS-4911 Modified $KMnO_4$ Aerosol Generator



KH-9A1064 Schematic Diagram of Test Unit



KS-2714 Aerosol Chamber

In these experiments, the size of the aperatures was varied while the flow-rate was held constant. The aerosol sample drawn into the standard filter (Type HA, Millipore Filter) at the right of "A" was equal to the aerosol sample exposed to the test filter. The standard filter to the left of "B" collected the aerosol that passed through the test filter. A comparison of the aerosol collected on the two standard filters permitted a determination of the particle collection efficiency of the filter under test.

Sample Analysis

The filter efficiency evaluations were accomplished in two phases. In the first phase, the particles deposited on the standard filter papers were analyzed under the light microscope. This phase involved the collection efficiency determinations of the filter media in the particle size range of 0.1 to 2.1 microns. In the second phase of these filter efficiency studies, the particles in the size range of 0.005 to 1.0 micron deposited on the standard filter papers were analyzed under an electron microscope.

In the light microscope phase of the evaluation, the Millipore Filter is impregnated with microscope immersion oil, which renders the filter transparent. A cover glass is placed over the sample and a standard size count is made. A comparison of the upstream and downstream size counts, corrected for scanning area, then yields the particle collection efficiency of the test filter for particles in the light microscope size range.

In the electron microscope phase of the efficiency evaluation, the Millipore Filter was treated for a size analysis by a silica replication* technique.

In the Silica Replication Method, the silica film is deposited on the filter by the rapid evaporation in a 0.1 micron vacuum of approximately 1.3 mg. of silicon dioxide or silicon monoxide from a coil tungsten filament. The filter is placed 10 cm. from the filament and normal to it. The evaporation must be done rather rapidly to avoid damaging the filter by the heat from the filament. Small pieces of the coated filter are then placed on microscope specimen screens, with the silica film in contact with the screen. The microscope specimen screen is placed on a 100 mesh screen forming a low table in a depression of a spot plate. Acetone

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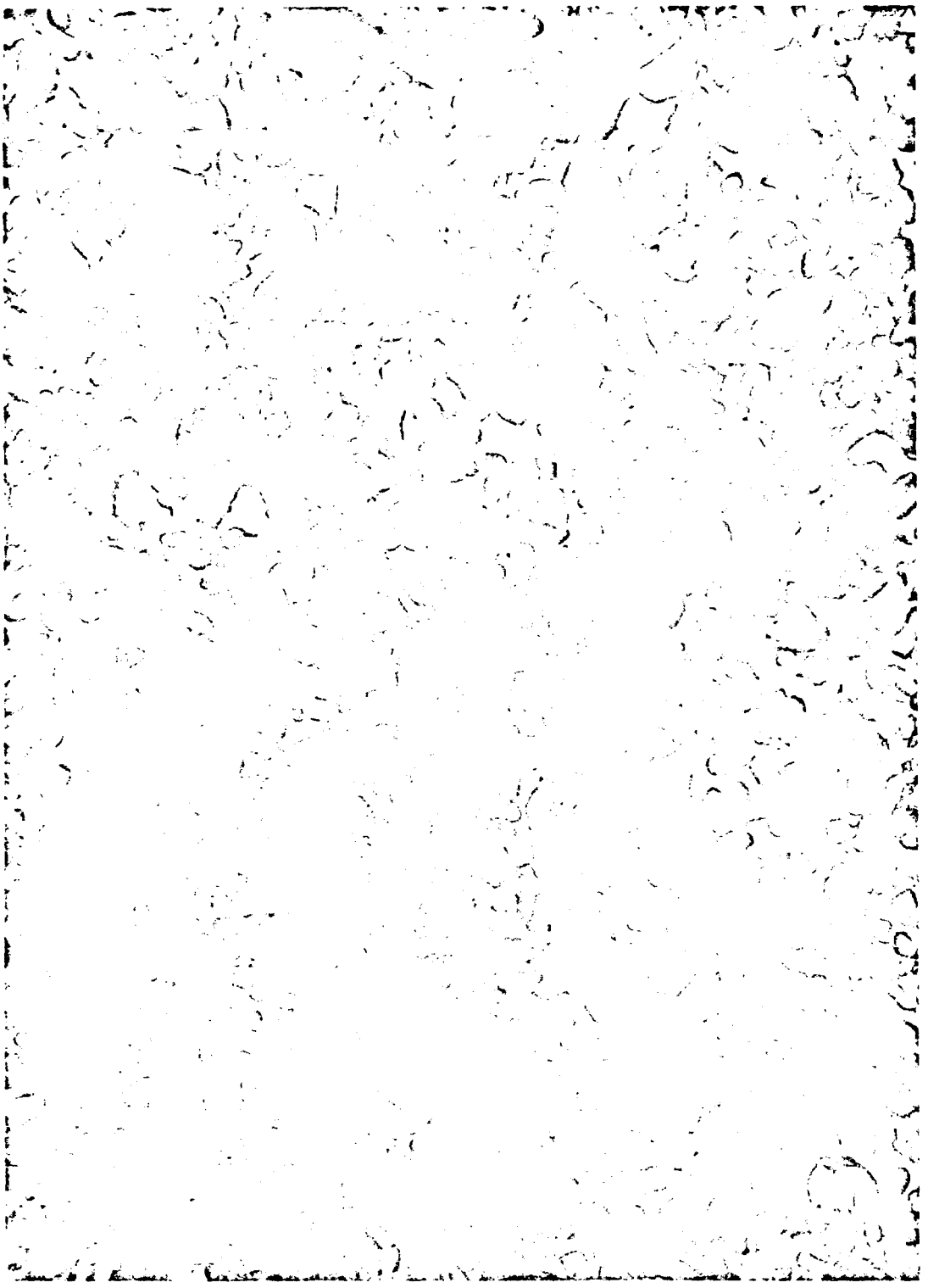
* KAPL-863, Semiannual Progress Report of Radiological Development Activities in the Health and Safety Unit, July - December 1952.

is placed under the table from a capillary pipette until the level of the liquid reaches the top of the table but does not cover the specimen screen holding the sample. Capillary action carries the acetone up to the filter. The level of acetone is maintained until the filter is dissolved.

Electron micrographs are made from the silica replicas after selecting fields representative of the particle size distribution and concentration. Size counts are made from the electron micrographs. The data are analyzed in the same manner, as the light microscope data were treated to establish the particle collection efficiencies.

It was necessary to determine the particulate background on unexposed Millipore Filter papers prior to determining the significance of submicroscopic particles shown on the electron micrographs of Millipore Filters exposed to the atmosphere. An electron micrograph of an unexposed on control Millipore Filter is shown in Photograph 1121212. The surface of the filter paper is shown in replica form with a magnification of 15,000.

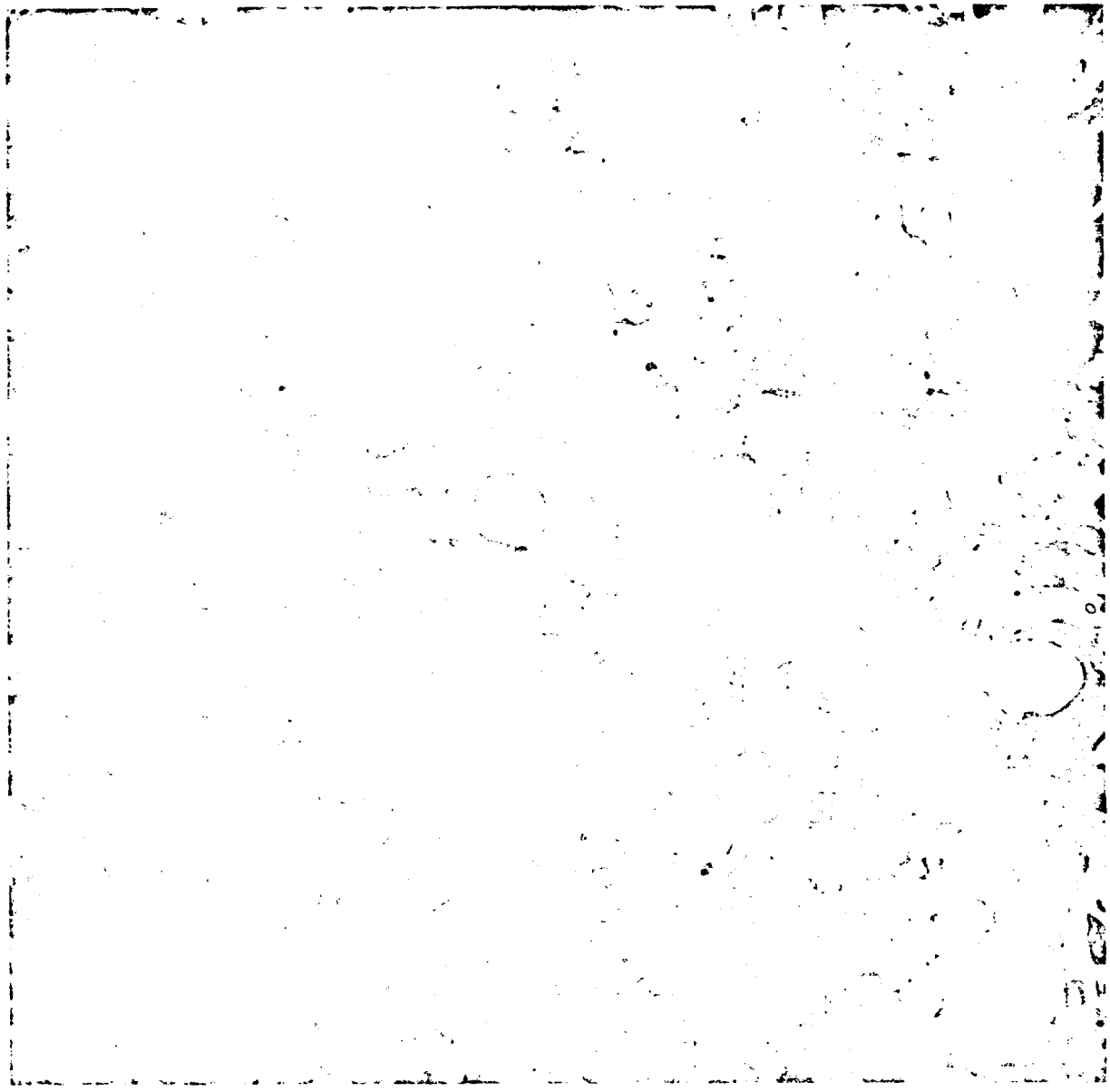
An electron micrograph of a Millipore Filter paper exposed to atmospheric test dust is shown in Photograph 1122162. The magnification is 20,000 and particles down to 0.005 micron are readily discernible even with the obstructing background. Some of this background, however, can be eliminated as shown in Photograph 1122161. There appears, however, to be some variation in the surface structure of the Millipore Filters which permits the reduction of the obstructing background rather than a variation in the technique applied in the preparation of the electron micrograph.



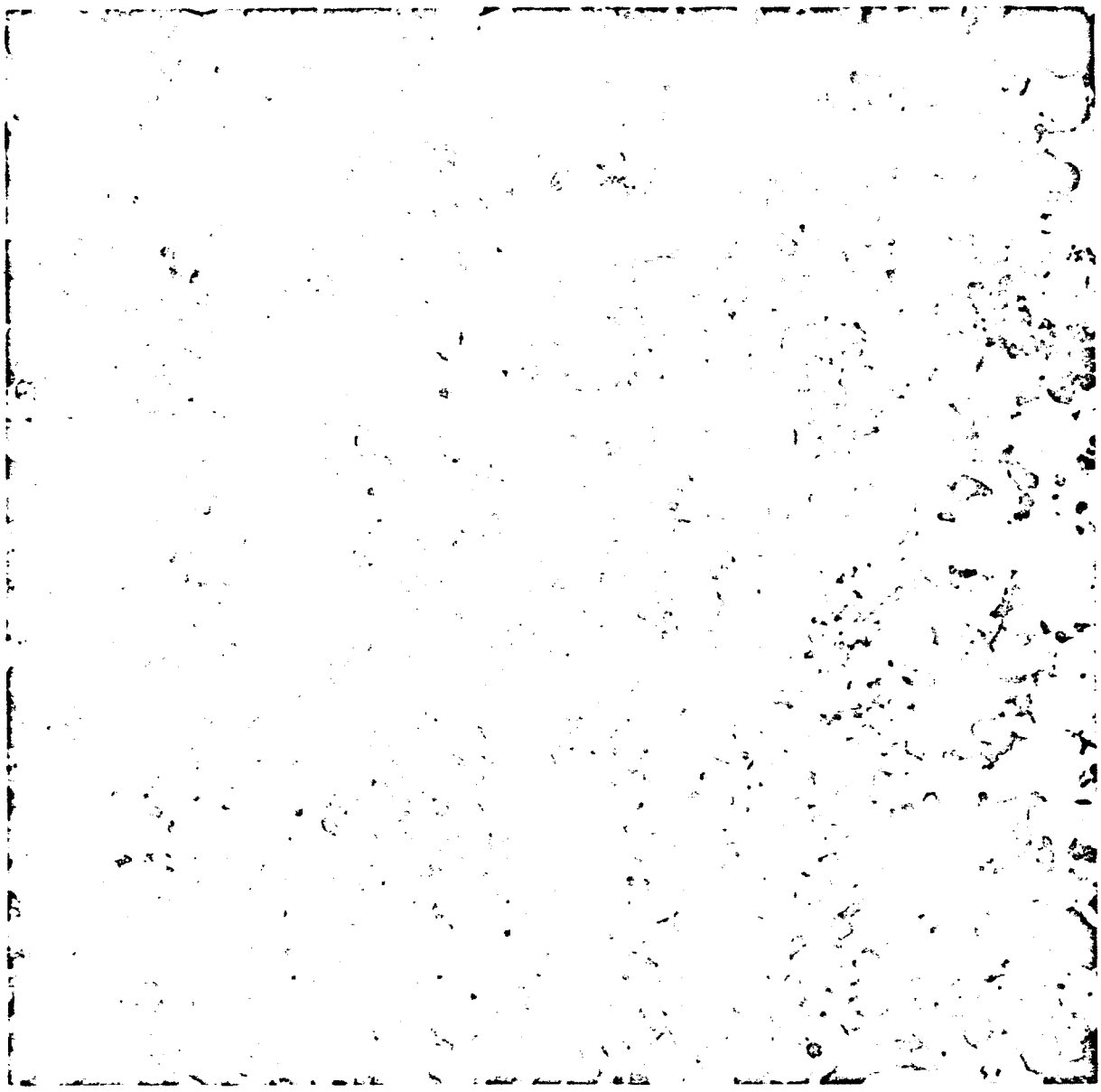
1121212

MILLIPORE FILTER UNEXPOSED-CONTROL FILTER

Magnification - 15000 Scale 0.5 micron



1122162
Millipore Filter, Type HA
Sample from downstream side of W-40 test filter
Magnification, 20,000X
Method of analysis, silica replication
Scale, 1 mm = 0.05 micron



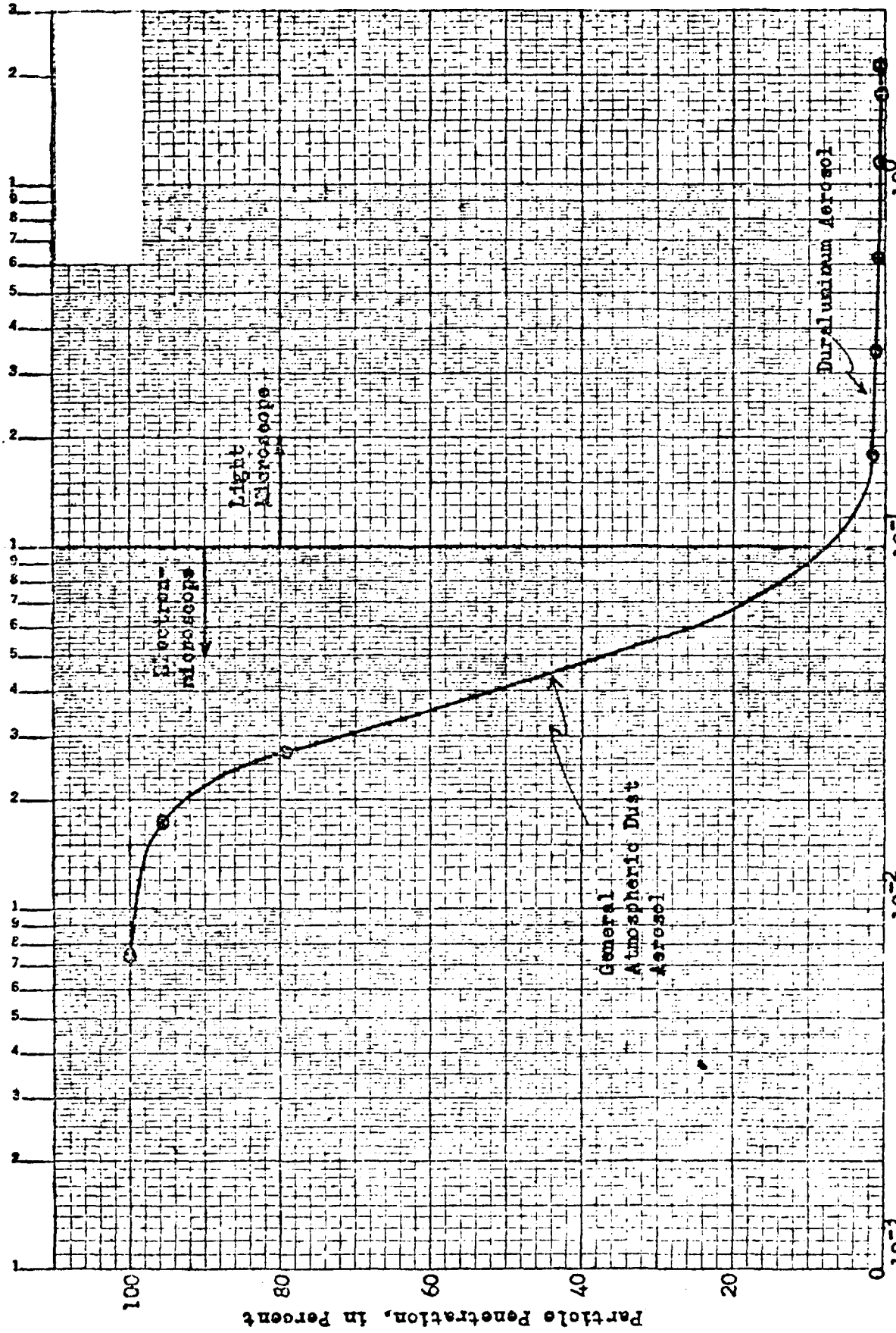
1122161
Millipore Filter, Type HA
Sample from upstream side of W-40 test filter
Magnification, 20,000X
Method of analysis, silica replication
Scale, 1 mm = 0.05 micron

EXPERIMENTAL RESULTS

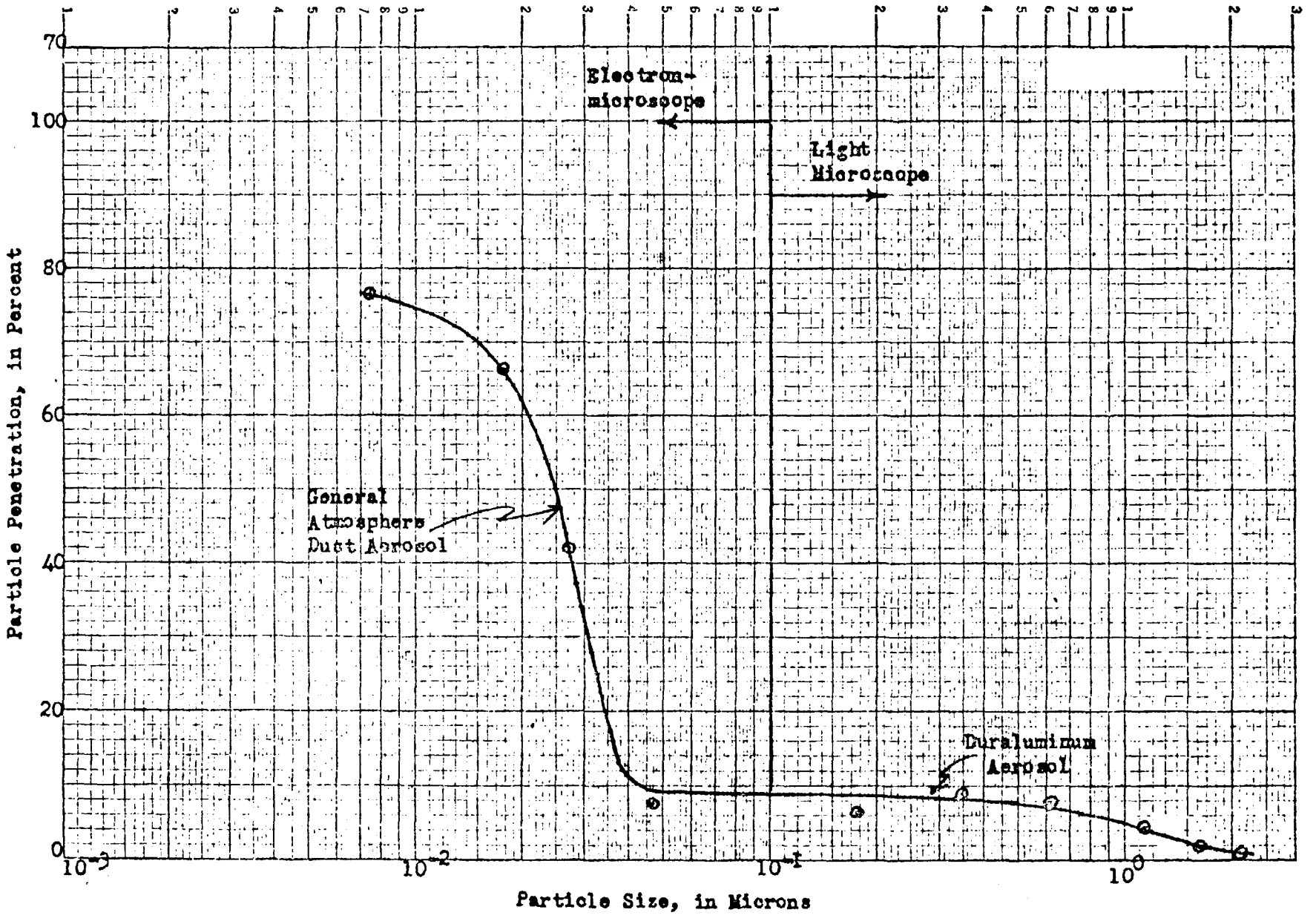
Air Sampling Filter Media

The collection efficiencies of the Whatman-40 and 41 filter papers decreased with particle size for particle velocities of 40 and 10 cm/sec, respectively, as shown in Figures KS-6126 and 6127. In these initial studies, duraluminum solid particles were used as the test aerosol in the light microscope particle size range. In the initial phases of this study it was not possible to produce sufficient quantities of the duraluminum aerosol in the lower particle size range. It was, therefore, necessary to use atmospheric dust which provided a larger number of the smaller particles for the study of the relatively low-efficient filter papers. The particle velocity chosen in these preliminary studies was one at which the collection efficiency was high in the light microscope particle size range. This choice was made to provide a maximum range in which the collection efficiency could vary as a function of particle size in the electron microscope range. Although a point of maximum penetration as previously defined was not detected in either of these initial studies, the shape of the curves indicated the possible existence of the point at the lowest detectable particle size.

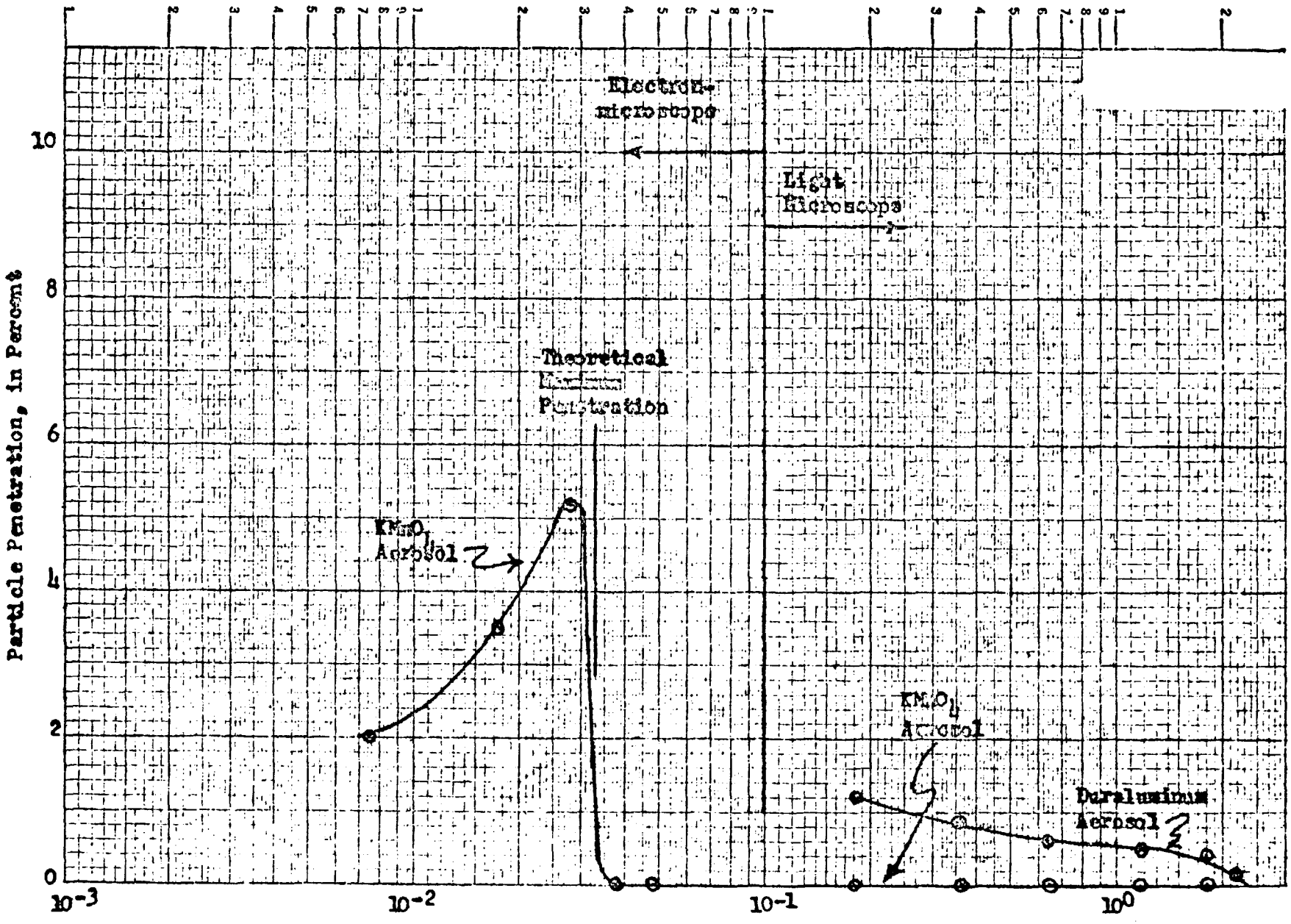
The modified liquid $KMnO_4$ aerosol generator provided sufficient quantities of the aerosol to determine the collection efficiency of Whatman-40 and 41 filter papers at a velocity of 150 cm/sec. This velocity was chosen to approximate the velocity used in the new Health Physics beryllium air samplers. As indicated in Figures KS-6179 and KS-6130, an optimum size for penetration through the filter papers was detected in the particle size range of 0.01 to 0.04 micron. Both of these points of maximum penetration are in good agreement with the theory of Davies and Green. The data also indicates that the Whatman-40 and 41 filter papers are greater than 90% efficient in the collection of KM_nO_4 aerosol over the entire



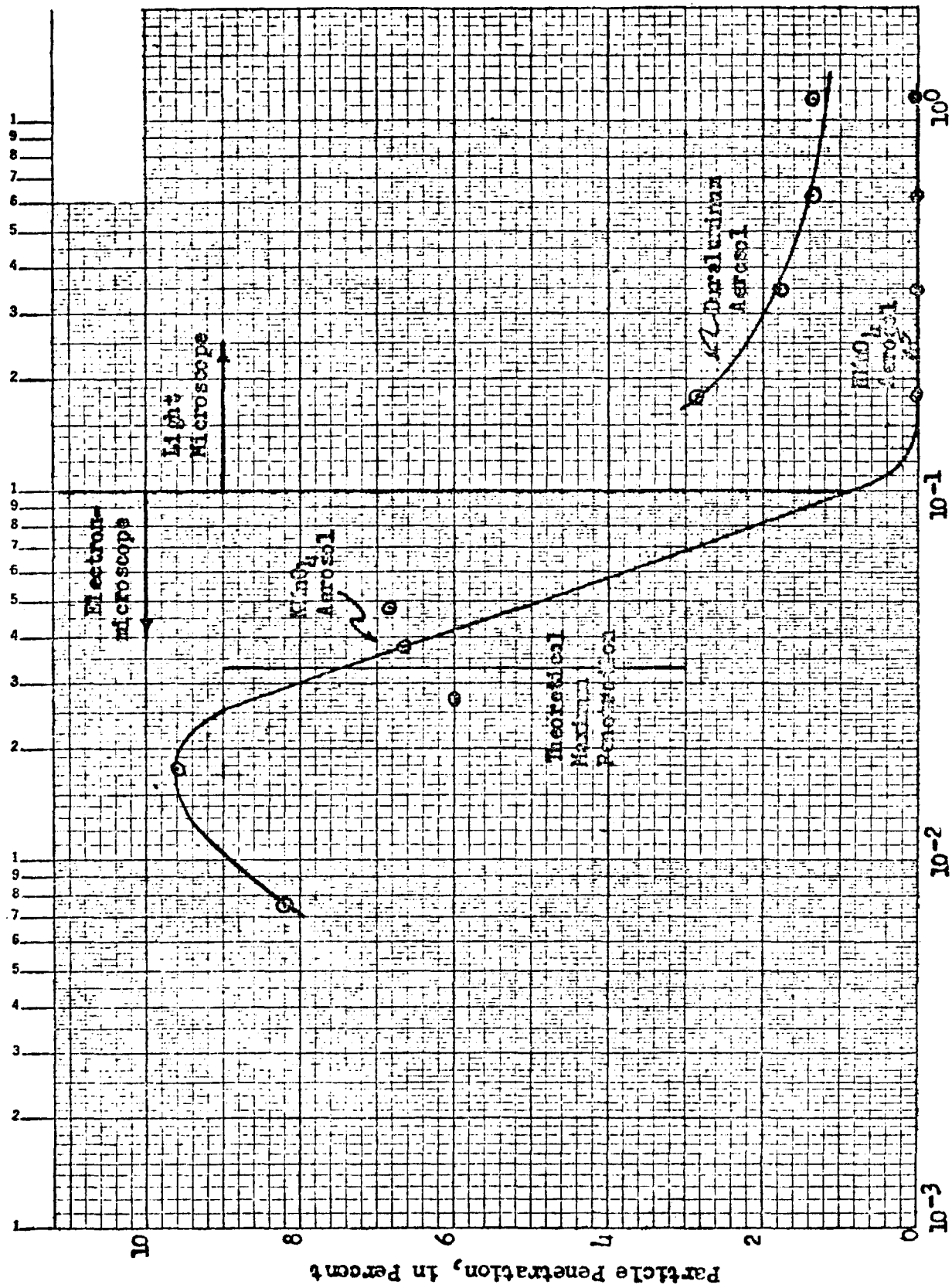
KS-6126 Filter Efficiency Whatman 40 (40 cm/sec)



KS-6127 Filter Efficiency Whatman 41 (10 cm/sec)



KS-6129 Filter Efficiency Whatman 40 (150 cm/sec)

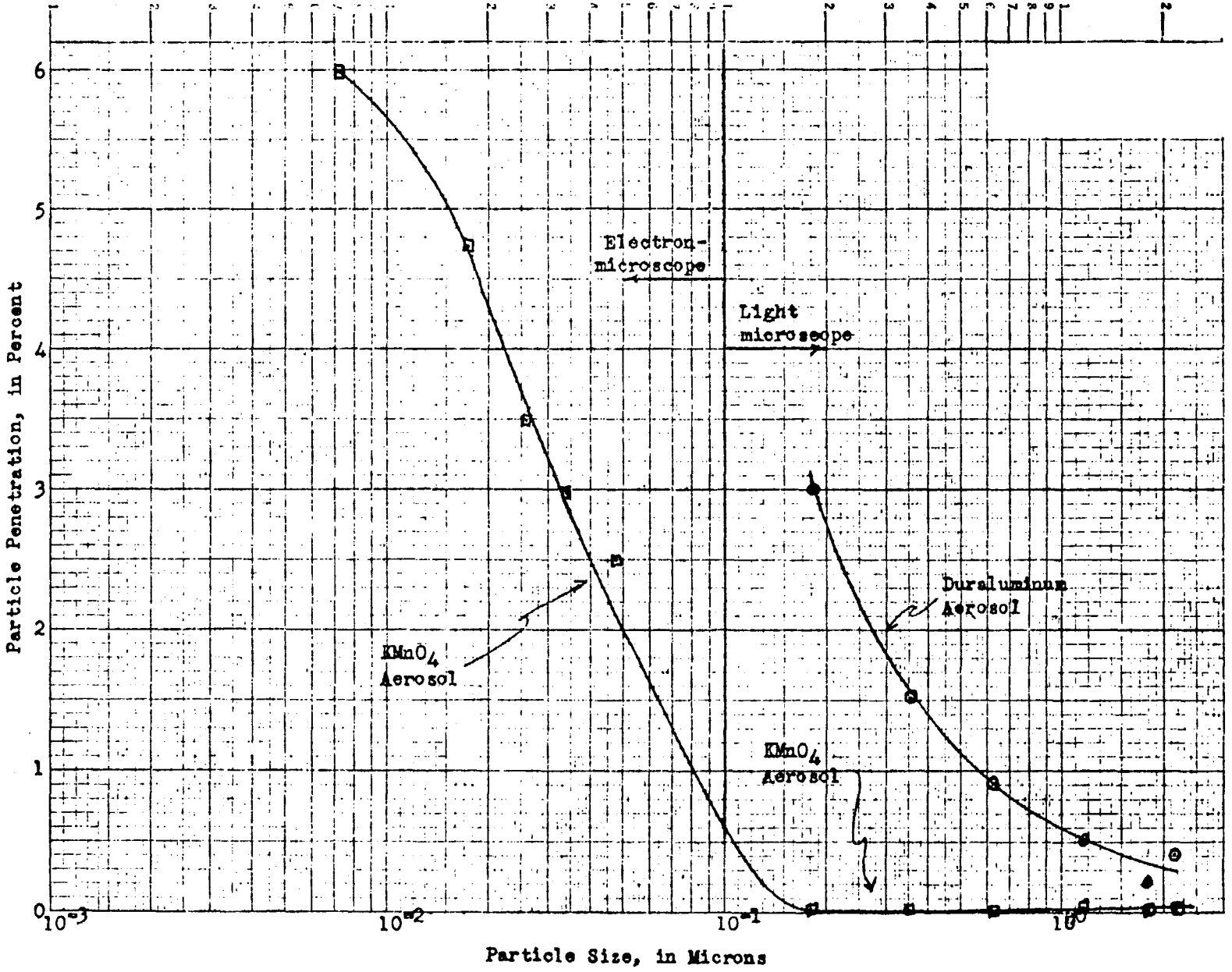


KS-6130 Filter Efficiency Whatman 41 (150 cm/sec)

particle size range. As illustrated in Figures KS-6129 and KS-6130, the Whatman filter papers were more efficient in the collection of liquid $KMnO_4$ particles than for solid duraluminum particles in the light microscope particle size range. The most recent data obtained by the analysis of these filter papers indicate that the collection efficiency at 150 cm/sec is greater for the solid duraluminum aerosols than for the $KMnO_4$ aerosols in the 0.005 to 0.1 micron particle size.

In a preliminary study using atmospheric dust, the efficiency of H-70 filter papers for the collection of particle sizes from 0.005 to 0.1 micron at a velocity of 80 cm/sec was very efficient. A determination of a point of maximum penetration was not possible in this study.

In subsequent collection efficiency determinations of the H-70 filter papers, a particle velocity of 10 cm/sec was chosen using the $KMnO_4$ test aerosol. The collection efficiencies using solid duraluminum particles were relatively low at this velocity in the light microscope particle size range. Since the H-70 filter paper has relatively high efficiency for the collection of particulate material, the velocity corresponding to the point of minimum collection was chosen to increase the number of particles collected on the downstream test filter paper. As indicated in Figure KS-6128, the H-70 filter paper at a particle velocity of 10 cm/sec, was more efficient for the collection of $KMnO_4$ particles than for duraluminum particles in the light microscope range. In addition, the collection efficiency over the entire particle size range (using the $KMnO_4$ aerosol) was greater than 94%. While no optimum particle size for penetration through the filter media was clearly detected, the curve does indicate the possible existence of an optimum particle size range investigated.



KS-6128 Filter Efficiency Hollingsworth and Vose, H-70 (9mil) (10-cm/sec)

Air Cleaning Filter Media

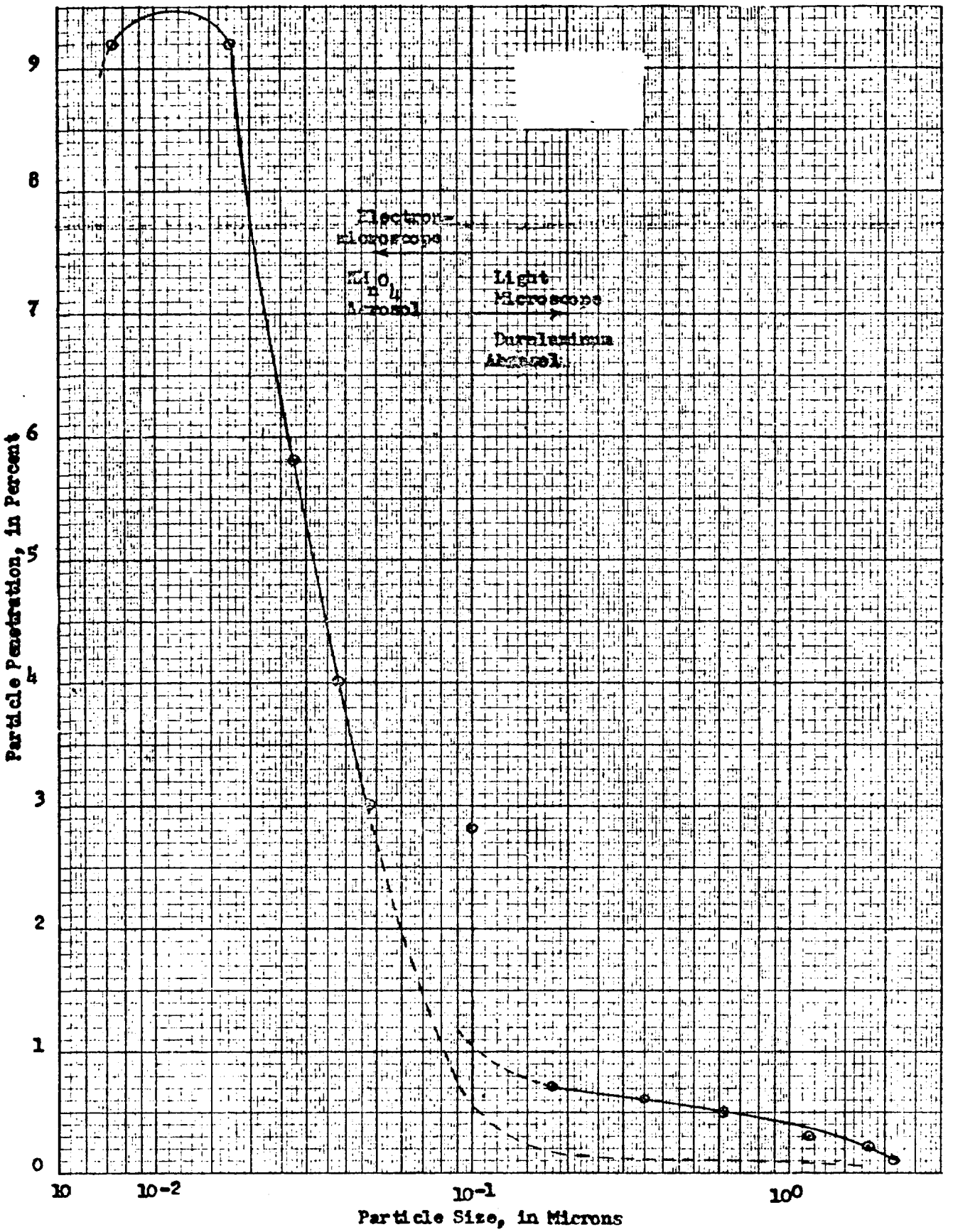
A point of maximum penetration was detected for each of the air cleaning filter media (AEC-1, MSA-1106-B, and CC-6) tested. The optimum particle sizes for AEC-1, MSA-1106-B and CC-6 filter papers as illustrated in Figures KS-6125, KS-6124 and KS-6123 were found in the particle size range of 0.01 to 0.02 micron. The efficiencies of the AEC-1, MSA-1106-B, and CC-6 for the collection of particles over the entire particle range was greater than 91.5, 93.0 and 93.0%, respectively. The estimated collection efficiencies for these filter media in the light microscope particle size range is indicated by the dashed line.

CONCLUSIONS

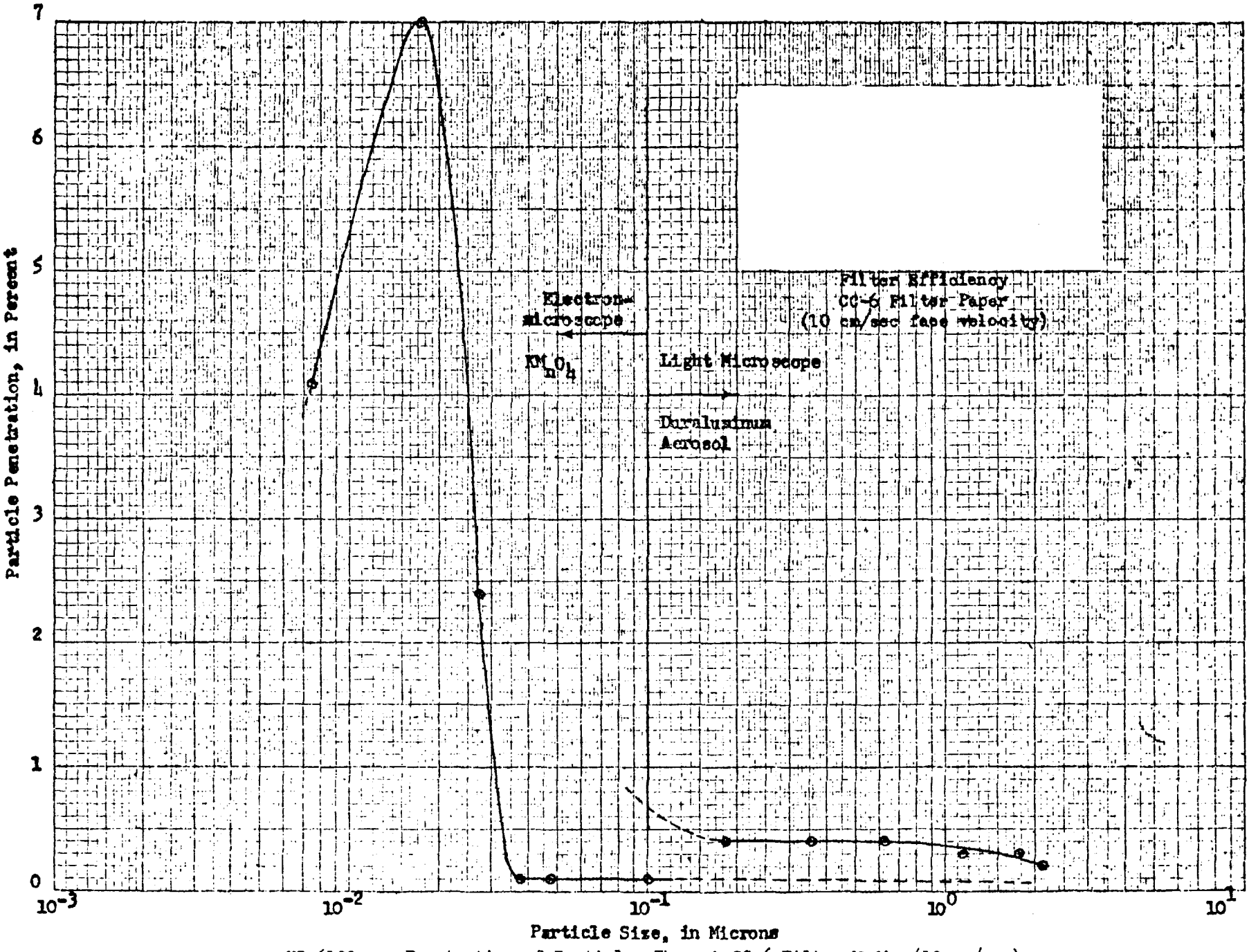
The Hollingsworth and Vose-70 filter medium and the air cleaning filter media tested in these experiments are significantly more efficient in the collection of submicron particles than the Whatman-40 and 41 filter papers. However, with a proper selection of the face velocity, relatively high collection efficiencies can be achieved with the use of the Whatman filter papers.

It has been demonstrated that the air sampling media used in these experiments are more efficient in the collection of the liquid $KMnO_4$ particles than in the collection of the solid duraluminum particles. This statement is valid for particle sizes of 0.2 to 3.0 microns. In the particle size range of 0.005 to 0.1 micron, there is some indication that the Whatman-40 and 41 filter papers are more efficient for the collection of duraluminum than for $KMnO_4$ particles. Since the collection efficiency varies significantly with the type of test aerosol used, one may question the reliability of applying the filter collection efficiency data to the collection of contaminated atmospheric dust having obtained the data using another type of aerosol.

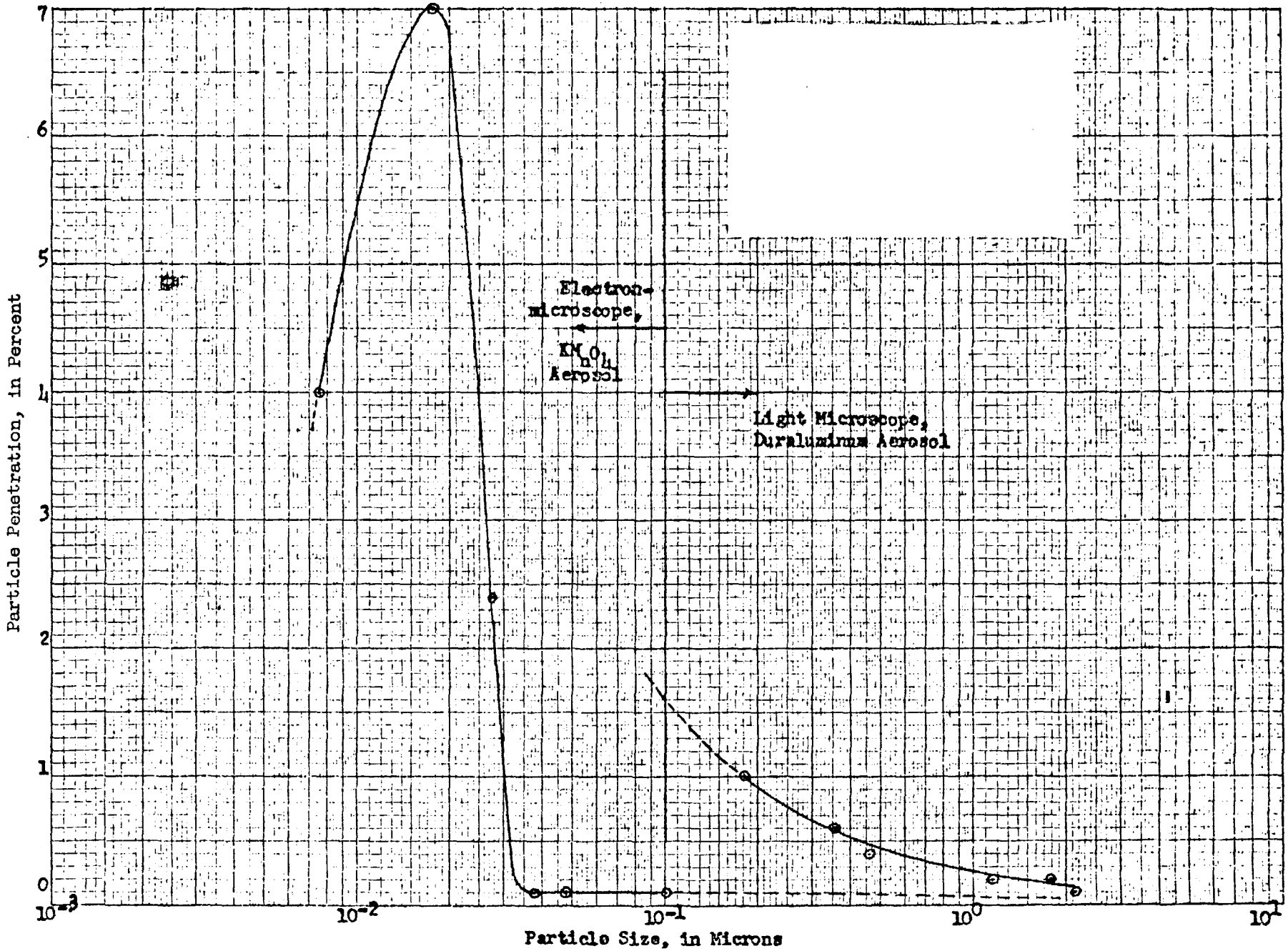
The optimum particle size for penetration through the air cleaning and air sampling filter media was detected or indicated in each of the studies conducted.



KS-6125 Penetration of Particles Through AEC-1 Filter Media (2 cm/sec)



KS-6123 Penetration of Particles Through CC-6 Filter Media (10 cm/sec)



KS-6124 Penetration of Particles Through MSA-1106-B Filter Media (10 cm/sec)

The optimum particle sizes for penetration through the Whatman-40 and 41 filter papers at a velocity of 150 cm/sec are in good agreement with the theory of Davies and Green.

With the experimental knowledge of these points of maximum penetration of particle sizes through the filter media; and with the knowledge of the complete collection efficiency of the filter media, one can choose more rationally the operational velocities for best utilization of the filter medium. With the above knowledge, a more reliable assessment of the air-borne concentrations can be made.

THE AEROSOL SIZE FOR MAXIMUM PENETRATION THROUGH FG-50 FILTER MATERIAL AND SAND

By J. W. Thomas and R. E. Yoder
Oak Ridge National Laboratory

The reality of the existence of an aerosol size for maximum penetration through mechanical filters has been a subject of controversy for 20 or 30 years. It is of fundamental importance to know that a size for maximum penetration does exist. Where extremely hazardous airborne alpha emitters are involved, it is not sufficient to know that the penetration of CC-6 filters is approximately 0.01% for 0.3 micron diameter DOP particles. We need to know that the filter provides protection against particulate material, even if the particles present are 0.01 micron diameter or less.

It is obvious that if the size for maximum penetration is known, one can have the assurance of protection against very small particles since below the size for maximum penetration, the smaller the particle, the less the filter penetration. Filters can then be designed whose performance can be guaranteed against all size particles, whether they are 1 mm diameter or single molecules (provided only that the incident particles stick to the filter and do not become re-entrained in the air stream).

Conceptions of aerosol filtration advanced by Langmuir, Stairmand, Davies, Ramskill and Anderson, LaMer, Johnstone, Ranz, Wong, Chen, etc., have been summarized recently in an article in Chemical Reviews by C. Y. Chen,[1] of the Illinois group. The theories of Langmuir, Davies, and Chen, especially, predict the existence of a size for maximum penetration. With the exception of limited experimental data of Chen, however, there has not been any recent experimental work confirming the theories. LaMer[2,3] (1951) and Ramskill and Anderson[4] (1951) did not find a size for maximum penetration.

FG-50 Filter Material Test

Results of this investigation (August 1955) are shown in Figure 1. The points on the curves were taken in random order to minimize any possible time dependence effects.[3] The DOP aerosol was generated in a LaMer type generator. The aerosols produced were presumably uncharged and reasonably homogeneous, as evidenced by 5 or 6 distinct color bands (for the large sizes). Particle size determinations were made using a lead shot column,[5] which had been previously calibrated with the polarization owl, the color-band owl, the diffusion battery[6] and by gravity settling in a convection free chamber.

The filter material used was FG-50, made by the American Air Filter Company. A microscopic examination of the filter showed most of the fibers to be about 1.25 micron diameter, as specified by the manufacturer. The filter pad, 10 cm diameter, was tested uncompressed and had a thickness of 1.2 cm. Porosity was 99.4% assuming the glass fibers to have a density of 2.5 g/cm^3.

Figure 2 shows a comparison of the results with the theories of Chen[8] and Davies.[7] The theories agree with our results to within a factor of 2. Both theories predict an increasing size for maximum penetration with decreasing face velocity. This is confirmed by the results, although there is less variation in the size for maximum penetration with velocity than predicted by either theory.

Sand Filter Tests

Although sand filters have been superseded, in some cases, by fibrous filters, they do have a unique utility for filtering low velocity air, when high temperatures and corrosive conditions are present. Figure 3 shows the sand placed in lucite holders for the aerosol penetration test. Figures 4 and 5 show typical results. The values of D_g, sand grain diameter, refer to average sizes calculated from sieves used to separate out the sand fractions. The sand having an average diameter of 0.161 cm was the fraction passing 8 mesh and caught on 20 mesh; 0.071 cm diameter, passing 20 mesh caught on 30 mesh; 0.036 cm diameter, passing 40 mesh and caught on 50 mesh. Void fractions were 0.41 for the Pennsylvania sands; 0.38 for the Clinch River sand.

The figures show the size for maximum penetration varies between 0.25 and 0.5 micron radius, depending on the size of the sand granule and the face velocity. Figure 5 is especially interesting in that it shows a large difference in penetration depending on the direction of flow through the bed with respect to gravity. Figures 4 and 5 show that for the sand filters, diffusion and gravity settling are the predominant mechanisms of aerosol filtration, since for even the largest particle size and highest velocity, penetration decreases with decreasing flow rate. We may assume that inertial impaction is playing a negligible part in this filtration process.

At the low velocities used in these tests, the diffusion effect is predominant for particles of 0.1-0.2 micron radius. As the particle size increases, the diffusion effect drops off and gravity settling becomes more effective. The combination of the two mechanisms of removal results in a size for maximum penetration at about 0.4 micron radius. Also, the column becomes increasingly more effective for downflow as compared to upflow. This difference in downflow and upflow efficiency is due only to the gravity mechanism of removal since the curves are convergent at the smaller particle sizes. The magnitude of the effect, however, is surprising. For particles of 0.8 microns radius, the columns can be 10 times as effective for downflow as compared to upflow.

The rough and irregular Clinch River sand showed better performance, by at least a factor of 2, then the nearly spherical Pennsylvania sand. This indicates the existence of a shape factor. It appears that the more irregular the sand grain shape, the better the filtration efficiency.

Summary

1. The existence of a size for maximum penetration through FG-50 fiber glass filter material has been established by the use of homogeneous DOP aerosols. It is 0.25μ radius for 0.94 cm/sec face velocity; 0.27 μ for 0.42 cm/sec face velocity; 0.29 μ for 0.21 cm/sec face velocity; and 0.35 μ for 0.094 cm/sec face velocity through the fiber glass material. The theories of Chen and Davies were confirmed to within a factor of 2.

2. Tests of sand filters have shown the existence of a size for maximum penetration. For large particle sizes and low velocities, filtration efficiency is much higher for downflow than for upflow.

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2. LaMer, V. K., P. Glendron, and R. Green, Nuclear Science Abstracts 5, No. 755 (1951).
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5. Thomas, J. W., and R. E. Yoder, Arch. Ind. Health (to be published).
6. Thomas, J. W., J. Colloid Science 10, 246 (1955).
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8. Chen, C. Y., WASH-170, page 368 (1954).

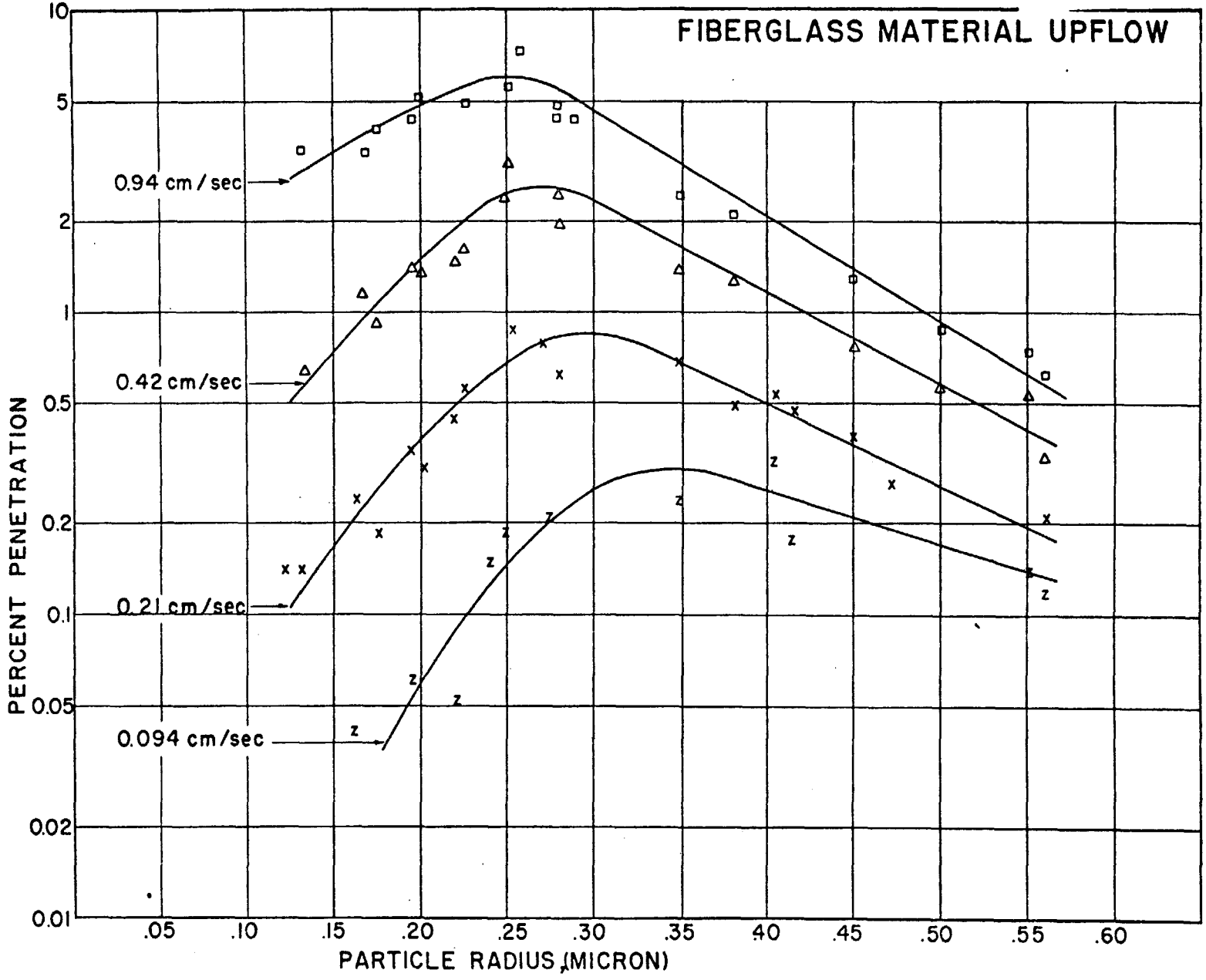

Fig. 1—DOP aerosol penetration through FG-50 filter material. Fiber diameter, 1.25 microns. Porosity, 99.43%. Filter thickness, 1.2 cm.

FACE VELOCITY IN FILTER MAT cm/sec	PARTICLE RADIUS FOR MAXIMUM PENETRATION, μ		
	CHEN'S THEORY 2μ FIBER	DAVIES' THEORY 2-20μ FIBER	EXPERIMENTAL RESULTS 1.25μ FIBER
0.94	0.12	~0.2	0.25
0.42	--	~0.3	0.27
0.21	--	~0.45	0.29
0.094	0.23	~0.65	0.34

Fig. 2—Comparison of theories and results.

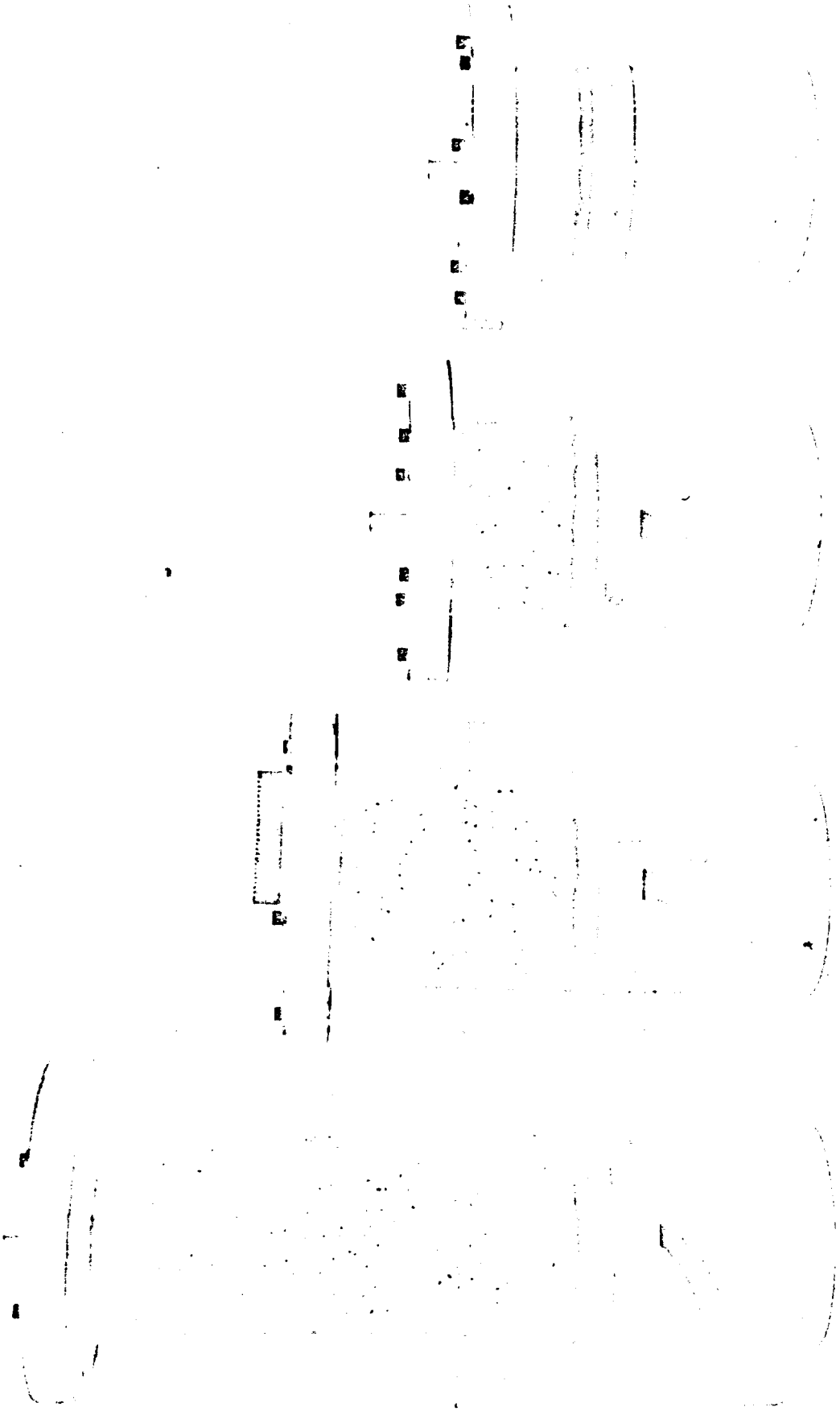

Fig. 3—Pennsylvania Sand in test holders.

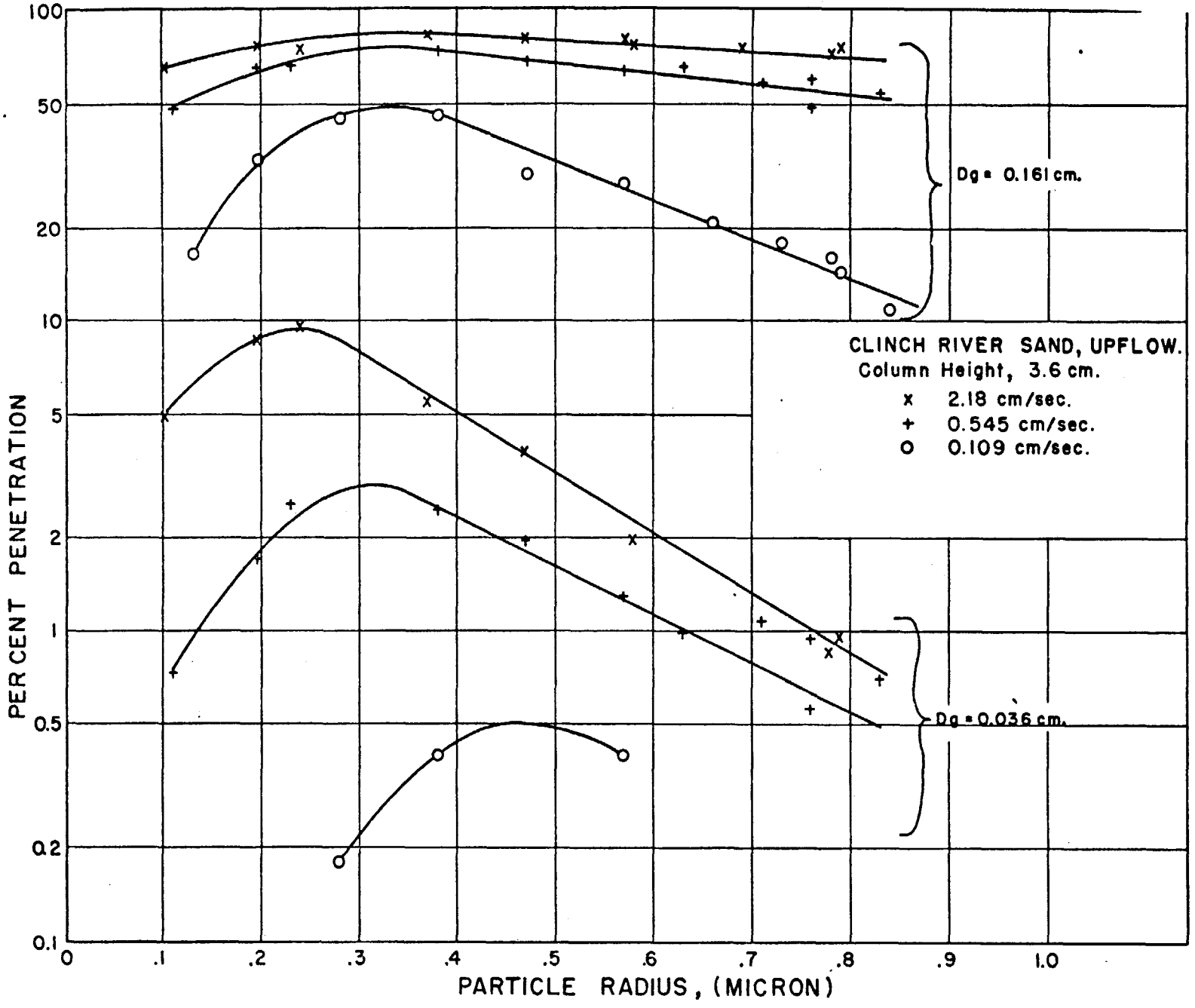

Fig. 4—DOP aerosol penetration through Clinch River Sand.

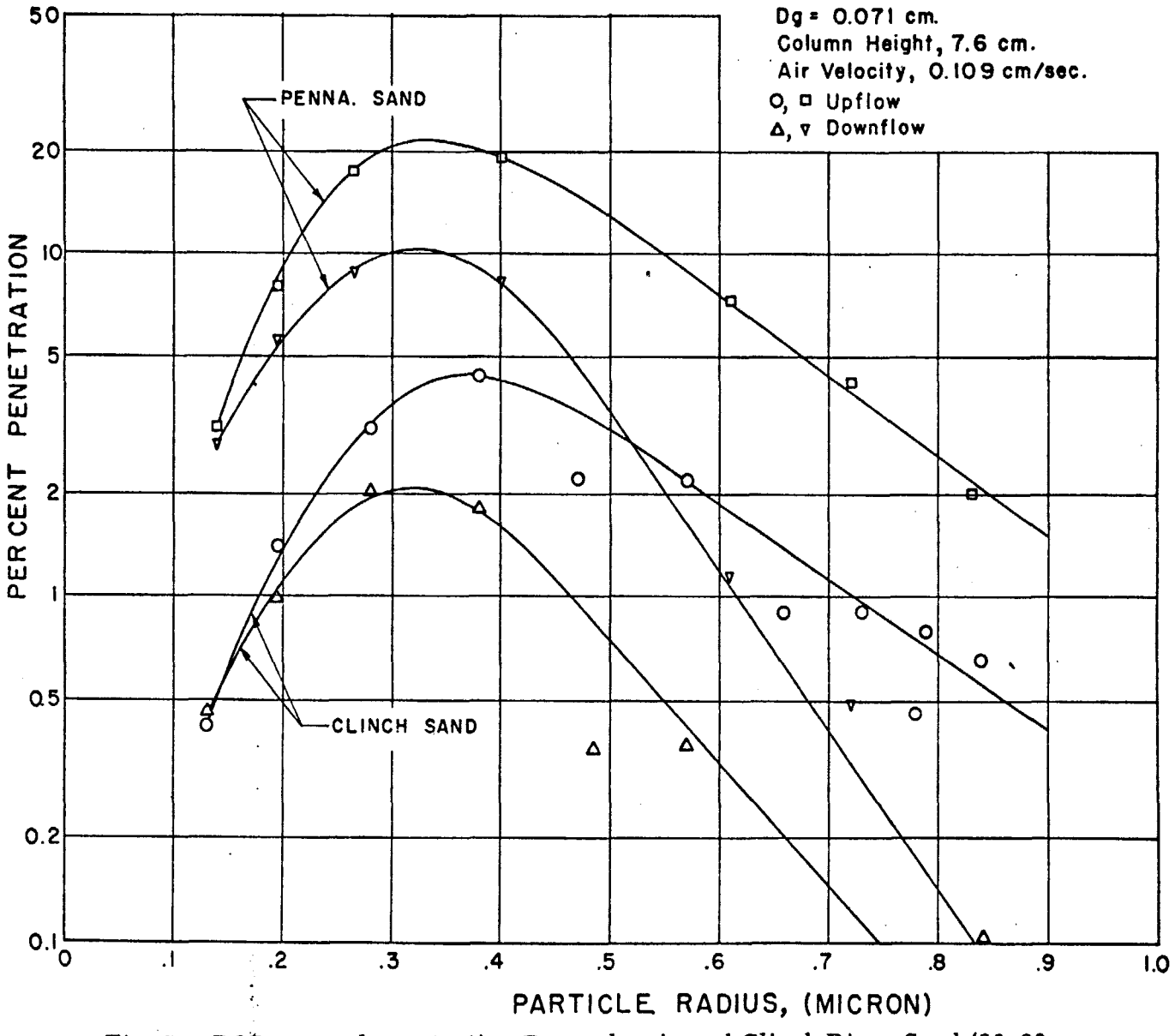

Fig. 5—DOP aerosol penetration Pennsylvania and Clinch River Sand (20-30 mesh sand, Dg = 0.071 cm).

A PRELIMINARY REPORT ON CONTAMINATION FROM UNCONTROLLED INCINERATION OF RADIOACTIVE PARTICULATES by W. B. Harris, New York Operations Office, U. S. Atomic Energy Commission.

Mr. Harris informally described preliminary results of an experiment in burning baled combustible material that was slightly contaminated with radioactivity. The information presented is being developed into a paper for presentation at the April 1956 meeting of the American Industrial Hygiene Association. The complete paper will be subsequently published in the "Quarterly," which is the official publication of the AIHA.

STATUS REPORT ON STANDARDIZATION OF AIR ASSAY PAPERS

by

Walter J. Smith
Arthur D. Little, Inc.

January, 1956

INTRODUCTION

Those of you who attended the last Air Cleaning Seminar (which was held at Los Alamos two years ago) will recall that we agreed steps should be taken to simplify or standardize on selection of air assay papers. Perhaps a quick review will refresh your memories. We had completed a survey at that time to determine what papers various laboratories were using for air assay work, what were the sampling requirements of those laboratories, and what conditions had to be met by the sampling papers. This survey revealed that twenty-two different media were in use among the laboratories canvassed. It was obvious that the number of media required could be reduced greatly without introducing any hardships or inconvenience.

Before making any firm recommendations, it was necessary for us to compare the characteristics of all the various media under a single set of test conditions. We gathered together samples of all the assay media that were reported in the survey and measured their properties as air filters. Results of this work were compiled into a paper that was issued at our last meeting. This paper was presented at an A.S.T.M. meeting by permission of the A.E.C. and was published in A.S.T.M. Proceedings for 1953. You may be interested to know, in passing, that there has been a very great interest in this subject even outside of this group. The number of requests for copies of the paper was a real surprise to us. We have had to make several printings and still we are out of

copies. Hundreds of them have been distributed.

A careful review of the survey returns and consideration of the measured properties of the various media being used for air assay work has led us to conclude that nearly all of the needs of the Atomic Energy Commission and associated groups can be met by the following five available air filter materials:

1. Whatman Filter Paper No. 41
2. Whatman Filter Paper No. 44
3. Membrane-type Filters
4. HV 70 Paper 18 mil thickness
5. Glass-fiber Papers

These media would be used as follows:

1. Whatman No. 41

   Where it is desirable to do large-volume sampling, and where a high-sampling rate will provide good collection efficiency.

2. Whatman No. 44

   Where a low-ash paper of good collection efficiency is needed, especially at low-flow rates. This should be the general-purpose paper of the air-assay laboratory.

3. Membrane Filter (Example: Millipore Types AA and HA)

   These media should be used:

   a. For the quantitative collection of the very finest particles (sub-micron).
   b. For collection of particles that are to be viewed, counted, or measured on the filter directly under the microscope.
   c. Where the particles must be collected wholly at the surface (as in α counting). Here HA is preferred.
   d. When quantitative collection of very small particles is coupled with the need to ash the filter during analysis.

4. HV 70 Paper

   a. For monitoring devices requiring a high-efficiency paper, and where ash content is of no concern.

   b. In continuous monitoring stations requiring low-resistance, high-efficiency paper in roll form, where color or ash-content of the paper is not important.

5. Glass-fiber Papers

   To be used where high-collection efficiency is required and where the use of cellulose is precluded. Sampling of high-temperature stack gases would be a case in point. MSA Paper No. 1106B (Mine Safety Appliances Company), or any equivalent paper, is recommended. Properties of such a paper are given in Table I of Appendix D[1] under the heading, "Hurlbut Glass Paper." The AEC all-glass, air-filter medium also may be used successfully for assay purposes. (Reference: Report NYO-4603, August 31, 1954, Columbia University)

I hope that it is not disappointing to you to see the number of media reduced from twenty-two to no fewer than five. However, it is a move in the right direction, and further reduction of the required number may yet be possible. At present there is no universal medium that can fill all requirements. We think that the final minimum number will be not less than three: a high-efficiency organic paper, a membrane filter, and a mineral-fiber paper.

It has been recognized for some time that an all-purpose air-assay paper is a distinct possibility and an item that would be of particular value to the operating areas of the Atomic Energy Commission. Such a paper, carefully made to meet definite specifications of properties and performance, could be the standard throughout all laboratories where air-sampling and-analysis are practiced. The ideal paper would have the following properties:

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[1] "Media for Air Cleaning and Air-Assay Purposes" summary report to A.E.C., October 3, 1955

a. High-collection efficiency on sub-micron size particles.

b. Usable for liquid or solid particles.

c. Low-flow resistance.

d. Low-ash content.

e. Low-radioactivity background.

f. Fine texture, with particle collection close to surface.

g. White--to be usable in discoloration tests.

h. Available in roll form. (For continuous analyzers.)

All of these properties would be met by an absolute-type filter material based wholly on cellulose or other organic fibers. High-efficiency filter papers require the presence of very fine fibers in the furnish. Achievement of this ideal assay paper, therefore, depends upon obtaining a reliable source of very fine organic fibers.

A program of experimental work has been carried out on the development of such a paper; some success has been attained on a laboratory scale.

We have considered two sources of the very fine fibers--fibrils from natural cellulose and superfine spun synthetic fibers.

When cellulose fibers are worked in a paper mill beater with light-to-moderate roll pressure, a progressive change occurs in the pulp. To the hand, the wet pulp acquires a softer and more gelatinous feel. If successive samples of pulp from the beater are examined under the microscope, fine fibrils can be seen that are being stripped away from the parent fiber.

Fibrils produced in the beating of natural cellulose fibers measure to less than a micron in diameter, and are in the size range suitable for high-efficiency, air-filter media. They should be ideal for making a low-ash, all-cellulose paper such as we are seeking.

However, the fibrils in the desired condition appear to be of transient

existence only. Very quickly they are attacked by surrounding water, become gelatinous, and lose their fibrous character. The whole problem in making a fine filter with cellulose is to retain the fibrils while they are still fibrils. To accomplish this we must defeat the hydration which destroys them. Various ways of doing this were tried:

a. Beating in hot water.

b. Beating in salt solution.

c. Beating with dimethylol urea in the beater.

d. Beating with cationic agents in the beater.

e. Beating with cationic resins in the beater.

f. Beating with chrome complex agents in the beater.

g. Use of alcohol or alcohol-water in the beater.

h. Washing out the fibrils as they are formed.

i. Acetylation of the cellulose.

j. Pretreatment of the cellulose to promote fibrillation.

Cotton fibers are a particularly good source of fibrils, and most of the experimental work was done using cotton--either linter board or, more often, clean cotton fiber purchased as roll batting.

Despite our efforts we were never able to produce an outstanding paper based on fibrillation.

Our most encouraging results were obtained with mixed cellulose and fine synthetic fiber of which the following is an example.

A cotton linter fiber furnish was prepared in a laboratory beater at 1 per cent consistency to a freeness of 14 at 70°F (Schopper Riegler). Acrylonitrile fibers in the size range of 1.0 to 1.50 microns diameter were beaten at high speed in a Waring Blendor for four minutes to reduce fiber length. A mixture of the following composition was prepared in the blender:

80 parts acrylonitrile fiber
20 parts prepared cotton linter fiber
1.6 parts Daxad No. 11
40,000 parts water

This was diluted with water twofold and cast into a handsheet.

Performance of this sheet when tested at 28 linear feet per minute with DOP smoke was as follows:

Smoke penetration - 0.32 per cent
Pressure drop - 240 mm water
Value of E - 1.1

This is far superior to any all-cellulose filters we have ever made, and far superior to any commercial all-cellulose paper of which we are aware.

Ash content of a paper so made is about 0.4 per cent. This may be reduced to something less than .04 per cent by treating the paper with mixed hydrochloric and hydrofluoric acids.

We believe that an air-assay paper based on cellulose fibers and fine synthetic organic fibers offers the best approach at present to a standard air-assay paper. All of the properties listed at the beginning of this section are well met with this type of paper. No plant, or even pilot plant runs were made because of limitation of funds. However, several manufacturers have expressed an interest in making the paper if a demand develops.

ARRESTANCE VALUES AND LOADING CHARACTERISTICS OF COMMERCIALLY AVAILABLE AIR FILTERS AGAINST 0-5 MICRON TEST DUST

By Ernest N. Hellberg and William R. Nehlsen
NAVCERELAB–USNCBC
Port Hueneme, California

The subject of this paper is the Arrestance Values and Loading characteristics of Commercially available Air Filters as tested against an aerosol of 0-5 micron test dust classified from Arizona road dust. However, before I report on the various tests conducted at NAVCERELAB, I thought I might explain just what the word NAVCERELAB, as listed on your program, stands for and why we are involved in testing air filters. The word NAVCERELAB is an abbreviation for the Naval Civil Engineering Research and Evaluation Laboratory, located at Port Hueneme, California. You can easily understand why the abbreviation is used. This Laboratory is under the direction of the Bureau of Yards and Docks in Washington, D. C. and was set up to work on their many and varied problems. BuDocks has cognizance of all the shore establishments of the Navy, both in the States and abroad, and one of its many responsibilities is the protection of these bases and its people against the hazards of ABC Warfare.

Gas masks will provide protection against ABC Agents for most of the individuals located at these Bases during and right after the actual attack, but are only suitable for relatively short periods of time. For personnel located in special purpose shelters, such as command posts, hospitals and communication centers, which require absolute protection for long periods of time, the Chemical Corps Collective Protectors are the answer. However, the relatively high cost of these special purpose collective protectors limits their use to essential operations and makes it desirable to determine if a more economical filter is available which will provide sufficient protection under most conditions of service. It was also desirable to determine which of these filters would make good roughing filters for the more expensive absolute filters.

Therefore, the Bureau of Yards and Docks directed the Laboratory to test all of the commercially available ventilation air filters to determine which type of filter, if any, would provide some measure of protection to personnel located in the Naval Shore Establishments, and to determine which type of filter would make a good pre-filter for use on the collective protector.

To insure that no potentially valuable filter would be overlooked, a thorough search for all available brands and types was made and three or more of each type was purchased through regular commercial outlets. All filters purchased were 20 × 20 inch nominal size unless otherwise stated, and included the metal viscous-impingement filters; the fibrous viscous-impingement filters; the dry, normal velocity, fibrous filters; and several of the dry, low velocity, fibrous filters to give comparative data on the more expensive commercial filters which approach "absolute" filtration.

TEST PROGRAM

The large number of filters involved made it necessary to divide the test program into two phases. In the first phase, every filter purchased was tested clean to determine its resistance and dust arrestance at a wide range of face velocities. This provided information for comparing the many makes, types, and thicknesses and for selection of specimans for more complete testing. This also provided much general information on filter performance against fine dust. The second phase which is still under way, will provide information on the performance of selected filters as they are loaded with dust.

An air filter testing apparatus, see Fig. 1, patterned after that designed by the Farr Company in Los Angeles, was used for all of the tests. It consists of a square duct totaling approximately 19 ft in length connected by a short transition section to the intake of a blower exhausting to the atmosphere, and a 3-ft long detachable intake plenum on which the dust feeder is mounted. The blower is driven by a 25-HP variable speed motor so that a wide range of air flow rates can be obtained. The air filter test section, including the intake plenum, is 18¼ in. square and is in detachable sections for ease in installing test filters and taking dust samples. Filters from 20 in. to 24 in. square and almost any thickness can be accommodated in this section. The air measuring section downstream from the test section is approximately 28 in. square and accommodates a standard ASME nozzle between two perforated plates of 40 per cent open area. Four standard nozzles have been calibrated to accurately measure air flow at all ranges of the test duct.

The dust feeder consists of a grooved metal tray which moves forward slowly by means of a rack and pinion gear driven by a synchronous motor; a pickup and vibrating mechanism for the test dust; and four air-aspirated conveyor tubes. A weighed amount of test dust is spread in the four grooves of the tray and is fed by rotating brushes into the aspirating tubes conveying the dust to the injection point in the duct where it is mixed with the air stream in a manner designed to produce uniform distribution.

The test dust used for the arrestance (efficiency) tests reported here is the 0-5 micron fraction of Army Standarized Fine Air Cleaner Test Dust. This test dust was selected because it approximates the expected particle size range of a biological warfare aerosol and was fed into the air stream of the duct at the rate of 20 gm/hr. This amount is greater than any expected BW aerosol concentration and provides a severe test for the filters. The dust was obtained by processing the commercially available air cleaner test dust through a multiple cyclone dust classifier.

To obtain a measurement of the particle size distribution, several samples of the dust cloud were collected on membrane filters just ahead of a test filter. The membrane filter was examined at 970 magnifications after it had been rendered transparent with standard immersion oil. A calibrated Whipple disc was used in the eyepiece of the microscope for size determination. The approximate size distribution is tabulated below (no particles over ten microns were detected):

Particle size range	Per cent of total number of particles
1 micron or less	78
1 to 2 microns	12
2 to 3 microns	5
3 to 4 microns	2.5
4 to 5 microns	1.4
5 to 6 microns	0.4
6 to 8 microns	0.04
8 to 10 microns	0.03

The filter arrestance was determined by taking samples upstream and downstream from the filter.

The term "arrestance" used in reporting performance is recommended by the Air Filter Institute for laboratory test work. "Efficiency" is used by this institute to define performance under in-service conditions. The samplers used were the Crismon type consisting of a one inch diameter copper tube about 1½ inches long. One end of the tube is closed with a 50 mesh wire screen to retain the sample collecting media of densely packed fine fiber glass wool. The other end of the tube, at which the air sample enters, is open with a beveled knife edge corresponding to the inside diameter of the tube. The samplers are placed in the sampling tubes upstream and downstream from the filter and during the test, air is drawn into them from the duct at isokinetic velocity. The samplers are weighed before and after on an analytical balance and the weight of test dust collected is used to calculate the arrestance.

A total of 90 different filters were tested against the 0-5 micron test dust at flow rates of 800, 1200, 1600, 2000, 2400, and 3000 cubic feet of air per minute to determine their resistance and arrestance values. The flow rate of 800 cfm is equivalent to a filter face velocity of 346 fpm, 1200 cfm equal to 518 fpm, on up to 866 fpm at 2000 cfm and 1298 fpm at the 3000 cfm figure. These values were originally reported in NAVCERELAB Technical Memorandum M-099 Ventilation Air Filters; 0-5 Micron Dust Arrestance by E. N. Hellberg and W. R. Nehlsen. However, because of lack of time and space the tabular data on all of the filters will not be present here. The following figures summarize that data. Figures 2, 3, and 4 show the high, low, and average performance curves for all of the metal viscous-impingement filters tested; while Figures 5 and 6 show the high, low, and average performance curves for all of the fibrous type Viscous-impingement air filters tested. It should be noted here that the high and low arrestance curves and the high and low resistance curves are not necessarily from the same filter. Figures 7 and 8 show the performance curves for the two types of dry standard velocity fibrous filters tested. Figure 9 shows the performance curves for the four types of low velocity dry fibrous filters tested. Test 8A shows the performance of a one inch shredded polyethylene filter at face velocities up to 1038 fpm. The other three curves are for filters composed of fine glass fiber pads set in five wedge shaped pockets and have a very low face velocity—only 40 fpm at 200 cfm. These filters have a fairly high arrestance as compared to the other types but the resistance increases rapidly as the load increases.

These curves, especially the ones showing the high, low and average performance of the filters, show very well the wide range of results that can be obtained with any particular type of filter. The results of the tests on the metal viscous-impingement filters at face velocities up to 2½ times the design figure indicates that there is no appreciable gain in arrestance over 1⅓ times the design figure.

The test dust used for loading the various selected air filters in the second phase was the Air Filter Institute (AFI) Standard Test Dust. This comprises of a mixture of 72% standardized air cleaner test dust, fine; 3% cotton linters, Wiley Mill Ground; and, 25% K-1 Carbon Black. It was selected because it was readily available from the James H. Herron Company in Cleveland, Ohio and provided a means of loading the filters within a reasonably short period of time, with an acceptable test dust. This test dust was fed into the air stream of the test duct at a rate of 40 gms/hours in the same dust feeder as described above.

The loading tests are continuing at this time; however, enough data has been collected to provide some interesting observations. Approximately fifteen selected filters representing all types will eventually be tested under this phase of the program. Each selected filter is tested in the Filter Test Duct at 800, 1200 and 1600 cubic feet of air per minute and is loaded until its resistance reaches 1.0 inches of water or until 1000 grams of dust has been fed into the air stream, whichever occurs first. Because of the time element, these limits had to be set. We only hope that this was long enough. Each filter is tested against 0-5 micron test dust to determine its arrestance at the start of each run and is again determined after each 40 grams of AFI Standard Test Dust has been fed to it. In this way a running account of its arrestance and resistance change is obtained. All of the 1-in., 2-in., and 4-in. metal viscous-impingement filters tested acted in approximately the same manner, in that there was no complete breakdown of the filter after 1000 grams of dust had been fed to them. As an example, Figure 10 shows how the 2-inch Farr 44 Filter performed. Neither the resistance nor the arrestance changed by any great amount during the test. Figure 11 shows how the American HV-2 performed. Both the resistance and arrestance increased at an accelerated

rate as the load increased. The explanation as to why both curves for the 800 cfm run crosses the 1200 and 1600 cfm curves is probably that the lower velocity allows a greater build-up on the filter with the consequent higher arrestance and resistance values. All I can say is "we calls them as we sees them." I also have no idea as to which of these filters would be the best in the long run. Certainly both filters have their good and bad points.

There are no slides available at this time which show the loading characteristics of the other filters tested, but I can describe briefly some of the results. For the dry, standard velocity, fibrous type, the filter life was shorter. For instance, the arrestance of the aluminum wool filter dropped rapidly at all air flows after less than 100 grams of dust had been fed to it, and at the 1200 and 1600 cfm air flow the resistance increased rapidly right from the start. The arrestance of the shredded polyethylene filter dropped off rapidly as soon as the dust load started to build up while the resistance increased at about the same rate. The resistance was over 1-inch at the 1600 cfm air flow so no tests were conducted. The arrestance of the dry glass wool filter dropped to nothing in all cases before 300 grams of test dust had been fed.

Of the two 2-in Fibrous Viscous-Impingement (Throwaway) Filters tested, the Hair filter showed excellent results, holding steady at about 62% arrestance at 800 cfm until the resistance reached 1 inch after about 750 gms of dust had been fed to it. The resistance of the hair filter increased much more rapidly at 1200 and 1600 cfm air flows as the load increased. The arrestance of the glass wool filter with a light oil coating dropped off rapidly at all air flows after only a relatively small amount of dust had been fed.

The arrestance of the low face velocity, dry, fibrous type filter composed of fine glass-fiber pads arranged in wedged-shaped pockets approached 100% for all the air flows tested; however, the resistance was extremely high,—which proves, I guess, that you can't always get something for nothing.

The loading tests are continuing on several other types of filters and several reruns are being made to check some of the results. A report will be issued in the near future and will include new data collected on the arrestance of various filters tested since the last report was issued and a summary of the data obtained on the dust loading tests.

Since the dust loading tests are not complete, it is probably too early to say definitely which type of filter will be best. But, I think we can safely say that the certain popular brands of the metal viscous-impingement filters will offer a higher arrestance at a reasonable resistance for a longer period of time than any of the other types tested.

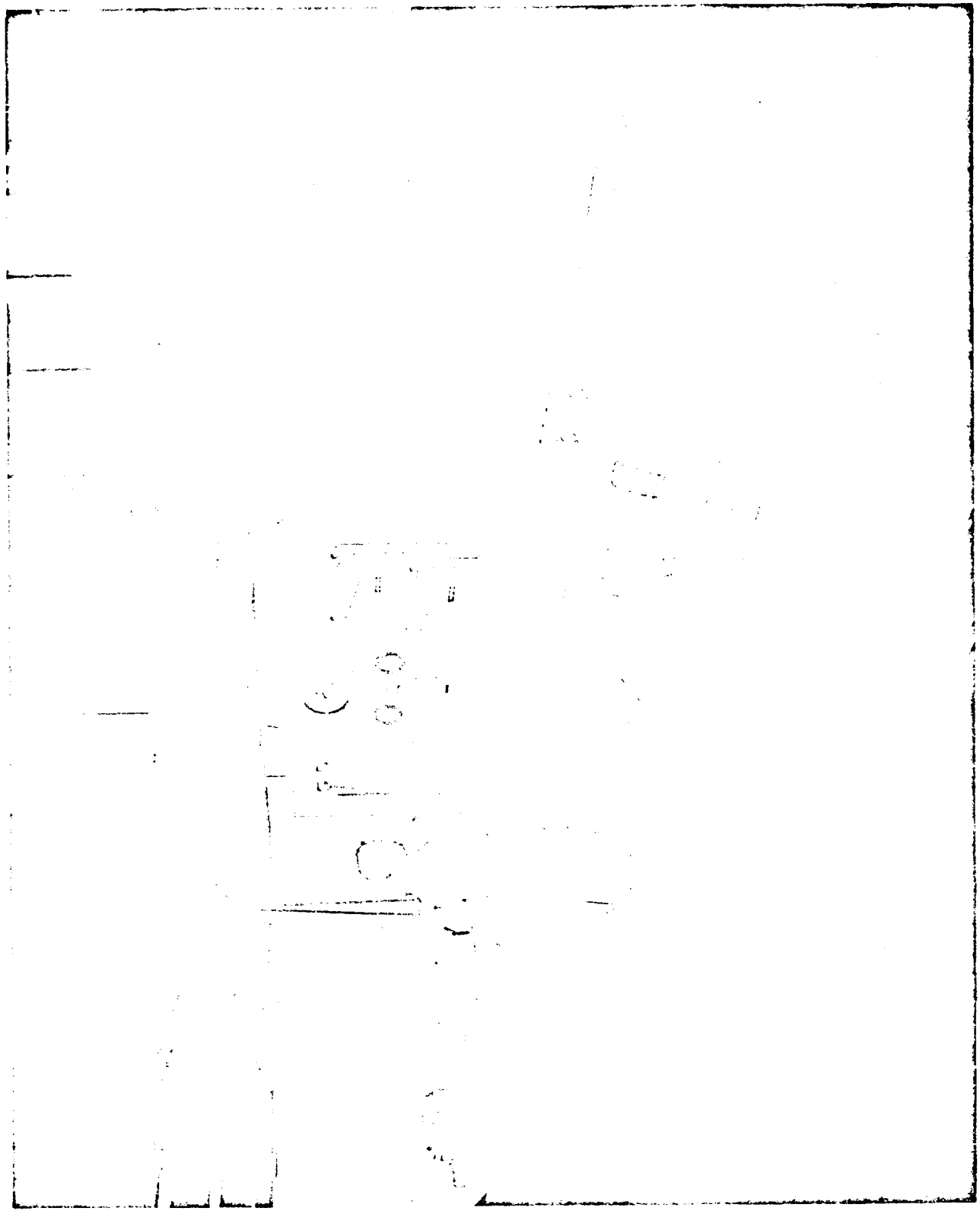

Fig. 1—Filter Test Duct.

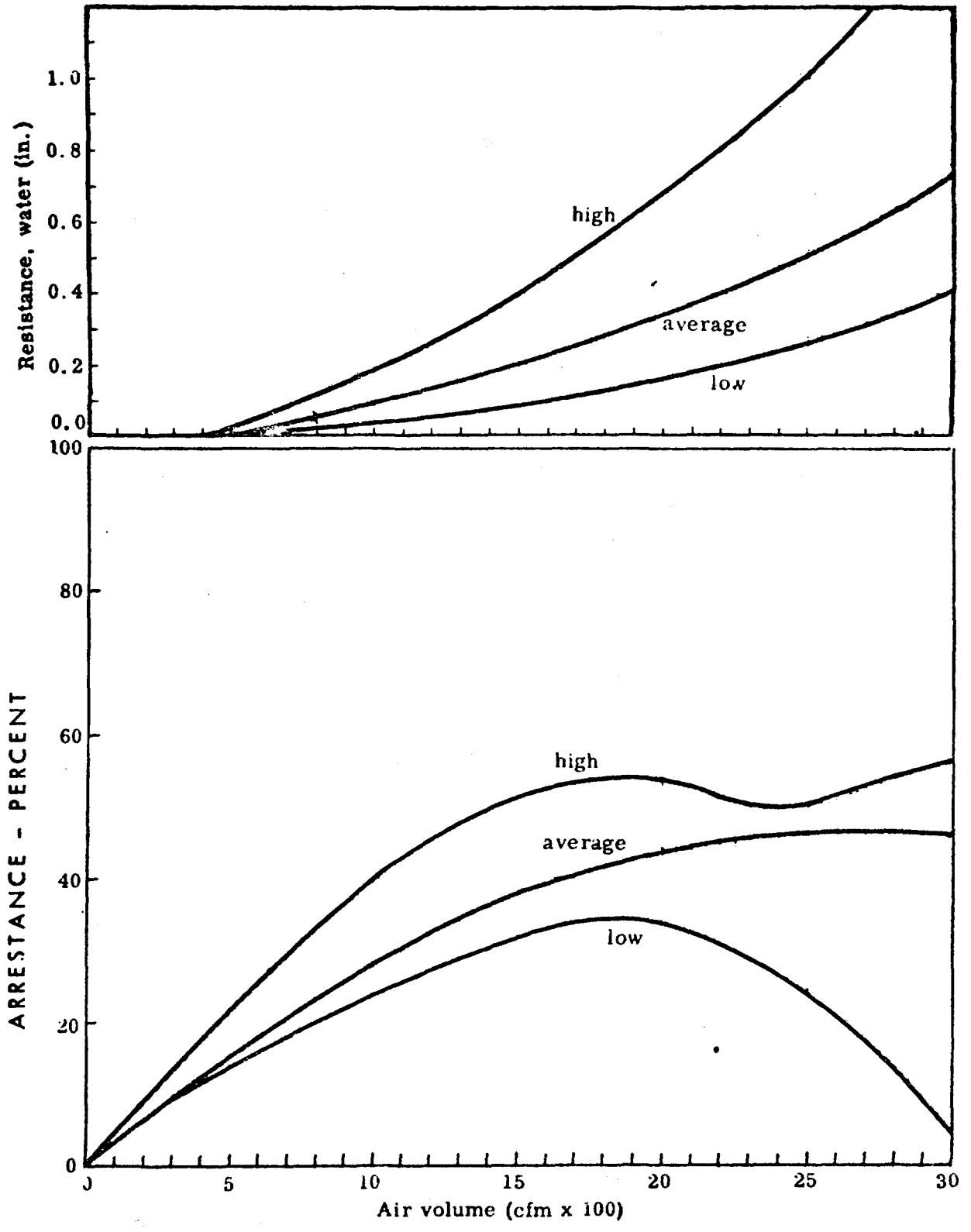

Figure 2. High, low and average performance curves for the 10 1-in. metal viscous impingement filters tested. The high and low performance curves do not represent the performance of individual filters. They are composites of the highest or lowest arrestances of any filters here tested.

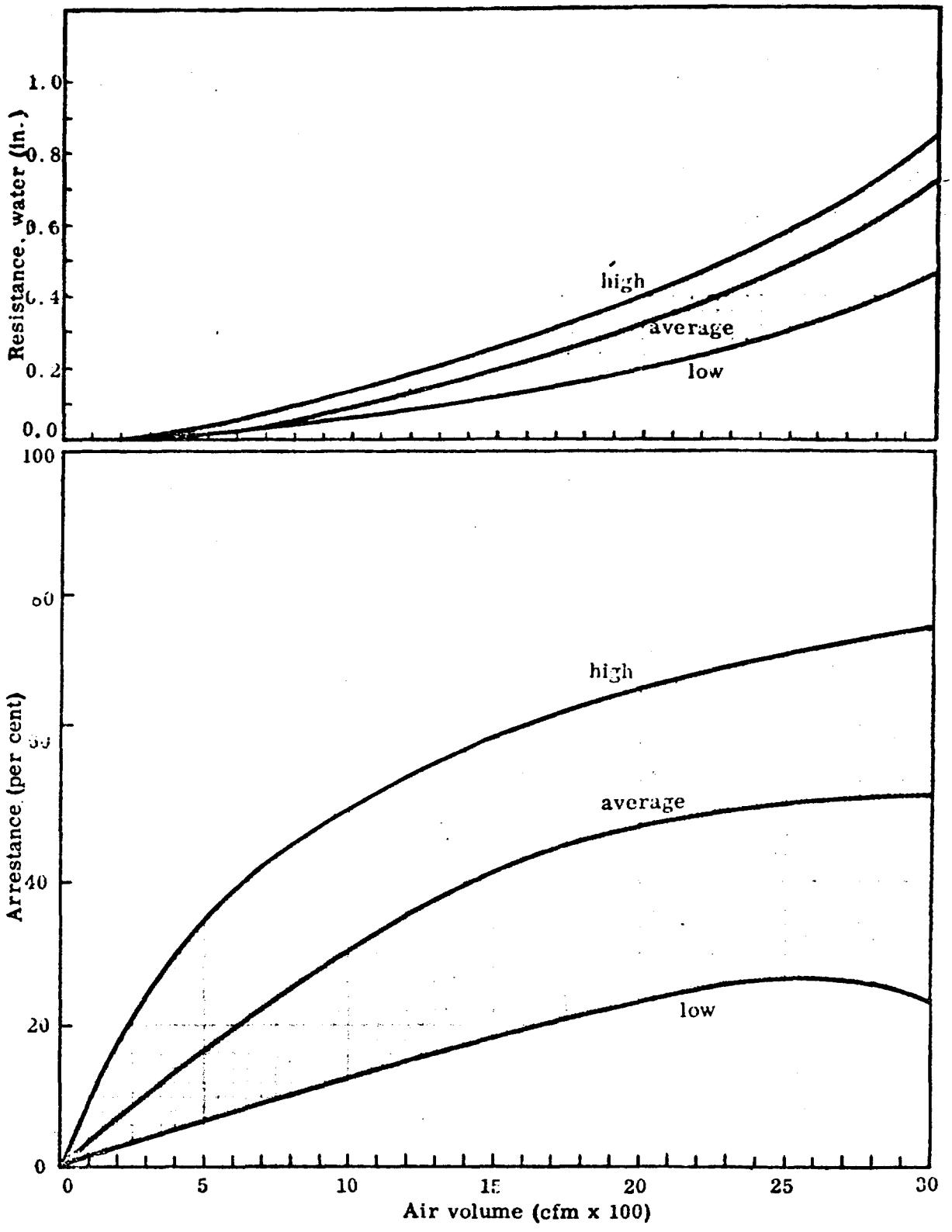

Figure 3. High, low, and average performance curves for the 22 2-in. metal viscous impingement filters tested. The low performance curve does not represent the performance of an individual filter. It is a composite of the low arrestances of any of the filters here tested.

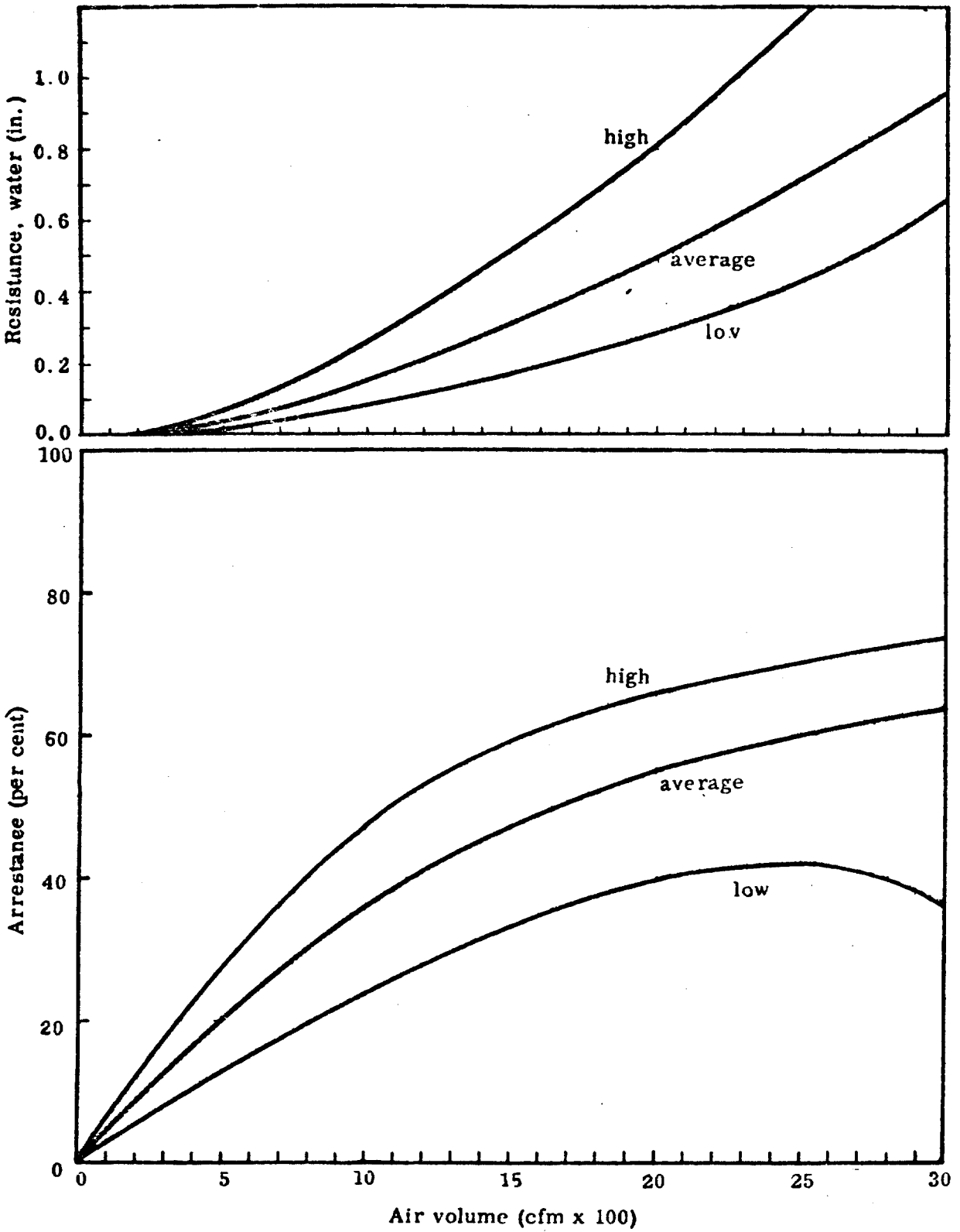

Figure 4. High, low, and average performance curves for the 18 4-in. metal viscous impingement filters tested. The low performance curve does not represent the performance of an individual filter. It is a composite of the low arrestances of any of the filters here tested.

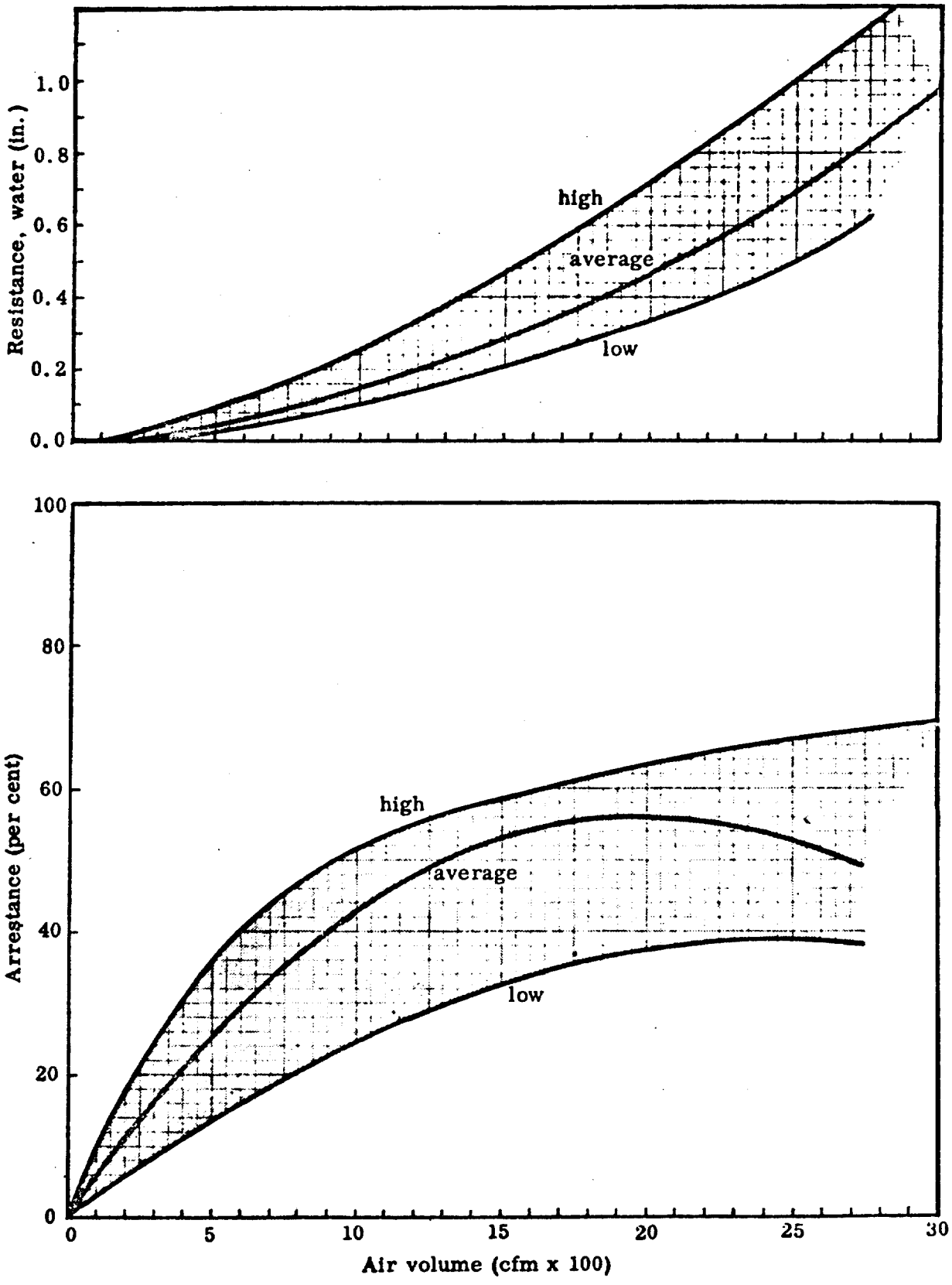

Figure 5. High, low and average performance curves of 8 1-in. fibrous viscous impingement filters tested.

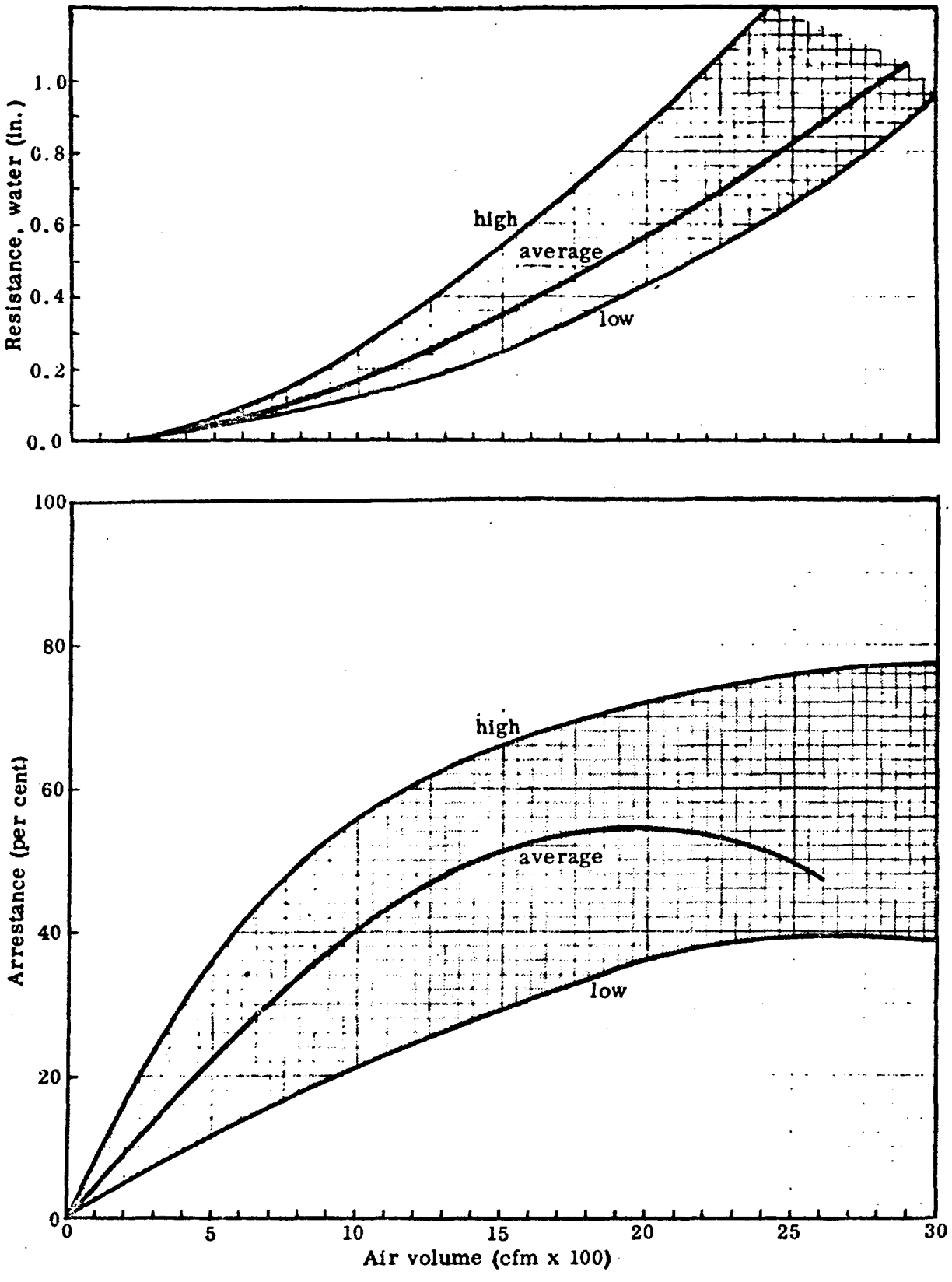

Figure 6. High, low, and average performance curves for the 9 2-in. fibrous viscous impingement filters tested.

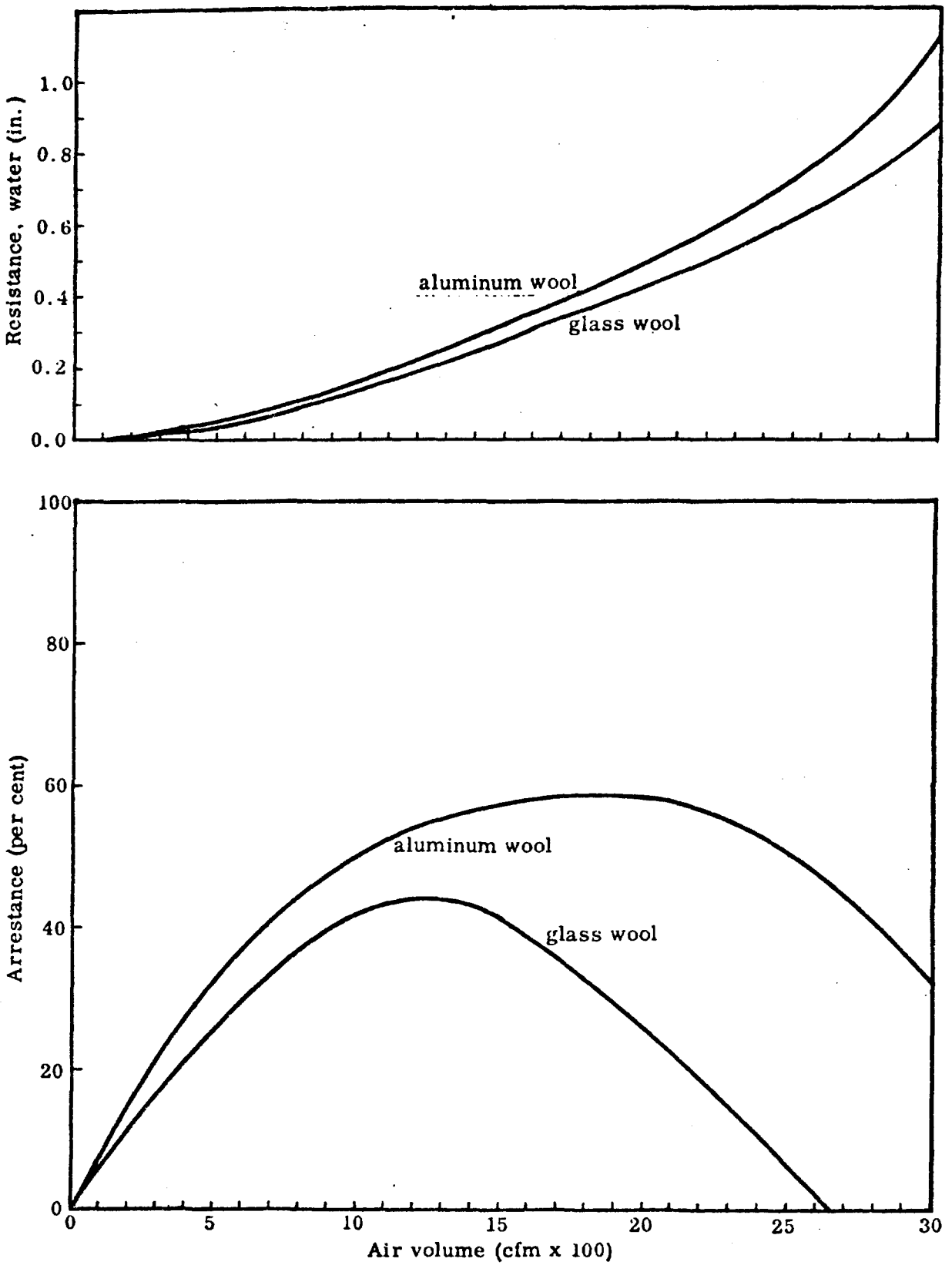

Figure 7. Performance curves for the 2 1-in dry standard fibrous filters tested.

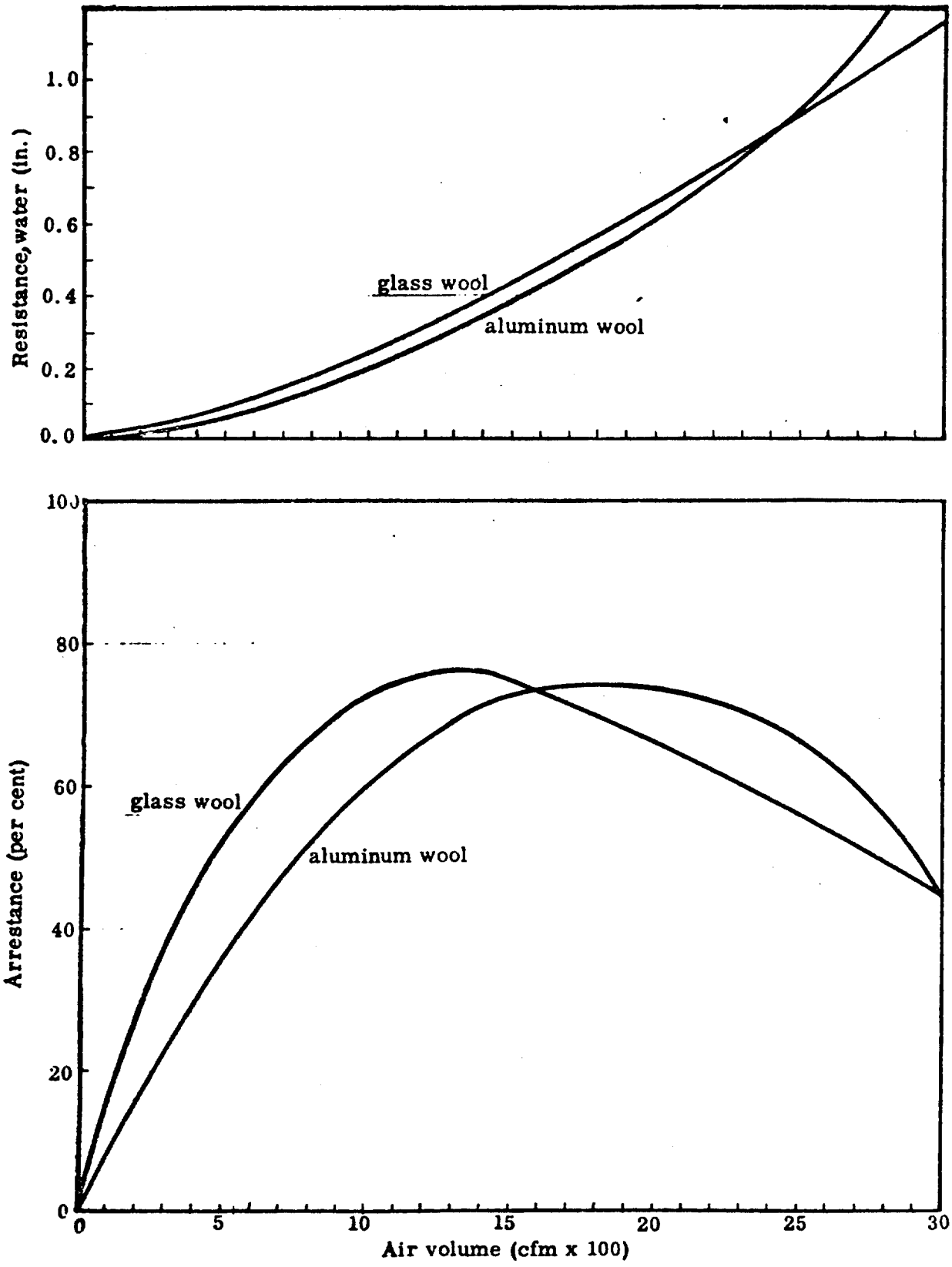

Figure 8. Performance curves for the 2 2-in. dry standard fibrous filters tested.

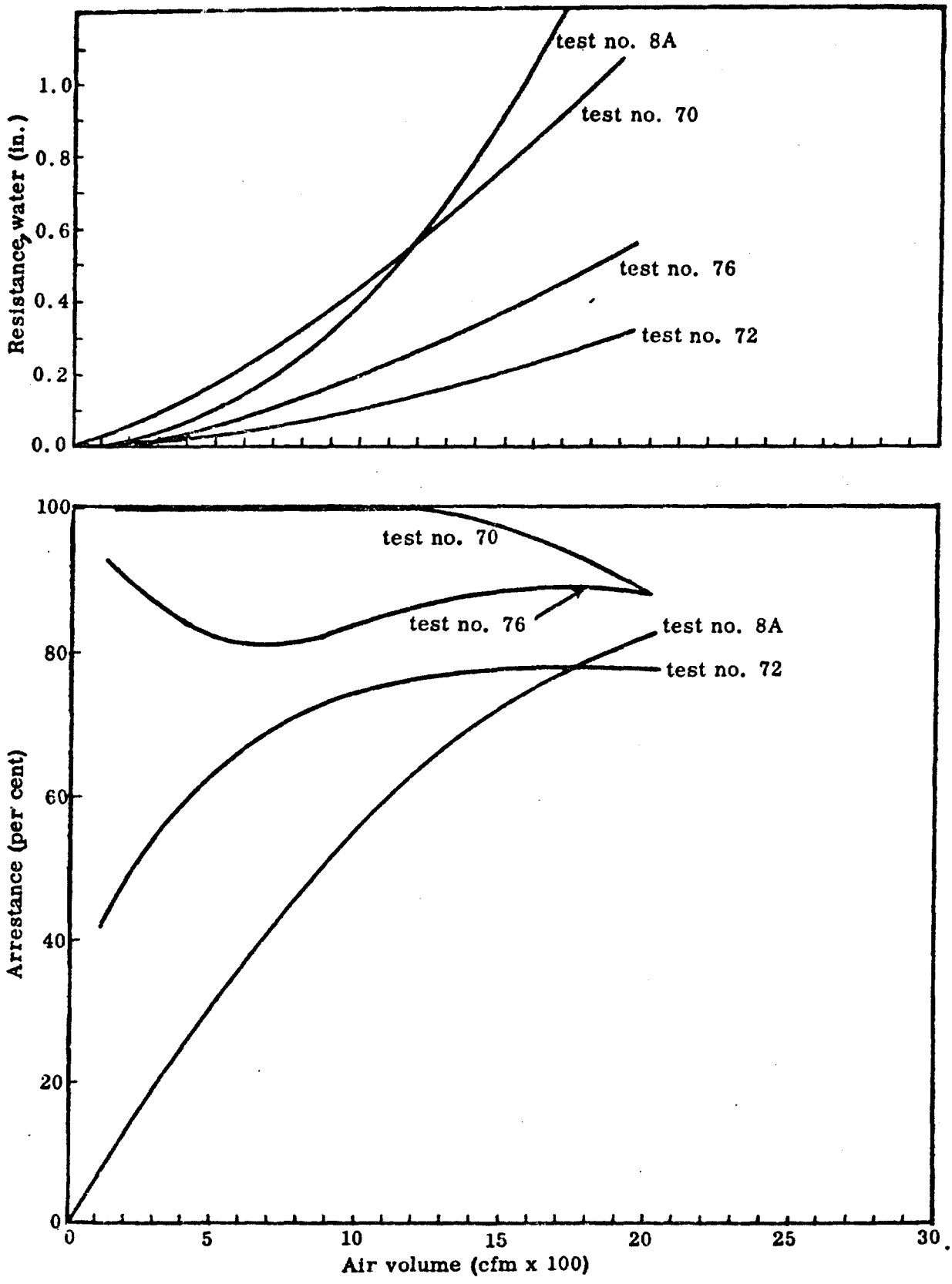

Figure 9. Performance curves for the low velocity dry fibrous filters tested.

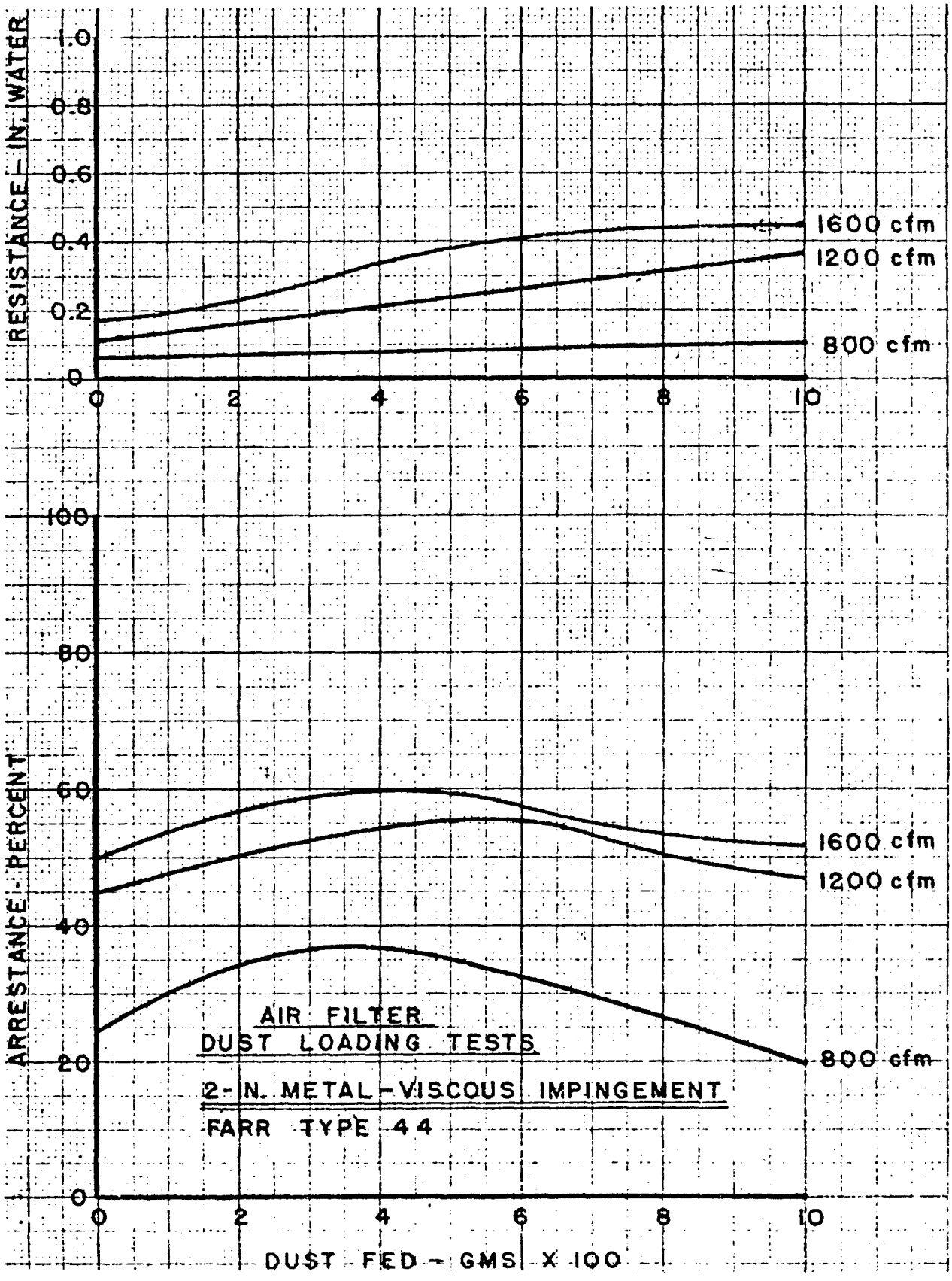
RESISTANCE - IN. WATER
1.0
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
1600 cfm
1200 cfm
800 cfm
ARRESTANCE - PERCENT
100
80
60
40
20
0
1600 cfm
1200 cfm
800 cfm
AIR FILTER
DUST LOADING TESTS
2-IN. METAL-VISCOUS IMPINGEMENT
FARR TYPE 44
0
2
4
6
8
10
DUST FED - GMS X 100

Fig. 10.

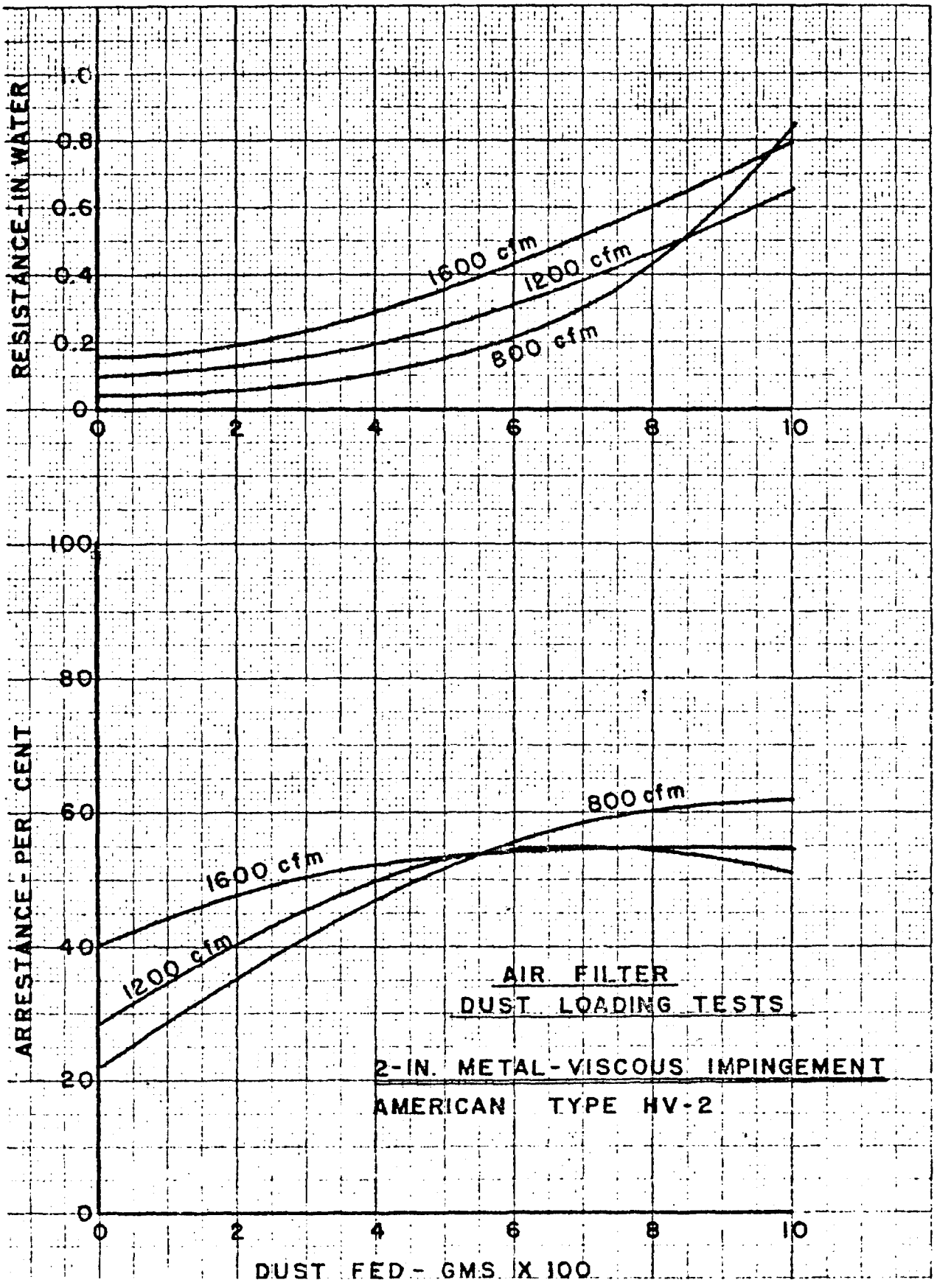
RESISTANCE-IN WATER
1.0
0.8
0.6
0.4
0.2
0
1600 cfm
1200 cfm
800 cfm
0
2
4
6
8
10
ARRESTANCE-PER CENT
100
80
60
40
20
0
800 cfm
1600 cfm
1200 cfm
AIR FILTER
DUST LOADING TESTS
2-IN. METAL-VISCOUS IMPINGEMENT
AMERICAN TYPE HV-2
0
2
4
6
8
10
DUST FED - GMS X 100

Fig. 11.

EVALUATION OF PARTICULATE FILTERS

By Herbert M. Decker, J. Bruce Harstad, and Frederick T. Lense

INTRODUCTION

There is a continuous and increasing need for highly effective air filtration systems in specific areas of hospitals such as operating rooms, in certain industrial processes, and in research laboratories in which particulate free air is required. Decker et al[1] have reported on the filtration arrestance of spun glass filter pads and mineral filter papers. The latter have been found to be efficient in the removal of a bacterial organism (Serratia indica) from an air stream.

This paper reports the degree of bacterial penetration of 3 types of particulate filter units made from pleated filter papers all having a pressure drop of approximately one inch of water at their rated flow.

DESCRIPTION OF THE FILTERS

The first type filter was a CmlC Ml particulate filter consisting of CmlC Type 6 paper. This paper was 0.035 to 0.045 inches thick and was composed of cellulose, rope and asbestos. Corrugated kraft separators were used between each pleat. The paper was sealed into its frame with rubber cement.

The second type filter evaluated was a high temperature commercially available unit. The paper was 0.03 to 0.04 inch thick and was composed of all glass fibers; 82% of the fibers were approximately 3 microns and 18% were 0.5 microns. Corrugated aluminum separators were used between pleats. The paper was sealed with refractory cement into a 16 gauge perforated cold rolled steel frame.

The third type filter evaluated was a commercially produced glass paper filter fabricated to withstand temperatures up to 1000°F. The paper was 0.010 inch thick and was composed of all glass fibers having an average diameter of 0.5 to 0.75 microns. The one outstanding feature of this unit was compatability of all materials. The frame, gasket and filter media were all made from identical basic materials and will all react the same.

TEST PROCEDURE

A bacterial suspension of B. subtilis var. niger spores (frequently referred to as Bacillus globigii) was used to evaluate the efficiency of the filters. The size of the organism is 0.5 by 1.0-1.5 microns. The organisms were nebulized by means of all glass direct-spray peripheral air jet Chicago Type atomizer into a cloud chamber. Biological material from this nebulizer is not alway unicelluler because agglomeration may occur during or after release of the aerosol. The cloud of bacteria was mixed with air, then passed into a prefilter sampling chamber, through the filter media at a face velocity of approximately 5 feet per minute into a post filter sampling chamber and finally exhausted by means of a blower to the outside air.

DISCUSSION OF RESULTS

The results of the Ml filter evaluation tests are shown in Tables 1 and 2.

The first column designates the test number. The average number of test organisms collected per cubic foot of air sampled before the filter during the test period is shown in the second column while the number of hours over which the average composite sample was taken is shown in the third column. Column 4 shows the cumulative hours of nebulization. Column 5 illustrates the cumulative total airflow through the filter, while the last column shows the percent penetration of the test organism through the particulate filter evaluated.

It may be observed that the percent penetration of B. subtilis spores decreased from 8.3×10^{-4} percent during the first hour of nebulization to 1.5×10^{-4} percent after 18 hours nebulization. Evaluation tests on another Ml filter are illustrated in Table 2. This filter unit showed penetration of 2.5×10^{-5} percent during the first hours nebulization which decreased 1.9×10^{-5} percent after 19 hours nebulization.

The same test procedures, compilation and reporting of data as outlined above were applied for evaluation of the all glass particulate filter sealed with refractory cement. Tests were conducted at the rated capacity of 25 cfm. The percent penetration of the unit was 4.6×10^{-3} percent during the first hour of the run, and increased to 8.0×10^{-3} percent after 22 hours nebulization as noted in Table 3. This increased penetration may be due to deterioration of the cement seal of the media to the frame. Cracking of the refractory cement was noted upon visual inspection of the filter. It is felt that the cement used in this filter will not hold up over prolonged periods of use.

Results of a series of 11 tests conducted over a 66-hour test period on the all glass paper filter unit comprised of 0.5 to 0.75 micron size glass fibers are recorded in Table 4. The average percent penetration during the first hour of the test period was 6.7×10^{-6} percent which decreased to 7.0×10^{-7} percent after a 66 hour period. It should be noted that there was considerable variation within this penetration range. This is accounted for by the fact that the filtration efficiency was so high that the post filter collection of a few organisms would greatly magnify the allowed penetration in such a low order of leakages. The data collected show this filter to be the most efficient of all the units evaluated.

It should be mentioned that in all filter tests, there was no significant change in pressure drop although there was an increase in efficiency for all filters evaluated, except the glass media filter sealed with refractory cement. This possibly may be accounted for by the fact that the deposited aerosol presents an increased number of targets for the removal of subsequent aerosol particulates. Since there was no significant increase in resistance the phenomena cannot be accounted for by a significant change in void volume.

SUMMARY

Three types of pleated paper air filters were tested at rated capacities for penetration by spores of B. subtilis var niger. The three filters were the Chemical Corps Ml particulate filter with CmlC Type 6 paper composed of cellulose, rope and asbestos; an all glass filter paper unit in which the filter paper was sealed to the frame with refractory cement; and an all glass filter paper assembly in which the frame, gasket and filter media were all made from identical basic materials. The three types of pleated paper filters show penetrations of less than one part per million when tested at linear airflows of 5 feet per minute with spores of B. subtilis var. niger. Penetration of the filters decreases with use provided the seal of the filter medium to the frame remains intact; the seal was the weak point in one of the filters.

Table 1—Penetration of Bacillus Subtilis Var. Niger Spores Thru Chemical Corps Particulate Filter (M1)

Test No.	No. organisms collected per cu. ft. air before filter	Duration of Test		Total airflow, cu. ft.	Percent penetration during test interval
		No. hrs. per test	Cumul. hrs.		
	$\times 10^5$				$\times 10^{-4}$
1	24.1	1	1	1,800	8.3
2	54.1	5	6	10,800	3.4
3	37.7	6	12	21,600	1.6
4	59.2	6	18	32,400	1.5

Note: Airflow 30 cfm.

Table 2—Penetration of Bacillus Subtilis Var. Niger Spores Thru Chemical Corps Particulate Filter (M1)

Test No.	No. organisms collected per cu. ft. air before filter	Duration of Test		Total airflow, cu. ft.	Percent penetration during test interval
		No. hrs. per test	Cumul. hrs.		
	$\times 10^5$				$\times 10^{-4}$
1	71.4	1	1	1,800	2.5
2	55.2	4	5	9,000	1.9
3	48.1	2	7	12,600	1.6
4	164.0	6	13	23,400	2.1
5	130.7	6	19	34,200	1.9

Note: Airflow 30 cfm.

Table 3 — Penetration of Bacillus Subtilis Var. Niger Spores Thru Commercially Produced Glass Paper Particulate Filter

Test No.	No. organisms collected per cu. ft. air before filter	Duration of Test		Total airflow, cu. ft.	Percent penetration during test interval
		No. hrs. per test	Cumul. hrs.		
	$\times 10^5$				$\times 10^{-3}$
1	155.0	1	1	1,800	4.6
2	108.0	2	3	5,400	4.1
3	40.7	1	4	7,200	7.5
4	70.8	6	10	18,800	4.9
5	42.0	6	16	28,800	7.5
6	198.0	6	22	39,600	8.0

Note: Airflow 25 cfm.

Table 4 — Penetration of Bacillus Subtilis Var. Niger Spores Thru Commercially Produced High Temperature All Glass Paper Filter

Test No.	No. organisms collected per cu. ft. air before filter	Duration of Test		Total airflow, cu. ft.	Percent penetration during test interval
		No. hrs. per test	Cumul. hrs.		
	$\times 10^5$				
1	40.4	3	3	5,400	6.7×10^{-6}
2	67.3	6	9	16,200	2.1×10^{-6}
3	60.0	6	15	27,000	1.6×10^{-5}
4	102.3	6	21	37,800	1.1×10^{-5}
5	114.3	3	24	43,200	5.7×10^{-6}
6	59.9	6	30	54,000	6.2×10^{-6}
7	106.0	6	36	64,800	3.5×10^{-6}
8	58.7	6	42	75,600	1.7×10^{-6}
9	33.9	6	48	86,400	1.9×10^{-6}
10	13.4	6	54	97,200	2.1×10^{-6}
11	51.7	12	66	118,800	7.0×10^{-7}

Note: Airflow 50 cfm.

METEOROLOGY AS RELATED TO AIR CLEANING

By Donald H. Pack
United States Weather Bureau
Washington, D. C.

The science of meteorology is intimately related to air cleaning. After all the oldest and (on a long term basis) one of the most efficient air cleaners is the atmosphere. This is just as well, else the fossil dust of some prehistoric dinosaur might be giving some of us hay fever today. Although enormous amounts of gaseous and particulate matter are constantly transported by the atmosphere, this is only a minute fraction of the amount that has, over geological time, been injected into the air, gradually dispersed, and finally deposited in the oceans and on the land. It is only since the Industrial Revolution that sources of pollution have been so concentrated as to strain and in some instances exceed the natural cleansing capacity of the air, in areas where the resulting concentrations are of biological concern. With the achievement of nuclear fission and the explosive expansion of machines, materials and facilities of a radioactive nature the problem has been made even more acute. For while there seems to be a cause and effect relationship between high concentrations of smog, SO_2, oxidants, etc.) and biological effects (for example witness the Donora, Pennsylvania disaster), the actual chain of events between release of material and evident biological damage is still obscure. On the other hand, the unchecked release of plutonium from a machining facility or all of the fission gases from a fuel processing plant and the subsequent exposure of personnel to internal and external radiological hazard would be an obvious way to cause damage.

Since we know that the atmosphere, unassisted, cannot always reduce local concentrations to levels we feel are acceptable, what place does meteorology play in air cleaning, planning and design? First, an obvious fact; air cleaning devices rarely remove all foreign material, they attempt to reduce the

concentration in the released air to tolerable levels. This does not imply that the air has lost any of its diluting capacity, only that we have overloaded a local segment of it. The back-up capacity of the air to reduce initial concentrations by several orders of magnitude in relatively short distances is a comforting safety factor in air cleaning.

Second, unless a valuable and marketable by-product is salvaged, the requirement for air cleaning may impose penalties of time, efficiency, and expense on the processes to which it must be applied.

Thus any assistance that the dilution capacity of the air can provide to increase the safety, or to reduce the costs, of air cleaning devices is useful.

METEOROLOGY AS A DESIGN CRITERION

Engineering design is usually a compromise between what is desired, what is possible, and what there is money to pay for. The use of meteorological data can assist in arriving at the optimum design level by describing the diffusion climate, or in other words the back-up air cleaning capacity of the air. Data such as the variation in wind speed from day to night and month to month, persistancy of wind directions, frequency and persistance of stable atmospheric situations, to mention only a few, all have a bearing on the amount of air cleaning required to obtain allowable concentrations. However these conditions vary widely over a country as large as the United States. The meteorological data now being collected here at Argonne, Brookhaven, NRTS, etc. are often used in the design of air cleaning equipment. Each of these sites measures parameters governing the travel and dilution of material in the atmosphere and has gathered a body of data that gives a fairly complete picture of the expected variation of atmospheric diffusion. Comparison of these data bear out the fact that the diffusion climates vary as much as the general weather. Although the general

pattern is similar in that atmospheric dilution is usually greatest during the day and least at night, the records show that poorest diffusion may occur at different times of the year at various sites, that wind persistance differs greatly, and that in general each location will have different problems in the dispersal of contaminants. None of these sites however are in particularly unfavorable dilution climates or locations. At the risk of belaboring the already hard pressed Southern California area, the coincident geographical location and restrictive terrain in that area results in a natural air trap. The West coast inversion "lid" and the mountains to the east confine the air movements to a relatively small area both vertically and horizontally. The result is that "smog" has become a serious threat to the community. Obviously in a situation of this type the back-up dilution capacity of the air is at a minimum and air cleaning devices need to be as efficient and as numerous as possible.

During recent years, as the interest in air pollution and the transport of material by the atmosphere has grown, meteorologists have developed methods for computing the concentration of material as it is diffused by the air. Some of the developments are wholly theoretical, some empirical, and some a combination of the two. A description of the development and assumptions underlying the various equations will not be attempted here. However an outline of a number of the various theories is contained in the recent publication "Meteorology and Atomic Energy [1] The equations of O. G. Sutton, [2] the British meteorologist, are quite flexible and have met with reasonable success when applied to practical problems of determining air and ground concentrations and cloud sizes.

Perhaps a better feeling for the practical aspects of the use of meteorological data in air cleaning design can be shown by an illustration. Figure 1 shows

the frequency distribution of various lapse rates at Oak Ridge, Tennessee. It is evident that relatively unstable conditions are most frequent during daylight hours, and that stable conditions are the rule at night. If reasonable "day" and "night" wind speeds are chosen we can obtain concentration curves that can be expected with these conditions. Figure 2 shows such curves, comparing the ground concentrations that would result in the "day" case with "night" conditions. It can be seen that diffusion is much slower with the "night-time" stable conditions. If the maximum permissible level of concentration is known it is immediately evident from computations such as these what requirements are imposed on an air cleaning device.

If the cleaning operation is difficult, or the device can be used only for a limited time of operation, an analysis of the frequency and duration of poor atmospheric diffusion conditions can be made and the time demands on the air cleaning device shown. Figure 3 shows a rough analysis of such data for a single year at the NRTS. The upper curve shows the total hours of stable conditions during each month of the year, with the annual total indicated in the right hand column. The two lower curves show the maximum duration of lapse and stable conditions, during each month of the year. If it is known that air cleaning is required during periods of poor diffusion, then data of this type permits an estimation of the amount time an air cleaning device must operate.

Another direct use of meteorology in air cleaning is in the design of exhaust stacks. As is well known, ground concentrations from an elevated source are less than those from an equivalent source at the ground. Thus tall stacks or high plume rises are beneficial in reducing ground concentrations. On the other hand the achievement of these greater heights usually means greater costs.

Holland [3] has shown that for given stack parameters (height, diameter, gas velocity, heat release, etc.) there exists a critical wind speed that will produce the maximum ground concentrations. If some tolerance concentration level is established it is possible to solve Holland's formula for stack height and compute the minimum stack height necessary to maintain ground concentrations below the established tolerance. The reader is referred to the original publication for the development of this treatment. One difficulty with this approach is that it does not fully account for irregularities in terrain or the influence of buildings. Sherlock and Lesher [4] have described an interesting combination of wind tunnel experiments with actual meteorological data to produce a method for the design of stacks. From both of these treatments a knowledge of the so-called critical wind speeds will permit a statistical determination of the frequency of undesirable concentrations. It is only necessary to examine the meteorological records and tabulate the frequency of occurrence and persistance of the particular speed of interest.

Other obvious uses of weather data in air cleaning design would be for the location of exhausts and intakes, frequency of precipitation and the accompanying wind directions in the evaluation of washout of contaminants, layout of plant buildings in accordance with prevailing winds to prevent mutual interference and contamination.

METEOROLOGY AS AN EVALUATION FACTOR

Whether or not meteorology is considered in the design and installation of air cleaning equipment, an adequate evaluation of the efficacy of the equipment in actual operation may depend on using current meteorological data. Here is a situation where statistically correct random sampling can give an entirely false

or misleading picture. This has actually occurred in at least one instance. Mobile samplers at a site were sent out various directions and distances at random and no activity had been observed. Eventually a sampling run detected a significant increase in activity. This measurement was regarded as instrumental error and discarded. Subsequently a meteorologist was discussing the sampling program and this supposed anomaly was mentioned. A quick check of the records showed that on this particular day the sampling run coincided with the wind direction. In fact the records for this single run represented the routine emission, and all the others were almost without meaning. This was verified when, after this discussion, sampling runs were made on the basis of the wind and weather records and values comparable to the single supposedly anomalous record were obtained consistantly. This is an extreme case but it serves to illustrate the necessity for considering all the parameters in the analysis of the control of effluents.

If a network of fixed monitoring stations is being established, the efficiency of the network can be improved by considering the distribution of wind speed and direction frequencies. A good example of this is at the NRTS at Idaho Falls. The mountains surrounding the Snake River Plain channel the majority of the winds into the northeasterly and southwesterly directions, thus it is advantageous to have the densest network of samplers northeast and southwest of the point of release if representative measurements of airborne material are to be obtained. In addition the differing wind velocities will result in a wide variation of possible concentrations, even if the emission rate remained the same. Figure 4 computed from the Sutton equations shows the theoretical ground concentrations resulting from the continuous or from the instantaneous release of

material at a height of 50 meters. A computation of this type can be used in two ways. If the winds are persistant in direction as at the NRTS, samplers can be placed in the center line of the average plume, near the point of maximum concentration, if this is feasible. Or, if the wind data shows that the sampling station was not in the center line of the cloud travel, but was off to one side, the wind and stability data can be combined with the values reported from the sampling station to compute the maximum concentration that actually occurred but was not intercepted by a sampler. From these computations it is easily possible to evaluate the air cleaning device. Of course the evaluation is not quite as simple as described here. Wind speed and direction variation over the sampling period must be taken into account. The effluent will probably not behave exactly as predicted by theory, and a large amount of laborious computation is required to come up with the proper numbers for the first few trials. However the technique does work and can be reduced to simple charts, nomagrams and templates if the program is a continuous one. Another useful application of this same technique is the identification of a single source of emission where several possible sources exist. When the effluent is not readily identifiable as originating from a known source, it is possible to work backwards from the point of detection using wind and stability information and reconstruct the probable trajectory of the material. This has been done in numerous cases, and just recently an incident occurred at ORNL where paint damage to automobiles was observed. Examination of the wind records showed that this damage was correlated with wind direction, and that the wind was from the direction of a new steam plant. To make doubly sure of the source, two meteorological blimps were used to carry a high volume sampler into the stack plume. Analysis of the sampler filter and of the fallout near the automobiles were almost identical.

However the design engineer or the plant operator working with air cleaning devices may say, and perhaps rightly so, that the preceding approach assumes that the air cleaning device will not meet its design performance or that it will break down.

It could be contended that if the air cleaning device actually works as well as expected the very small amount of material that escapes the device will always be safely below tolerance. This brings us to a more subtle and more difficult aspect of the uses of meteorology. This is the use of weather data in the evaluation of long term, repeated exposure to contaminants in the atmosphere. Each location has its own preferential weather pattern of winds and stability. We have mentioned this in the location of sampling stations. However in relatively open terrain the dominant features of the pattern may be only a few per cent different from the next most frequent so that relatively uniform dispersal over the whole surrounding area is obtained. Past experience however, shows that the demand for water and the need for isolation very often results in locating industrial plants in general, and nuclear plants in particular, in narrow river valleys where the air flow is restricted to certain directions a very large percentage of the time. Also the terrain may be so irregular as to make application of the diffusion equations open to serious question. We know that in cases of this type, "hot" spots can develop where preferential deposition of material occurs, or perhaps that the side of a hill or bluff is almost always exposed to released effluent. If the effluent should be for example, long lived alpha material, even though the amount released were very small, the operation of the plant for a number of years might result in concentrations in these pockets higher than desirable. In sites of this type it may be necessary to make very careful analyses of the wind and stability patterns using portable

meteorological equipment and tracer methods such as smoke pots, or fluorescent particles. From these methods the areas subject to repeated exposure can be defined. Sampling at these points can evaluate any build-up of material and provide information on the long term efficiency of air cleaning.

The evaluation of the long term problem may involve the continuous collection of meteorological records, interspersed with intensive and detailed studies. Since each new site seems to act as a nucleus for subsequent growth and addition of facilities, these changes must be taken into effect in the long term analysis. Addition of new buildings, leveling of hills, removal of trees, and particularly the installation of new sources of contaminants, can change not only the concentration patterns, but may actually influence the small scale air flow.

CURRENT EXAMPLES OF METEOROLOGY APPLIED TO AIR CLEANING

It would be impossible to list all of the current projects under way where the collection and analysis of meteorological data is being used to provide assistance in air cleaning, however a few of the newer projects can be mentioned. Of course there are the continuing programs at the larger AEC sites and in recent months a measuring program was established for the PWR site at Shippingport. This site, about 30 miles northwest of Pittsburgh is a narrow section of the Ohio River valley with high bluffs rising on both sides of the river. In this case the terrain was put to work. The valley is too deep to erect a tower of any practical height so that wind and temperature measuring equipment was placed on the top of a hill overlooking the site, with a second set near the river on the site itself. Comparative measurements from these two locations provide information on the general air flow and the flow in the valley and also the temperature gradients between the floor of the valley and the hilltop.

At the Connecticut Aircraft Nuclear Engine Laboratory south of Hartford, Connecticut the Atomic Energy Commission has requested the Weather Bureau to make a micrometeorological survey of the site. The Weather Bureau together with Pratt and Whitney, the prime contractor, is working to set up a measuring program to describe the air flow and diffusion over the site. This location is again in a river valley, this time the Connecticut River, but the plant location is on a plateau about 150 feet above the river level. In this case it is possible to erect a 200 foot tower from which representative wind and temperature measurements can be obtained.

A third and much more ambitious project is just getting under way at the Taft Sanitary Engineering Center of the Public Health Service in Cincinnati. The last session of Congress authorized a broad scale national investigation of air pollution with the program administered and coordinated by the Department of Health, Education and Welfare. Numerous groups, including agencies such as the Weather Bureau and Bureau of Mines, and various state, local and private organizations are combining to survey every phase of air pollution. This will involve, among many other things, extensive urban surveys, sampling networks, chemical analysis of contaminants, tracing the chain of biological effects, determining major sources of pollution, developing a nationwide climatology of air pollution potential, and in general attempting to learn more about how clean air can be assured in the urban United States.

In conclusion it can be fairly stated that when there is an actual or even a potential source of foreign material that can be released into the air the science of meteorology can assist in evaluating the results and minimizing the effects of such events.

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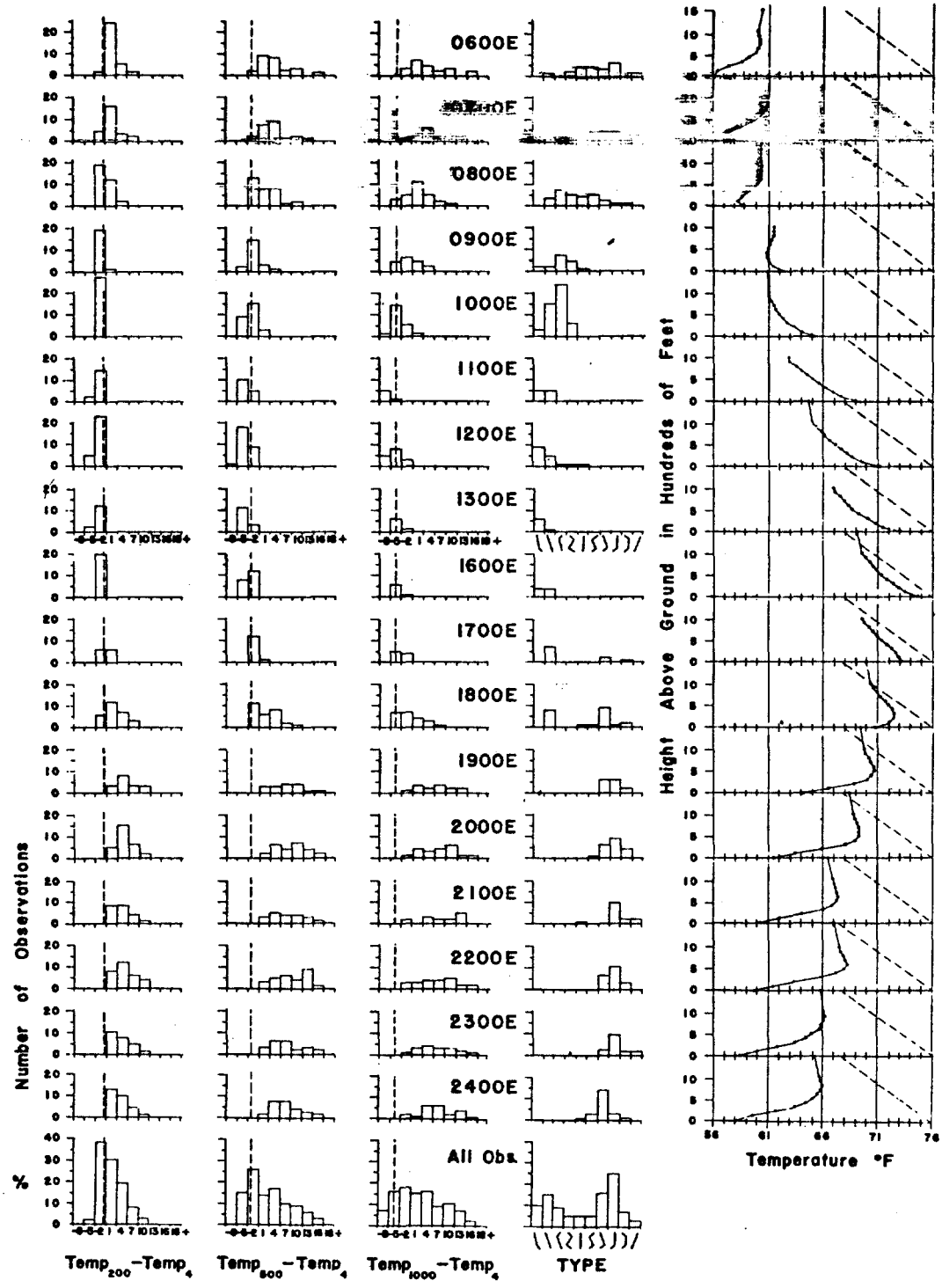


FIG. 1

TEMPERATURE GRADIENT FREQUENCIES (OAK RIDGE, TENNESSEE)

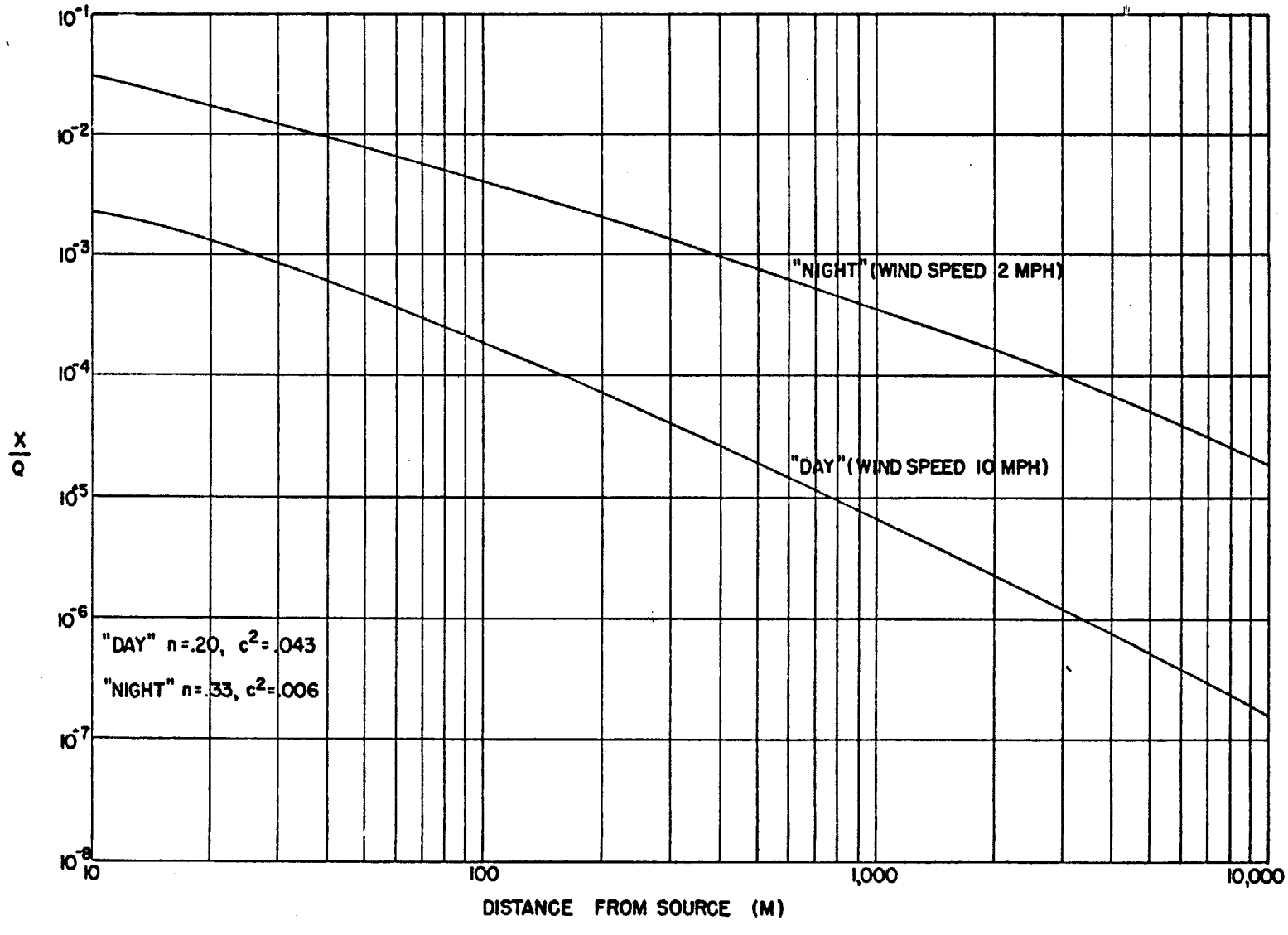


FIG. 2 COMPARISON OF GROUND CONCENTRATIONS

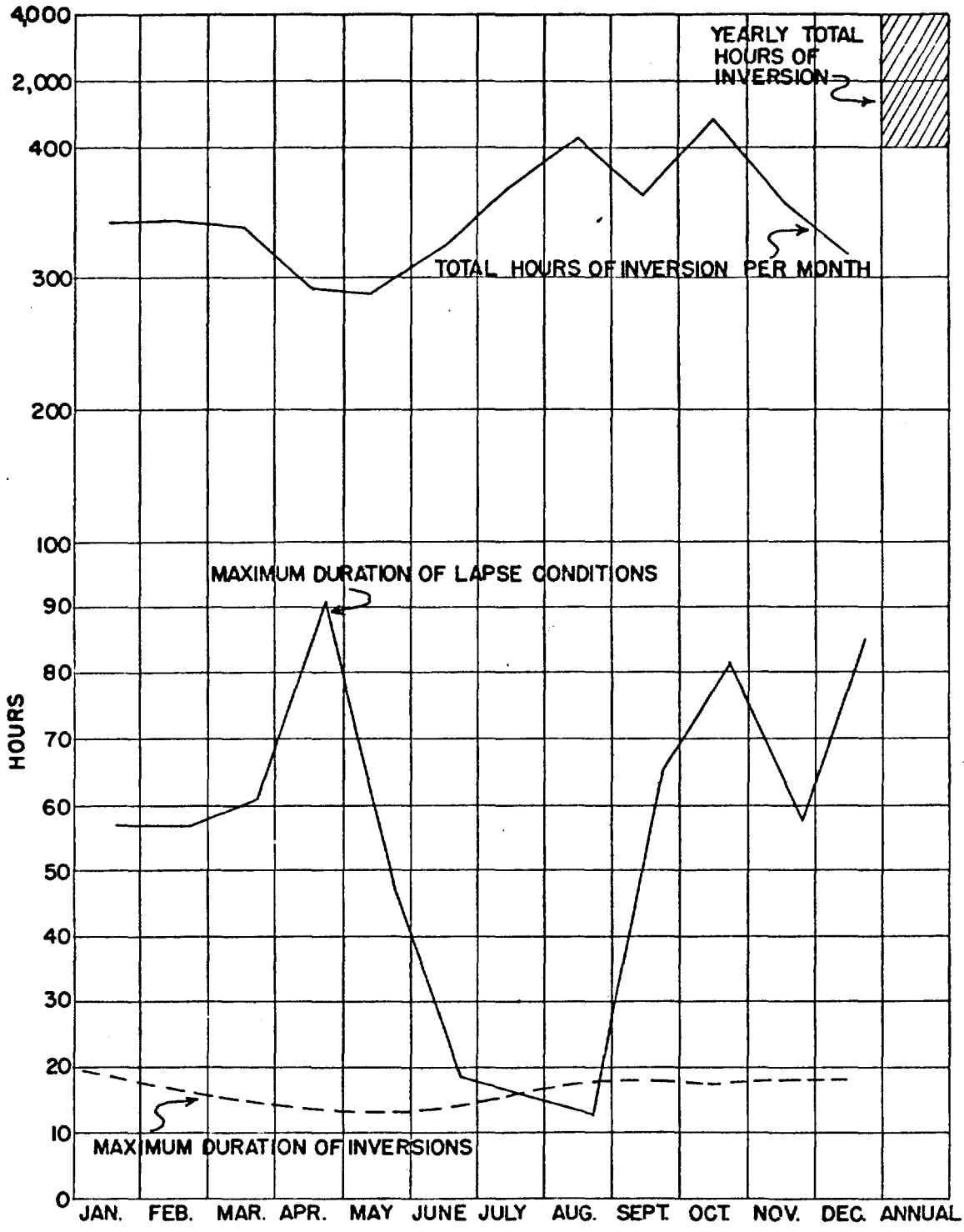
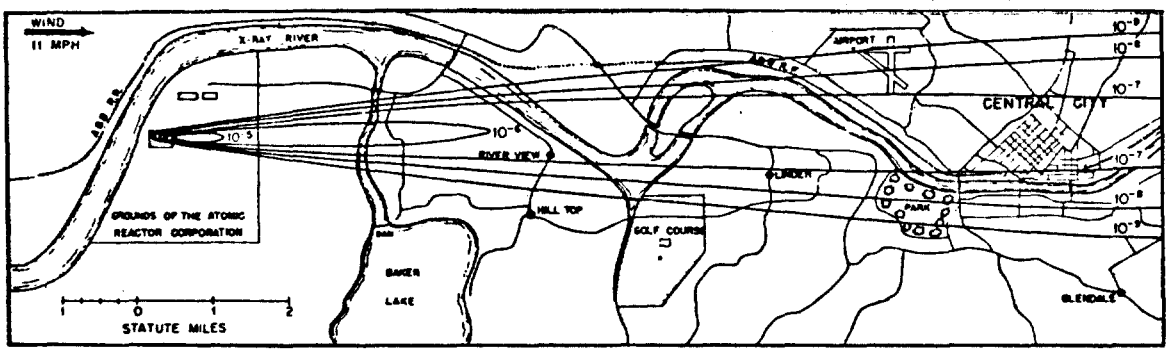
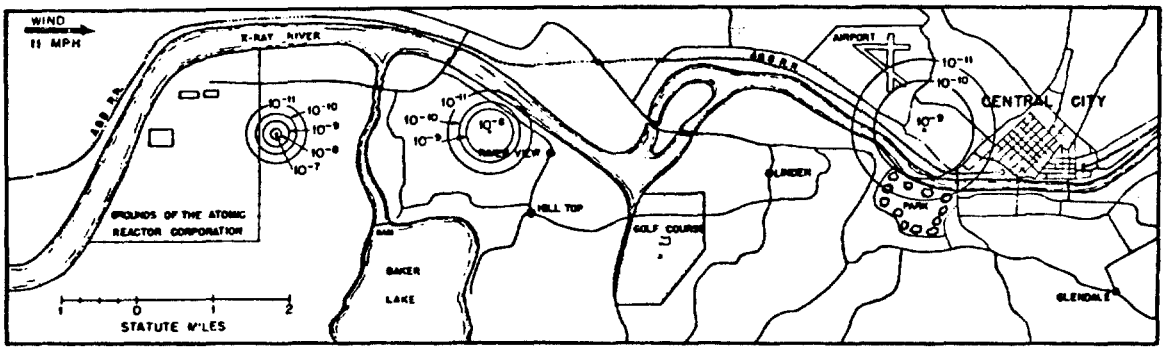


FIG. 3 LAPSE RATE DURATION



(a) Surface concentrations for continuous release from 50 meters



(b) Successive surface concentrations for instantaneous release from 50 meters (8 minutes, 23 minutes, and 53 minutes)

Figure 4. Isopleths of ground concentration (from Sutton formulae).

SAMPLING THE ATMOSPHERE

by

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Several groups at Brookhaven have devoted much attention to problems associated with air cleaning and air sampling. The activities conducted by the Health Physics Division in relation to air cleaning have been summarized in an earlier presentation by Gemmel. My purpose is to review briefly a few aspects of the Meteorology Group atmospheric sampling program. Atmospheric sampling separates into three rather distinct studies denoted by the terms sampling methods, periods and locations. The last of these has been given full consideration, but there are several developments within the first two categories that may be of interest to this assemblage.

Early efforts toward obtaining accurate oil-fog sampling techniques were largely directed toward light-scattering instruments similar to those of Gucker [1] . These developments led to a photometric densitometer that is completely suitable for its specific field use. The device utilizes the 90° scattering of visible light by small particles as the basic operating principle. It differs from other instruments of this general type largely in the refinement of the equipment to give a high degree of stability in field operations. Noteworthy are the use of nickel-cadmium batteries operated in conjunction with a 6-volt charger to provide a constant wattage at the light source, and a completely sealed, dehumidified chamber enclosing both the range switch and its associated resistors. The units are shielded from shock and vibration by rubber mountings. A uniformly clean,

background atmosphere for "zeroing" in the field is provided by helium gas. The instruments in their present form can detect .003 mg/m^3 of oil-fog even while in motion.

Although these units provide [illegible] each requires a vehicle and a complex assortment of auxiliary equipment. As such they are not likely to be used in large numbers, for the cost in dollars and manpower would be excessive. To obtain a large number of simultaneous samples, a filter-type sampler has been developed. This instrument is essentially similar to many other battery-operated units, but it is considerably cheaper, more accurate and draws a larger volume of air than most. The heart of the sampler is a Trico EV-105 pump operated by a standard automobile storage battery. This pump, available in quantity at a unit price of approximately $14.00, will draw 0.75 cfm through a 1-inch Millipore filter for more than 2 hours with a decrease of only 10% in flow rate. The unit currently used at Brookhaven employs the 6-volt model, but the 12-volt assembly would probably operate at lower temperature with longer life. A high order of accuracy is achieved by determining the pressure-drop flow rate curve for each individual filter and head, and subsequently measuring the pressure-drop during field operations by a mercury manometer mounted on the case. The manometer was chosen because of the difficulty experienced with several types of small flowrators.

The Millipore filter is of course not a necessary component of the assembly for all purposes. It is used for the oil-fog testing because it has proven highly reliable in both the collection and the subsequent fluorometric analysis. Measurements of .008 mg of oil are possible with the technique in its present form, and as many as 100 samples can be pro-

cessed during a normal working day.

The most recent development is the conversion of the filter system for airborne operation. Based on considerable unfortunate experience with airborne sampling techniques, it was decided at the outset that any sampler involving excessive weight, complicated electronics, wires or control lines might as well be discarded without test. A simple device, preferably inexpensive since the chance of loss is great, was the objective. A very suitable solution was found in the Fox 35 model aircraft motor. This semi-diesel, "glow plug" motor is used with the Millipore filter head in two ways. In the first, a portion of the intake vacuum draws air through the filter. The volume is necessarily small (0.05 cfm), but the flow rate is reasonably steady and successful runs of 30 minutes or more are common. The second model makes use of a cut-down Trico pump coupled to the motor to provide a flow rate of 0.5 cfm, comparable to that of the ground sampler. The weights of the two assemblies including filters, tubing etc. are 1.5 and 3.5 lbs. respectively. Since the J-1400 Kytoon has a static free lift of 2.2 lbs., they can also be described as 1-Kytoon and 2-Kytoon models. Oil-fog concentration measurements during temperature inversions have already been obtained, and test runs extending to 1000 feet above ground have been shown to be practicable. Two men are required for launching, and one can manage the instrument afterward.

The use of the filter samplers focuses attention directly on the problem of sampling time. The dependence of sampling accuracy on the time scale of concentration fluctuations was described at the recent Symposium at Pasadena by Smith and Singer [2] . Further efforts along this line have resulted in the preparation of a UNIVAC program for the processing of both wind and

concentration power spectra. Enough data have been studied by this means to show conclusively that in typical daytime conditions, eddies having periods of 6-10 minutes dominate the dispersion from the 355 foot test stack at Brookhaven. If additional studies give results in agreement with these initial data, it will be necessary to consider rather far-reaching revisions in much of our instrumentation as well as our sampling techniques. After all the emphasis on fast response equipment, it would be ironic to find that heavily-damped instruments were really the most suitable for typical pollution problems.

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SOME OBSERVATIONS OF PARTICLE DISTRIBUTION WITH HEIGHT IN THE LOWER ATMOSPHERE

by

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ABSTRACT

Quantitative observations of dust particle concentrations and particle size-frequency distributions at various heights up to 400 feet above the ground surface are presented. It is observed that particle concentrations decrease rapidly with height near the ground and less rapidly at higher elevations. The decrease in concentration of large particles with height is much more rapid than for small particles.

SOME OBSERVATIONS OF PARTICLE DISTRIBUTION WITH HEIGHT IN THE LOWER ATMOSPHERE

I. INTRODUCTION

The particle load carried by the free atmosphere is of direct interest in at least two general problems of air cleaning. The amount of particulate material and the size of the particles carried by the atmosphere to the air intakes of an industrial plant is of practical interest since these quantities determine the amount and type of air purification required to meet the plant requirements for particle-free air. Similarly, the particle loading of the air leaving the plant has direct consequences in the problems of deposition and deleterious effects of the particles on the surrounding area.

The present paper is directed to the first of these problems. In particular, observations of dust particle loading of the lower atmosphere due to the erosive action of the wind upon the ground surface are presented to show, 1) the relative decrease in concentration of particles of various size with height, and 2) how the mass of particulate material per unit volume of air decreases with height above the ground surface. Prediction of the total dust loading of the atmosphere at any particular locality and under a given set of surface and meteorological conditions must be done on a largely empirical basis at the present time. Work on the specification of the necessary and sufficient parameters for the prediction of surface erosion, and subsequent airborne concentrations,

has gone forward during the past few years but no adequate quantitative treatment of this problem has yet emerged.

II. PARTICLE DISTRIBUTION WITH HEIGHT

Under natural conditions the energy necessary to remove particles from the surface and lift them to some height must be derived from the kinetic energy of the air motions. In the case of particle removal from the surface this momentum transfer is accomplished in two ways, 1) by direct drag of the air on the particles, and 2) by the impingement of previously airborne particles on the surface, the impinging particles having been accelerated by the air motions during their time of flight. Since the work done in moving a particle upward is directly proportional to the mass of the particle, heavy, or large, particles are more difficult to remove from the surface and these large particles are not carried to as great heights as the small particles by this initial impulse.

Once the particles are airborne they are dispersed by the turbulent motions of the wind. But the large particles have fall velocities which are generally large with respect to these turbulent motions and the large particles tend to return to the surface rather quickly. The small particles are more at the mercy of the air motions and may be dispersed to appreciable altitudes.

The net effect of the differential removal and dispersion of particles according to the size or mass of the particles is two-fold: 1) the concentration of particles decreases with increasing particle

size at all levels, and 2) the concentration of large particles decreases more rapidly with height than does the concentration of smaller particles. [illegible] substantiate this picture quite well and indicate the magnitude of these concentrations and vertical concentration gradients at Hanford.

We may specify more exactly what is meant by "large" and "small" particles from work done by W. S. Chepil[1]. From wind tunnel experiments and some observations made under field conditions, Chepil has classified the relative erodibility of various particle* sizes as follows:

Particle Diameter	Relative Erodibility
$d < 20\mu$	Non-erodible except under excessive wind speeds ($>$ 50 mph at 6 in.)
$20 \leq d < 50$	Difficultly erodible.
$50 \leq d < 500$	Highly erodible.
$500 \leq d < 1000$	Difficultly erodible.
$d \geq 1000$	Non-erodible except under excessive wind speeds ($>$ 50 mph at 6 in.)

Chepil[2] also points out that wind erosion of soils is more nearly controlled by the fraction of each of these particle sizes present on the surface so that particles less than 50μ in diameter are easily erodible in the presence the highly erodible particles 50-500μ in diameter.

According to the above classification we should not expect to find airborne particles greater than 1000μ in diameter simply because

*Natural dust particles, density assumed to be 2.65 gm/cm^3.

they are seldom removed from the surface. Hence, a particle 500-1000 μ in diameter could be considered to be a large particle. On the other end, the smallest airborne particle size is probably dictated by the smallest particles present in the surface soil.

III. PARTICLE CONCENTRATION MEASUREMENTS

All of the particle concentration measurements reported here were made with cascade impactors of the type shown in Figure 1. The impactor is on the left and temperature, wind speed, and wind direction sensors are shown to the right. The particle size-frequency distributions were obtained by visual sizing and counting of the particles impacted upon the four slides or stages used in this instrument. In order to obtain vertical distributions of particle concentrations three or more impactors were operated simultaneously at various heights above the ground. The 400-foot Meteorology Tower and the 42-foot Portable Mast were used as platforms for these observations.

The particle size-frequency distribution for one of these observations is shown in Figure 2. The five class intervals chosen for grouping of particles according to size are shown at the bottom of this figure. These class intervals of diameter correspond to Chepil's classification according to relative erodibility.

The average particle diameter and the mass mean diameter for this particular size-frequency distribution of particles are also

shown in Figure 2. The average diameter is simply the arithmetic mean while the mass mean diameter is defined as the particle diameter which would be observed if all the particles were of a uniform diameter and density. (The particles are assumed to be spherical and of a uniform density, 2.6 gm/cm^3, for all mass calculations.) Since the particle concentration decreases through no less than four orders of magnitude, the mass mean diameter gives a somewhat more representative measure of the size-frequency distribution, although it cannot supplant the size-frequency distribution.

The average concentration of particles in each of four class intervals of size and at various levels up to 400 feet above the surface on August 1, 1955, are shown in Figure 3. The decrease of particle concentration with increasing particle size and the relatively rapid decrease of concentration of large particles with height are clearly evident. The ratios of both of these quantities for the class intervals of size used here may be measured in terms of orders of magnitude.

The average mass concentration of dust particles and the mass mean diameter of these particles for the August 1 observations are shown in Figure 4. The mass concentration decreases ten-fold in the first 100 feet above the ground and is nearly constant above that level. The mass mean diameter also decreases with height, indicating the relative abundance of large particles in the lower levels.

The remaining observations of particle concentrations were made with the Portable Mast and are therefore limited to the first 41 feet above the surface. Only the average mass of dust particles and the mass mean diameters are shown in the figures; a more complete tabulation of particle size-frequency and average wind speeds are given in Table 1.

An observation of dust loading of the atmosphere when the Portable Mast was downwind from traffic over a dusty road is shown in Figure 5. This is not natural wind erosion, of course, but it is interesting to note that the dust kicked up by traffic did not rise to the 15-foot level even though abnormally high concentrations of dust were present at the 0.9-foot level.

A pair of observations of dust concentrations, one made in the morning and the other in mid-afternoon of the same day, are shown in Figure 6. These observations were made under natural conditions and the average wind speed was 3-5 mph during both periods. The dust concentration at each level was practically invariant between the observation periods. Again we note a rapid decrease in dust load in the lowest layers of the atmosphere.

A similar pair of observations, made during the morning and afternoon of May 27, 1955, are shown in Figure 7. Light rain had fallen during the afternoon and evening of the previous day so that the ground surface was damp during the morning of the 27th but dried out during the day. Particle concentrations were low during the

morning and there was practically no vertical gradient of dust mass. With increased erosion during the afternoon particle concentrations increased in the lower levels and the usual gradient of mass concentration was reestablished.

The observations shown in Figure 8 were made during a windy period on October 5, 1955, when the ground surface was dry. Again we observe a rapid decrease of dust concentration with height in the lower layers and essentially uniform concentrations above 15 feet.

IV. CONCLUSIONS

The implications of these observations of dust concentrations at various heights above the surface are obvious so far as the position of air intakes is concerned. A reduction of dust concentrations by a factor of one-fifth or one-tenth can be achieved by placing the air intakes at ten to fifteen feet above the surface. These observations are not strictly applicable in the vicinity of a large building since the building itself introduces turbulent motions which may mix particles to greater heights. But there appears to be little doubt that airborne dust concentrations, produced by erosion of the soil, decrease rapidly with height in the vicinity of the ground surface.

Similar observations have been reported by Chepil and Milne[3]. They found that approximately 93% of the total dust load transported

by the atmosphere over an open field in Canada was transported in the layer between the surface and a height of one foot.

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Table 1

Measurements of dust particle size-frequency distributions in the lower atmosphere at HAPO. 1955.

TOWER	Date	Time	Height	Particle Size Range* A	B	C	D	E	Ave. Mass Conc.	Average Particle Diameter	Mass Mean Diam.	Average Wind Speed
			ft	No. per ft^3	No. per ft^3	No. per ft^3	No. per ft^3	No./ ft^3	x 10^{-5} gm/ft^3	μ	μ	mph
400 ft	Aug. 11	1600 to 1700 PST	1¼	6381	2585	747	71		73.7	12	39	14
			50	5181	1557	275	9		12.5	9	24	24
			100	3377	1138	185	3		5.8	9	24	26
			200	3821	1159	148	1		3.6	8	17	27
			400	2254	819	88	2		3.4	9	19	31
42 ft Portable Meteorology Mast	Apr. 8	0830-1530 PST	0.9	920	330	80	56	16	142	21	92	2-10**
			14.7	3500	800	84	4		5.1	7	21	2-12**
			41.3	2500	480	36	1		1.6	7	16	2-14**
	May 4	0900-1100 PST	0.9	2200	350	37	2		2.4	6	19	3
			14.7	1500	190	6	0.3		0.4	6	12	4
			41.3	1600	180	8	0.9		0.2	6	10	4
		1300-1600 PST	0.9	2200	590	56	1.4		2.3	7	18	3
			14.7	1800	180	8	0.3		0.5	5	12	4
			41.3	1600	180	9	0.6		0.8	6	15	5
	May 27	0830-1230 PST	0.9	870	150	19	1		1.2	7	20	6
			14.7	580	110	9	1		1.1	7	23	8
			41.3	720	110	13	1		1.1	7	22	10
		1300-1530 PST	0.9	1600	670	77	2		3.2	9	22	5
			14.7	1400	320	24	2		2.2	7	21	7
			41.3	1200	270	13	1		1.2	7	18	8
	Oct. 5	1215-1315 PST	0.9	5000	750	83	8		8.6	7	22	6
			14.7	3500	243	35	2		2.4	5	17	13
			41.3	5000	230	30	2		2.3	5	15	18

* A: 0.9 to 5 μ; B: 5 to 20 μ; C: 20 to 60 μ; D: 60 to 240 μ; E: 240 to 500 μ.

** Range of hourly average wind speeds observed during this period.

FIGURE-1

CASCADE IMPACTOR AND METEOROLOGICAL INSTRUMENTS

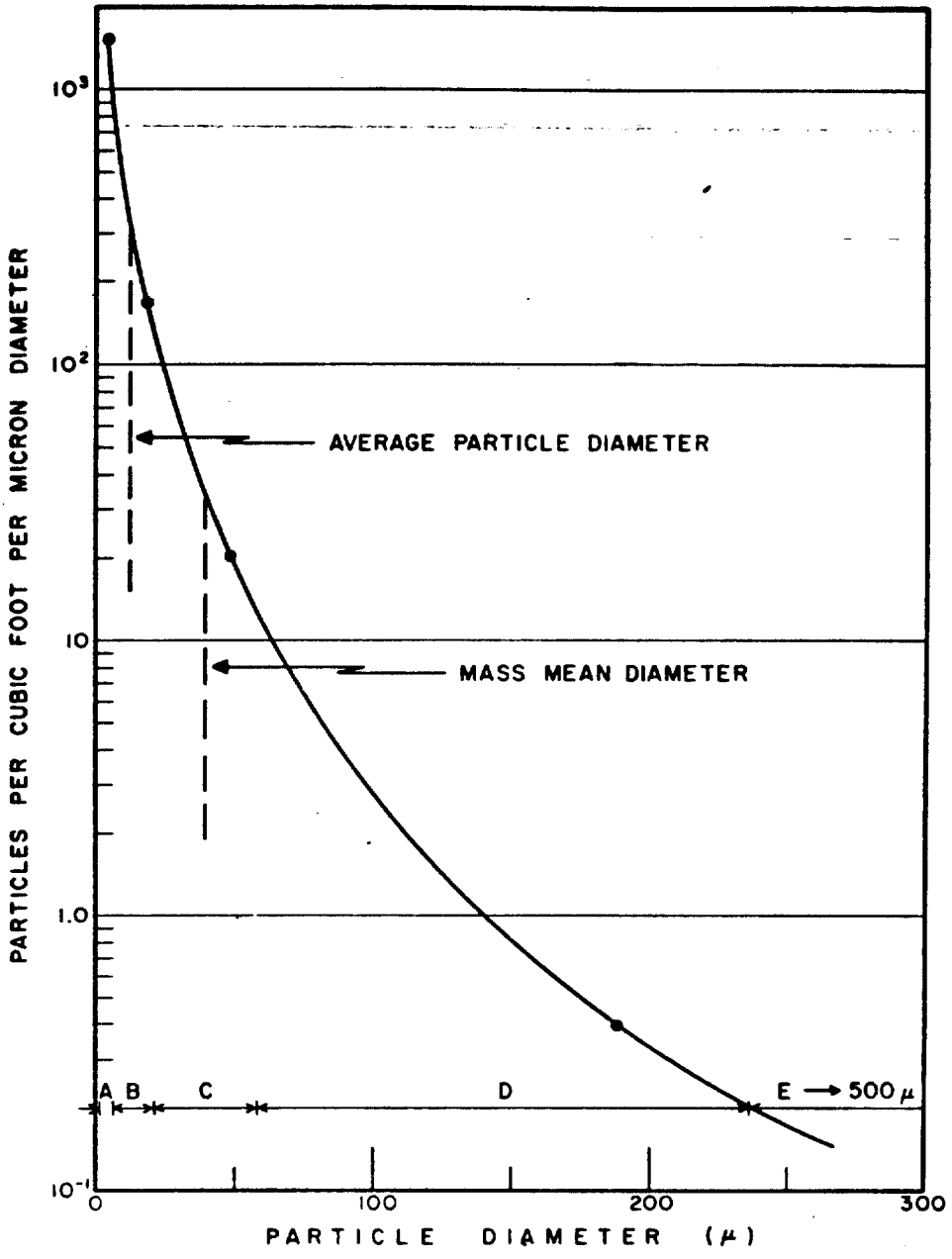

FIGURE – 2
PARTICLE SIZE-FREQUENCY DISTRIBUTION
15 INCHES ABOVE GROUND LEVEL.
METEOROLOGY TOWER, HAPO. AUGUST 1, 1955

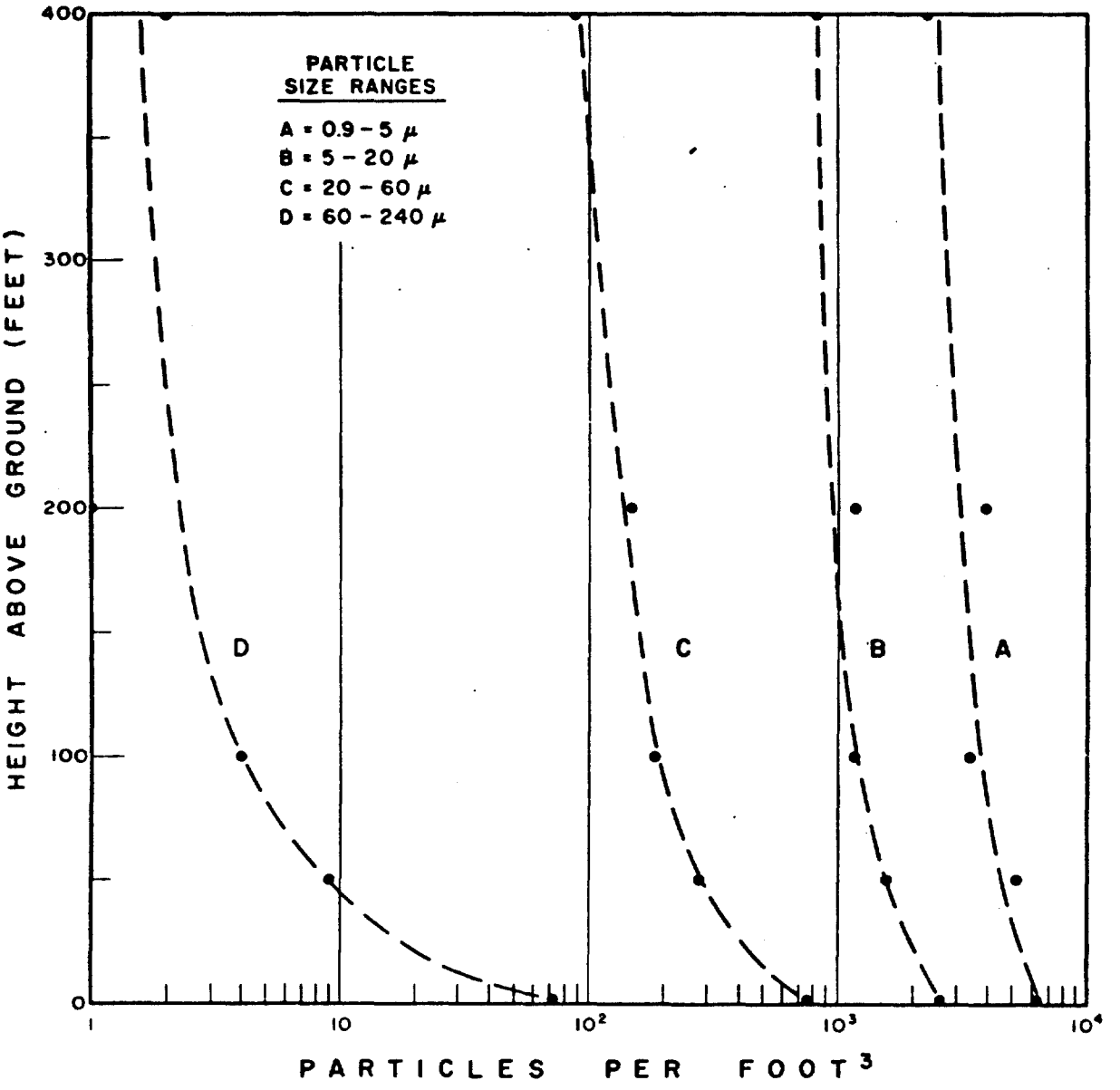

FIGURE - 3
AVERAGE CONCENTRATION OF DUST PARTICLES IN VARIOUS SIZE RANGES UP TO 400 FEET ABOVE GROUND LEVEL. METEOROLOGY TOWER, HAPO. AUGUST 1, 1955

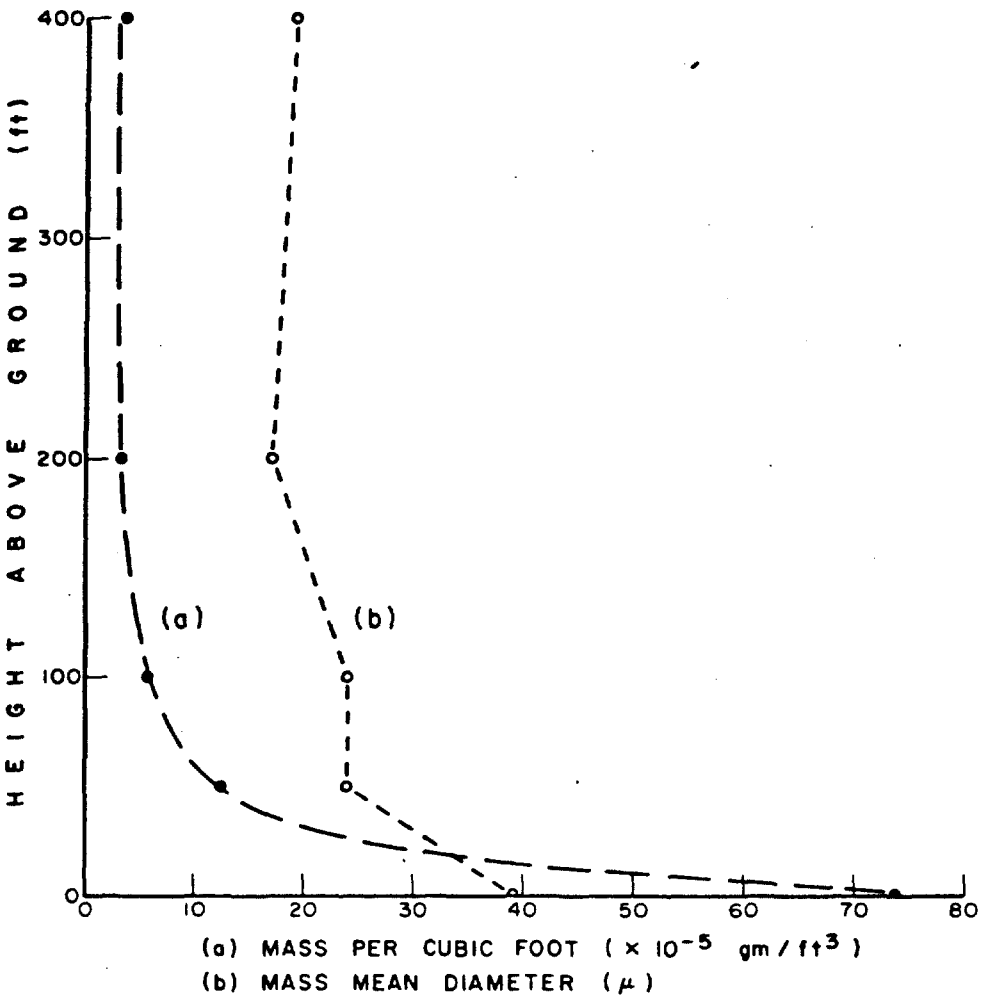

FIGURE – 4
(a) AVERAGE MASS OF DUST PER FOOT^3, AND
(b) MASS MEAN DIAMETER OF DUST PARTICLES.
METEOROLOGY TOWER, HAPO. AUGUST 1, 1955

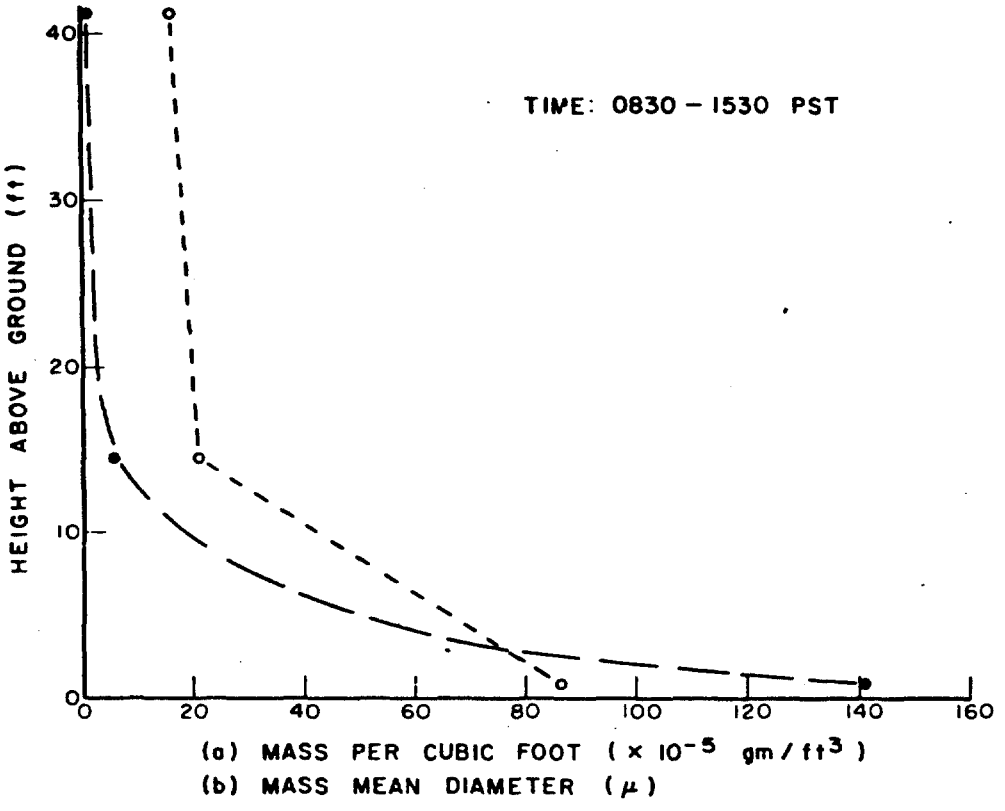

FIGURE – 5
(a) AVERAGE MASS OF DUST PER FOOT^3, AND
(b) MASS MEAN DIAMETER OF DUST PARTICLES.
PORTABLE MAST, HAPO. APRIL 8, 1955

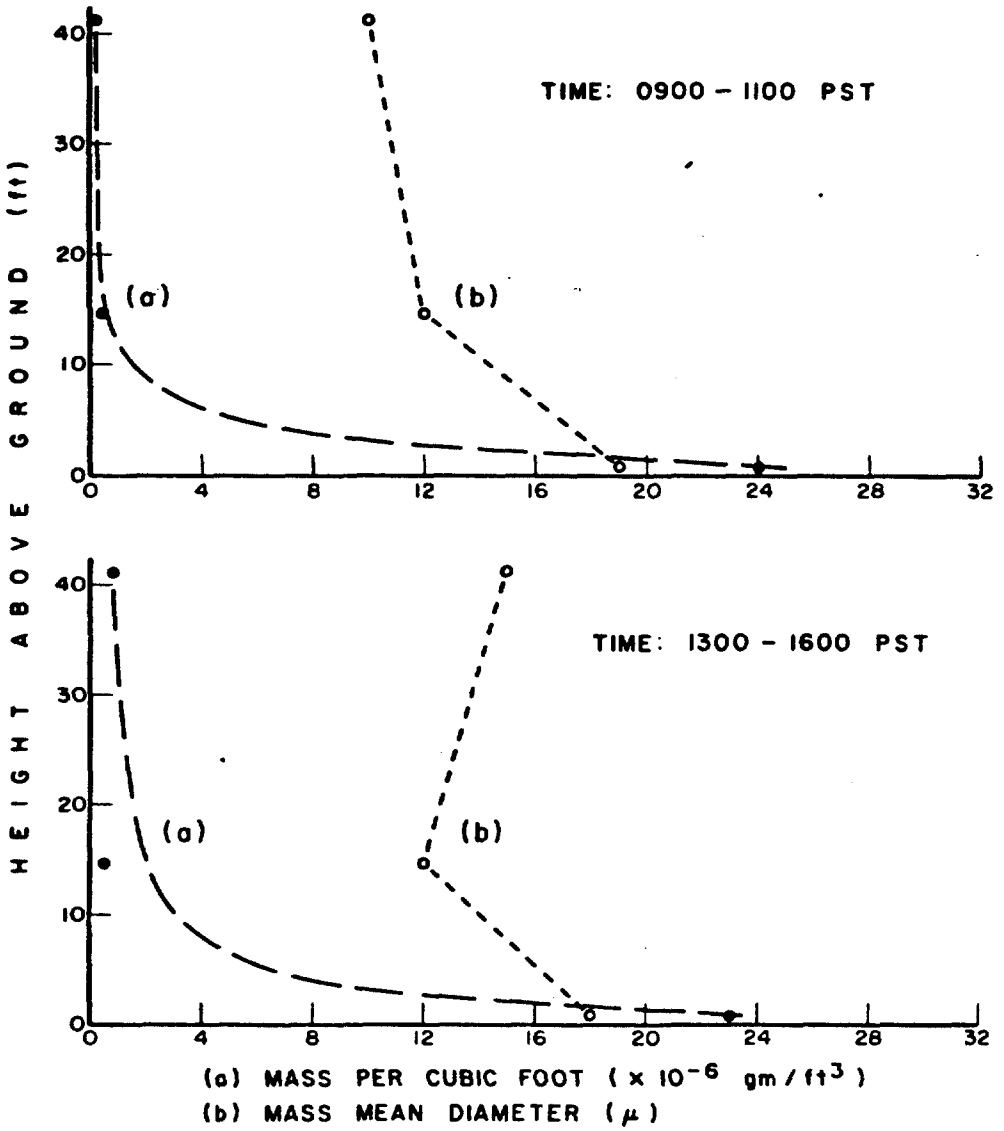

FIGURE – 6
(a) AVERAGE MASS OF DUST PER FOOT^3, AND
(b) MASS MEAN DIAMETER OF DUST PARTICLES.
PORTABLE MAST, HAPO. MAY 4, 1955

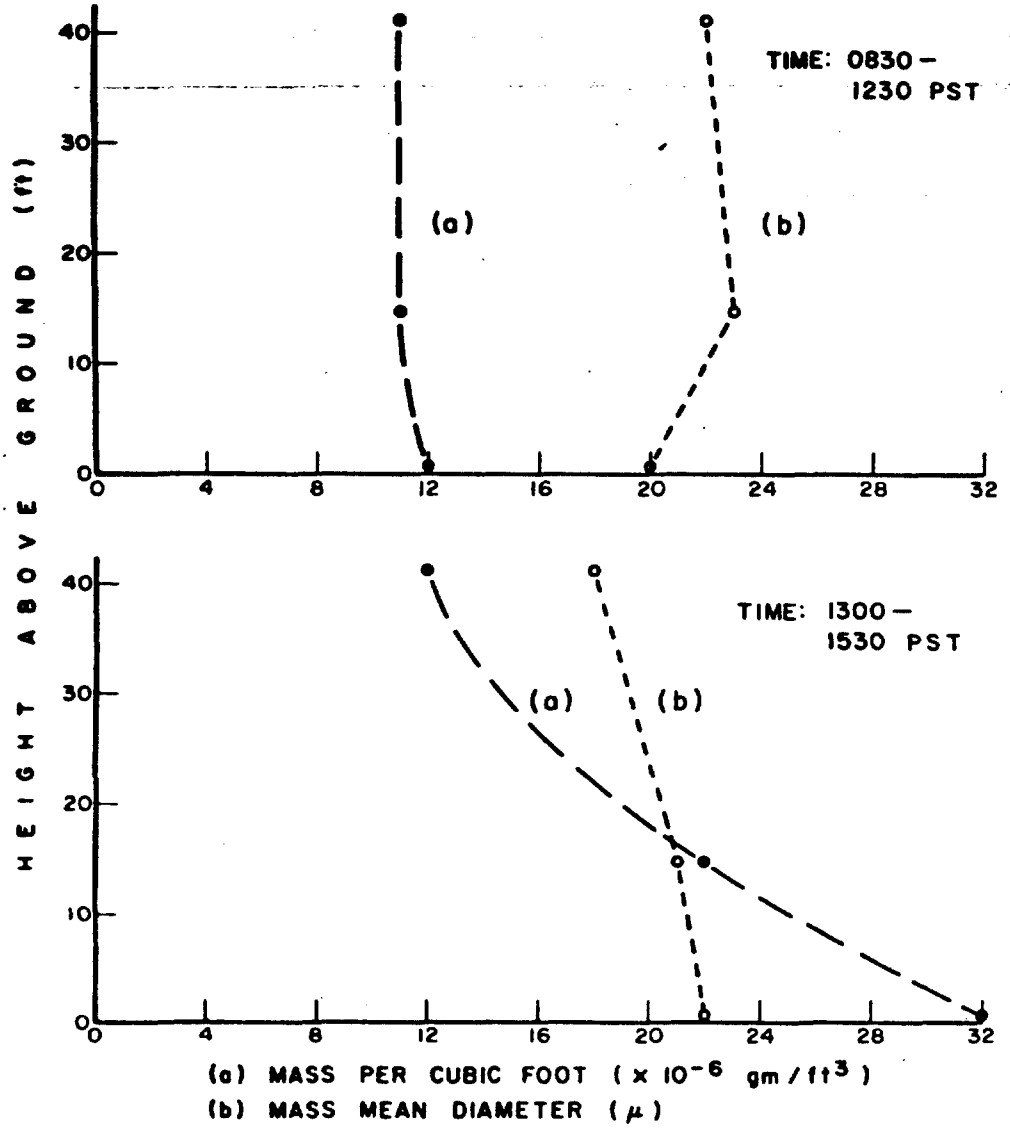

FIGURE – 7
(a) AVERAGE MASS OF DUST PER FOOT^3, AND
(b) MASS MEAN DIAMETER OF DUST PARTICLES.
PORTABLE MAST, HAPO. MAY 27, 1955

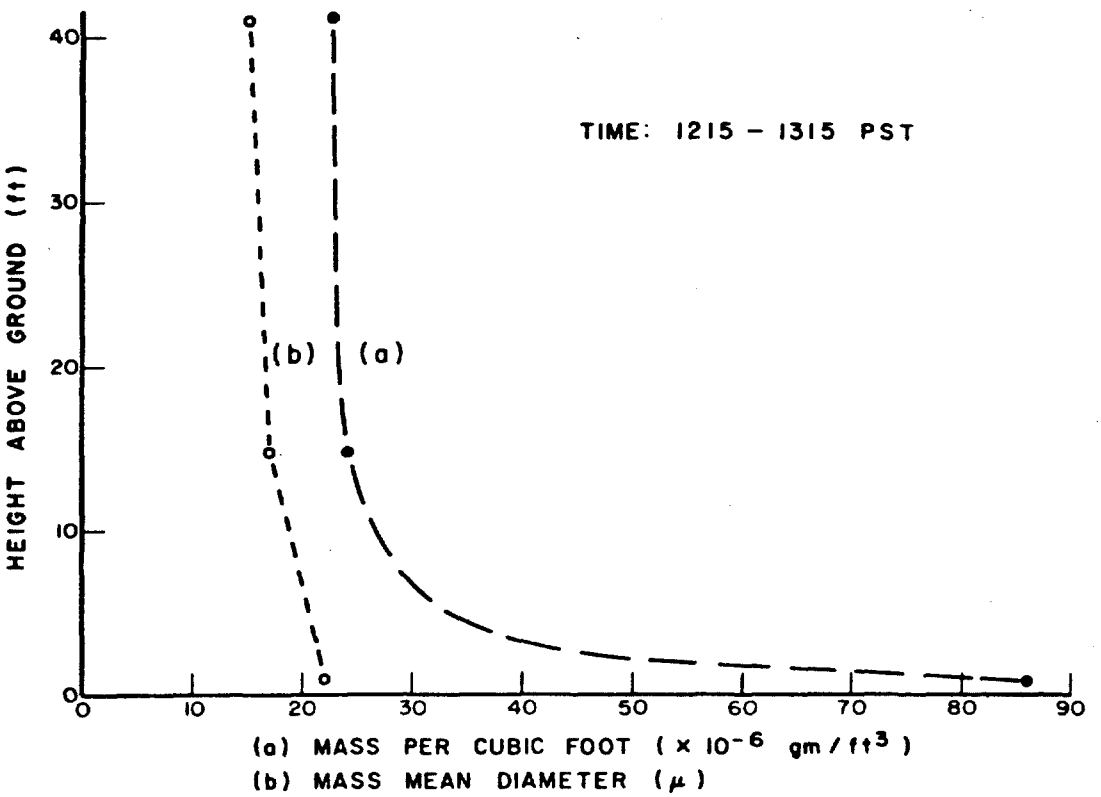

FIGURE – 8
(a) AVERAGE MASS OF DUST PER FOOT^3, AND
(b) MASS MEAN DIAMETER OF DUST PARTICLES.
PORTABLE MAST, HAPO. OCTOBER 5, 1955

ATMOSPHERIC DIFFUSION STUDIES USING FREON 12 AS A TRACER*

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I. Introduction

The problem of determining the concentrations of an effluent downwind from a building stack or some other source frequently confronts the industrial meteorologist or engineer. This problem becomes especially important when the material involved is toxic. To provide an estimate of the concentrations to be expected, one of the currently fashionable diffusion formulas is applied. Numbers are thus obtained describing the concentrations. All too rarely are valid checks or verifications of the estimates obtainable unless damage has occurred to property or mammals.

The biggest difficulty in applying the diffusion equations is in knowing what values to assign to the diffusion parameters; C_z, C_y and n in the Sutton[1] equations or "p" and "q" in the Bosanquet and Pearson[2] equations. Values have been suggested by Sutton, Bosanquet and Pearson and others[3] but usually the conditions of the problem to be solved are sufficiently different from those upon which the equations are based that there is some doubt concerning the validity of the estimates. In most cases the meteorologist or engineer is forced to use the suggested values of the diffusion parameters for want of something better. In this paper three cases are presented where actual measurements of concentrations are compared with predictions from Sutton's formula.

A. Experimental Technique

Freon 12 was used as a tracer in these experiments. This substance is especially desirable since it is inexpensive, readily available and non-toxic. It is also colorless, odorless and tasteless in gaseous form.

For these experiments freon 12 was released from three different locations: (1) thirty inches above the ground, (2) the 37.5-foot level of the Meteorology Tower, and (3) the stack on Building 310, 53-feet above the ground. Either 10 or 25-pound tanks of freon 12 were used. The freon from the tanks passed through a measuring apparatus which consisted of a reduction valve, pressure gauge, Fischer-Porter Flowrator, heat-exchanger and nozzle before it was released to the atmosphere. For the experiments on Building 310 the freon was injected into the ventilation ductwork just ahead of the last bank of filters.

A special sampling bottle for use in these experiments was designed at the Argonne National Laboratory by Dr. Harvey A. Schultz and Mr. Jack Dodd. This bottle shown in Figure 1

* Performed under the auspices of the Atomic Energy Commission.

consists of a round-bottom 1-liter flask, a two-hole neoprene stopper, a balloon, a stopcock, and glass tubing. The balloon is fastened to a piece of glass tubing which is inserted into one of the stopper holes. Another piece of glass tubing joined to the stopcock passes through the other hole. The stopper is securely fastened to the bottle in the manner shown with the balloon inside the flask.

Prior to taking an air sample the balloon is inflated while the stopcock is open so that most of the air in the flask is displaced. The stopcock is then closed. The balloon cannot deflate because of the pressure balance between the air inside the balloon and the air outside the balloon but within the bottle. To take an air sample the stopcock is opened and the balloon is allowed to deflate. This causes air to flow into the space between the outside of the balloon and the inner walls of the flask. The stopcock is then closed to retain the sample. The air sample is released when the stopcock is opened and the balloon is reinflated.

About 20–30 sampling bottles were set up in a grid downwind during each experiment. The bottles were mounted on ½-inch metal rods either driven into the ground or fastened to ring-stands. Jaw clamps attached to the rods held the bottles at about 30 inches above the ground.

Prior to the experiment the balloons were inflated. About a minute after the freon release began, a signal was given to a group standing by to open the sampling bottle stopcocks. Each man opened about 4 or 5 bottles on his assigned route. Calibrated glass capillaries were attached to the intakes of the bottles so that the sampling time was held to a predetermined period. This was three minutes in most cases. At the end of the period the men were signalled to close the stopcocks. The sampling bottles were then taken to the laboratory for analysis.

Analyses were performed under the direction of Dr. Harvey A. Schultz by means of a General Electric Halide Detector modified at Argonne. The sensitive element of this instrument consisted of two concentric thin-walled platinum cylinders. The outer one was 40 mm long and 7 mm in diameter and the inner one was 30 mm long and 5 mm in diameter so that the annular space between them was 1 mm. A potential of 200 volts was applied between the two cylinders with the inner one positive. Also, the latter was heated to a temperature exceeding 1000°C. When air containing small concentrations of freon 12 was passed through the annular space, the current developed was proportional to the concentration.

As used at Argonne, the output of the halide detector was fed into a specially designed amplifier and the data were recorded on an Esterline-Angus recorder. Other modifications consisted of more accurate temperature control of the inner cylinder and accurate flow control of the freon-containing air sample. Dr. Schultz found that the relative humidity of the sample affected the readings. A cold trap was therefore used to cool it to −15°C in order to remove a large fraction of the water vapor. Also a trace of hydrogen was injected into the sample to stabilize the operation of the equipment.

Two methods were used to determine the emission rate of the freon. The first method consisted of weighing the freon tanks before and after the experiment. Since the emission rate was held constant and the period of emission was known, it was possible to calculate the emission rate. In the second method the source strength was calculated from readings of a Fischer-Porter Flowrator. The two methods gave values which agreed to within about ten percent.

Ground Source Data

At the time of this run, 1346:40–1350:40 CST August 16, 1951, a high thin overcast with lower broken clouds was present. The wind at 6.5 feet was light ranging from 4 to 8 miles per hour from a direction of 20°. No stability measurements were available during this run. Freon 12 was released in the vicinity of the Meteorology Tower from a level of 30 inches above the ground at the rate of 3.2 grams per second. The concentration isopleths measured are shown in Figure 2. As often happens during experiments of this type there was a shift of wind direction after the sampling grid was set up. As a result only slightly more than one-half of the plume passed over the grid. However, measurements on either side of the maximum concentration line were obtained.

Theoretical isopleths using Sutton's equation have been calculated and are superimposed in red on the measured isopleths. These are shown in Figure 3. The diffusion parameters of n = .25 and $C_z = C_y = .20$ were chosen. The value for n was determined from the ratio of the wind speeds at the 6.5 and 150-foot levels. The agreement between the theoretical and measured isopleths is quite good although the measurements indicate somewhat higher concentrations on the 50-foot arc at 20–25° from the center line.

Elevated Tower Source Data

These data were obtained during the period 1457:30–1501:00 CST on September 13, 1951. During this time there were scattered clouds at 3000 feet and the wind at 37.5 feet was from 260° at 14 miles per hour. The temperature difference between 144 and 5.5 feet was 0°C. Freon 12 was released from the platform on the Meteorology Tower, 37.5 feet above the ground at a rate of 17.2 grams per second.

Figure 4 shows the concentration isopleths measured during the test. Three sets of theoretical isopleths were calculated for this run. In the first set, Figure 5, n was taken as .25, C_y as .21, and C_z as .12. The value for n was obtained from wind speed ratio measurements from anemometers on the tower. Values for C_y and C_z were values recommended by Sutton for neutral conditions. These isopleths indicate that the theoretical concentration occurs farther from the stack. Also the plume is more confined.

The second set of theoretical isopleths shown in Figure 6 were obtained by taking n = .25, $C_y = .15$ and $C_z = .19$. These values of C_y and C_z were determined from the measured isopleths in the following manner: Since the distance at which the maximum concentration occurred can be determined from the measurements and the source height is known and n has been measured, C_z can be calculated from the expression:

$$x_m = \left(\frac{h^2}{C_z^2}\right)\frac{1}{2-n} \tag{1}$$

Where x_m = distance in meters to point of maximum concentration from source measured along the horizontal
h = source height in meters

C_z was thus found to be .19.

Assuming the measured value for the maximum concentration to be correct, C_y can be calculated from the expression:

$$\chi_{max} = \frac{2Q}{e\pi uh^2}\left(\frac{C_z}{C_y}\right) \text{ or } C_y = \frac{2Q\,C_z}{\chi_{max} e\pi uh^2} \tag{2}$$

Where Q = the emission rate in grams per second,
χ_{max} = the maximum concentration in grams per cubic meter,
u = the wind speed in meters per second,
and h = the source height in meters.

Substituting the value for C_z obtained from equation 1, equation 2 yields a value of .15 for C_y.

From Figure 6 it is evident that the actual dispersion was much more pronounced than the theoretical values. Note the value of .19 ppm on the 220° radius and the distance of the .10 ppm line from the center line. Another point of interest is the higher concentrations on the 100-foot arc. These may well be due to the eddies around the tower.

The third set of isopleths shown in Figure 7 compare actual and theoretical values where n was taken as .25 and $C_y = C_z = .50$. In this case the fit is very poor. Although the dispersion

is greater because of the larger magnitude of C_z and C_y the measured and theoretical concentration values agree poorly. Also the magnitude and location of the concentration maximum differ in the two sets of curves.

Building Stack Source

This run was made during the period 1427:00–1431:00 CST on September 27, 1951. Lower scattered clouds at 4000 feet were present and the wind was from 277°, 22 miles per hour at 37.5 feet. The temperature difference between 144 and 5.5 feet was 0.1°C, the upper level being colder. Freon 12 was injected into the ventilation ductwork of Building 310 prior to the last bank of filters at a rate of 24.5 grams per second. The air flow through the ductwork was about 300 cubic feet per minute and its temperature varied from 92 to 102°F.

Figure 8 shows the measured concentration isopleths. The wide dispersion of relatively high concentrations is evident from this figure. An attempt was made to obtain values for the peak concentration in the vicinity of the building. The freon was traced by means of bubbles generated from a commercially available toy bubble compound. It was necessary to use bubbles instead of smoke because tests showed that the halide detector reacted to smoke but not to bubbles. The bubble generator was located on the roof of the building near the emitting stack. Observers followed the bubbles and took short-period samples in regions near the building where the bubble concentration was at a maximum. A peak concentration of 1.95 ppm was obtained.

Several sets of theoretical Sutton isopleths were calculated for this case also. The value of n was calculated from the meteorology tower anemometers and found to be .33. At first, a calculation was made allowing C_y to equal .21 and C_z to equal .12. The fit was very poor. The maximum concentration came out to be .25 ppm as against 1.32 ppm and the horizontal distance 1100 feet as compared with about 200 feet. Using the measured value of the maximum concentration and its distance from the stack and equations 1 and 2, C_z was found to be .52 and C_y equal to .17.

A new set of theoretical isopleths was calculated setting n = .33 and these values for C_y and C_z. These are shown in red in Figure 9. It is evident that the fit is still poor. The actual dispersion is markedly larger and the concentrations higher.

Of course, Sutton's equations were not designed to be used to determine concentrations around buildings. However, at times, they have been used as a guide for want of something better. This case is presented to indicate the magnitude of errors to be expected and emphasize the caution that must be applied even in using the theoretical expressions as a guide.

Acknowledgments

Thanks are due to Mrs. Harriet R. Newton for aid in planning and carrying out these measurements. She was in charge of the Meteorology Group at the time of the freon experiments. The assistance of Mr. Frank C. Kulhanek and other members of the Radiological Physics Division is gratefully acknowledged. Their help contributed substantially to the success of the experiments. The cooperation of Mr. Walton A. Rodger and Mr. Donald C. Hampson of the Chemical Engineering Division in connection with the measurements in the vicinity of Building 310 helped immeasurably. Their assistance is appreciated.

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1. O. G. Sutton, The Theoretical Distribution of Airborne Pollution from Factory Chimneys, Quarterly Journal of the Royal Meteorological Society, 73: 426 (1947).
2. C. H. Bosanquet and J. L. Pearson, The Spread of Smoke and Gases from Chimneys, Transactions of the Faraday Society, 32: 1249-1264 (1936).
3. L. L. Falk, et al., Savannah River Plant Stack Gas Dispersion and Microclimatic Survey, DP-19, E. I. du Pont de Nemours & Co., Inc. (1953).

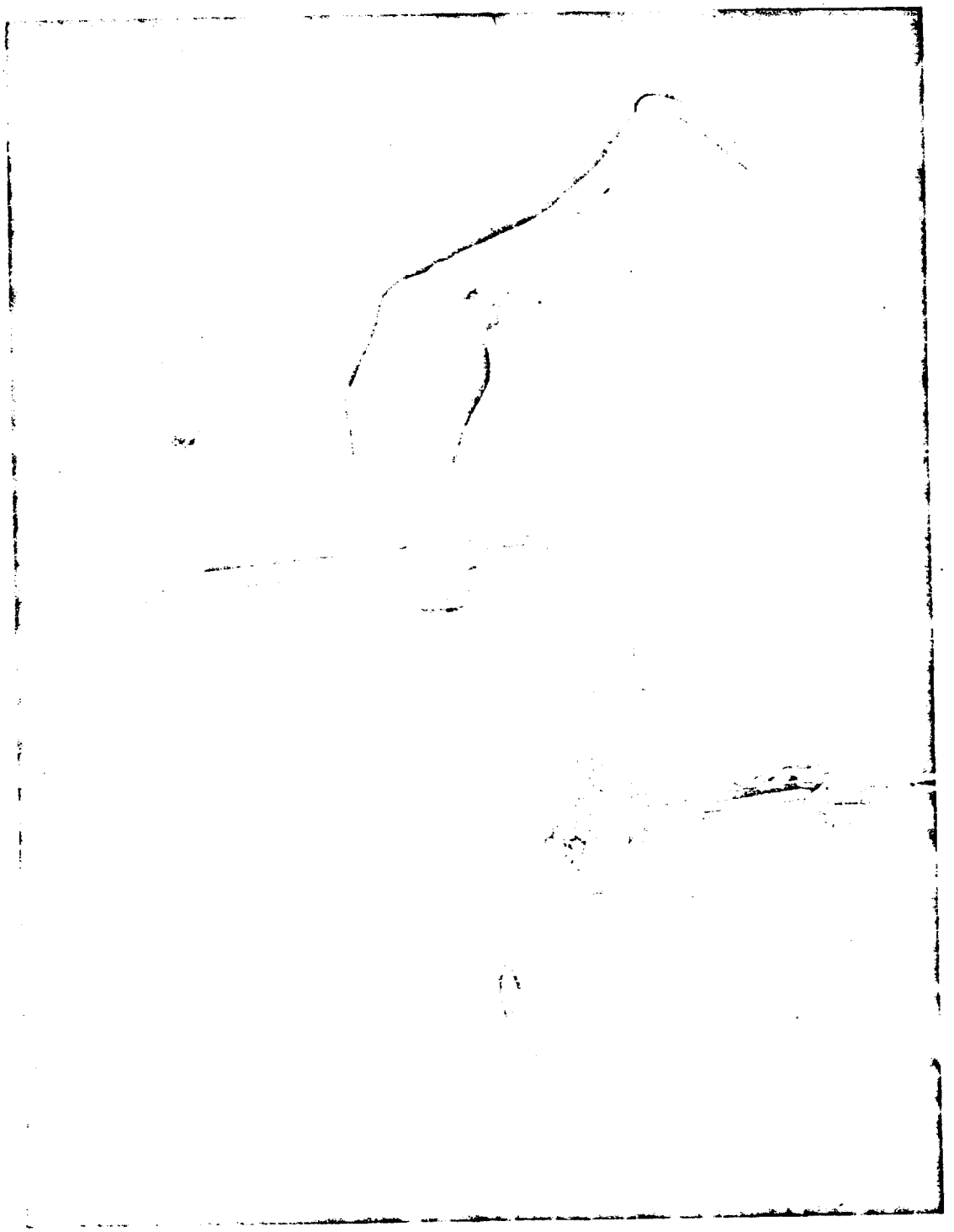


Figure 1

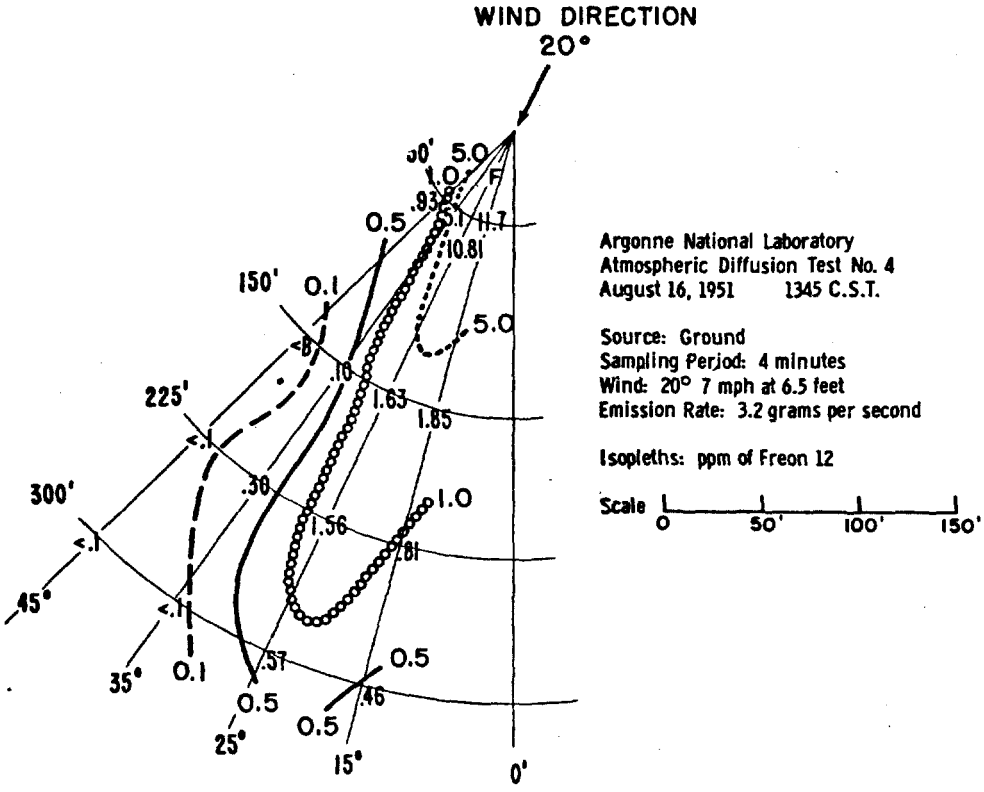


FIGURE 2

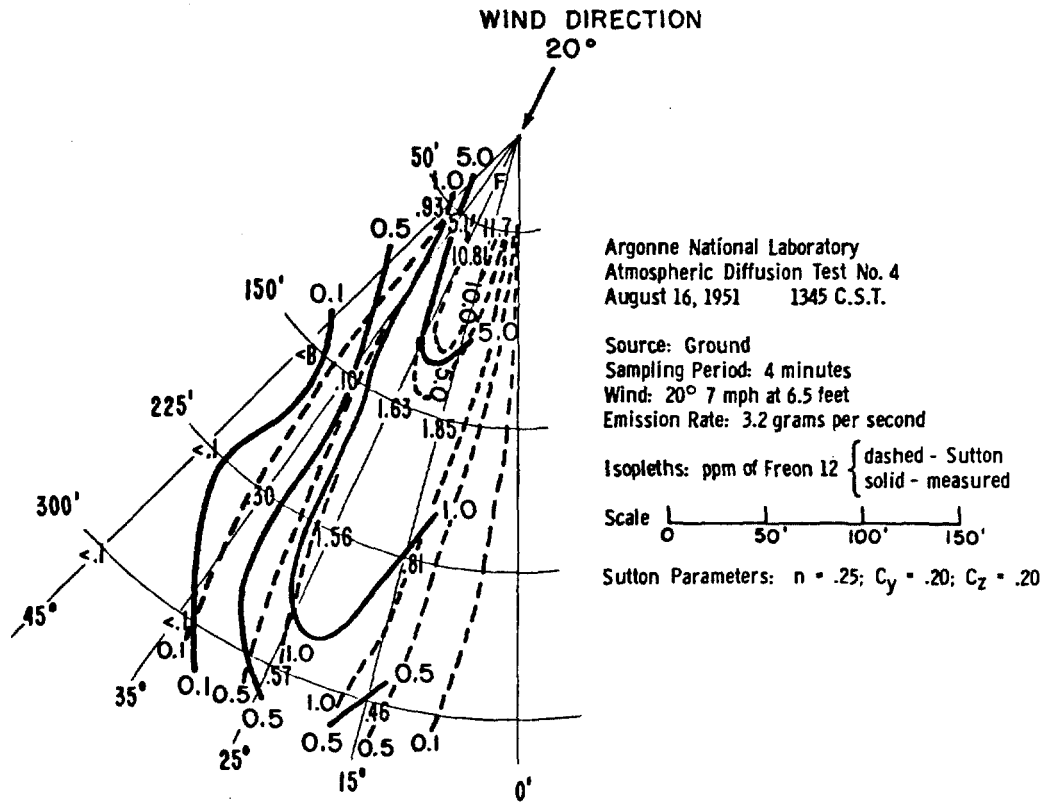


FIGURE 3

Argonne National Laboratory
Atmospheric Diffusion Test No. 7
September 13, 1951 1500 C.S.T.

Source: Meteorology Tower - 37.5-foot level
Sampling Period: 3 minutes
Wind: 264° 14 mph at 37.5 feet
Emission Rate: 17.2 grams per second of Freon 12

Isopleths: ppm of Freon 12

Scale: 0 100' 200' 300'

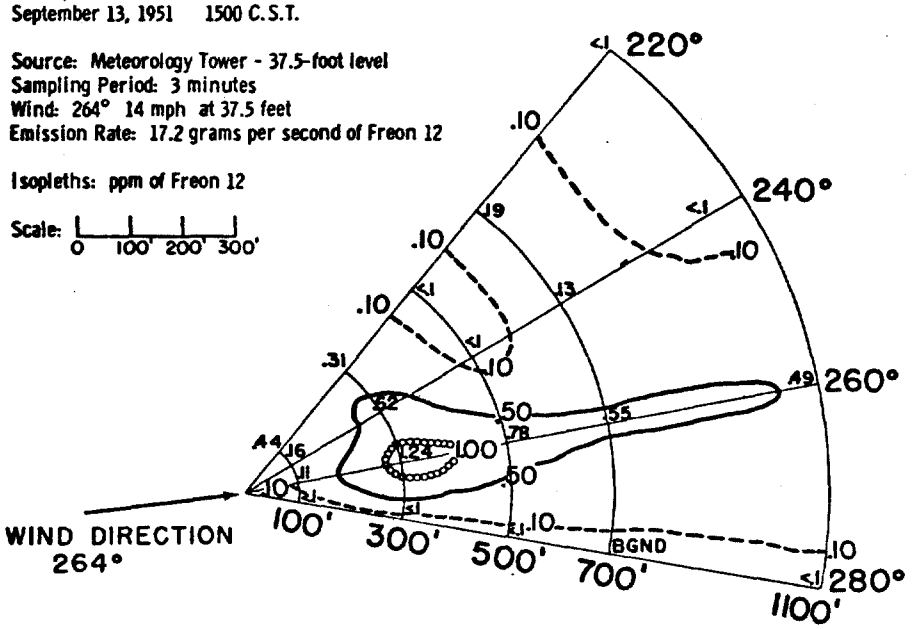


FIGURE 4

Argonne National Laboratory
Atmospheric Diffusion Test No. 7
September 13, 1951 1500 C.S.T.

Source: Meteorology Tower - 37.5-foot level
Sampling Period: 3 minutes
Wind: 264° 14 mph at 37.5 feet
Emission Rate: 17.2 grams per second of Freon 12

Isopleths: ppm of Freon 12 { dashed - Sutton; solid - measured }

Sutton Parameters: n = .25; C_y = .21; C_z = .12

Scale: 0 100' 200' 300'

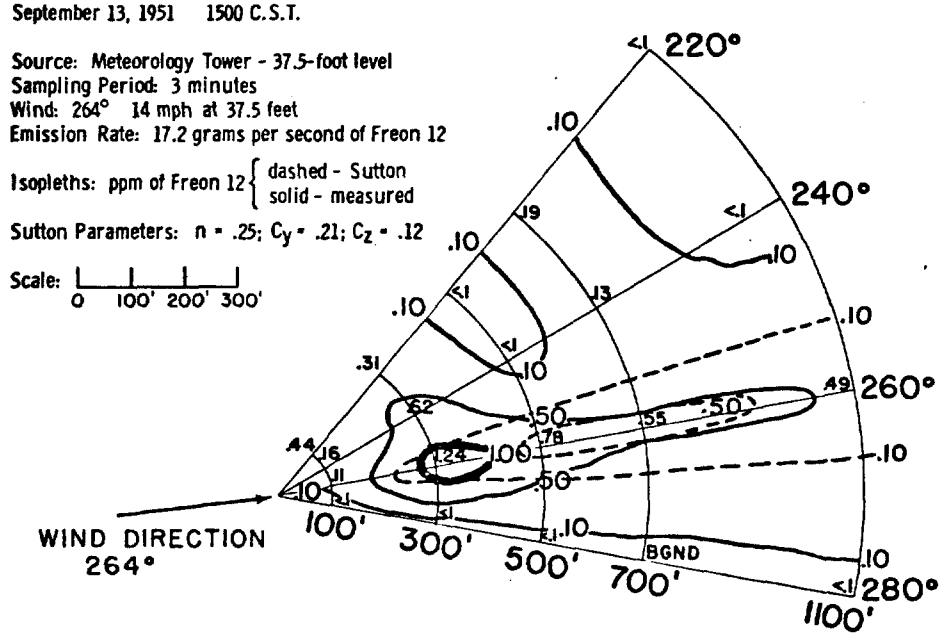


FIGURE 5

Argonne National Laboratory
Atmospheric Diffusion Test No. 7
September 13, 1951 1500 C.S.T.

Source: Meteorology Tower - 37.5-foot level
Sampling Period: 3 minutes
Wind: 264° 14 mph at 37.5 feet
Emission Rate: 17.2 grams per second of Freon 12

Isopleths: ppm of Freon 12 { dashed - Sutton
solid - measured

Scale: 0 100' 200' 300'

Sutton Parameters: n = .25; C_y = .15; C_z = .19

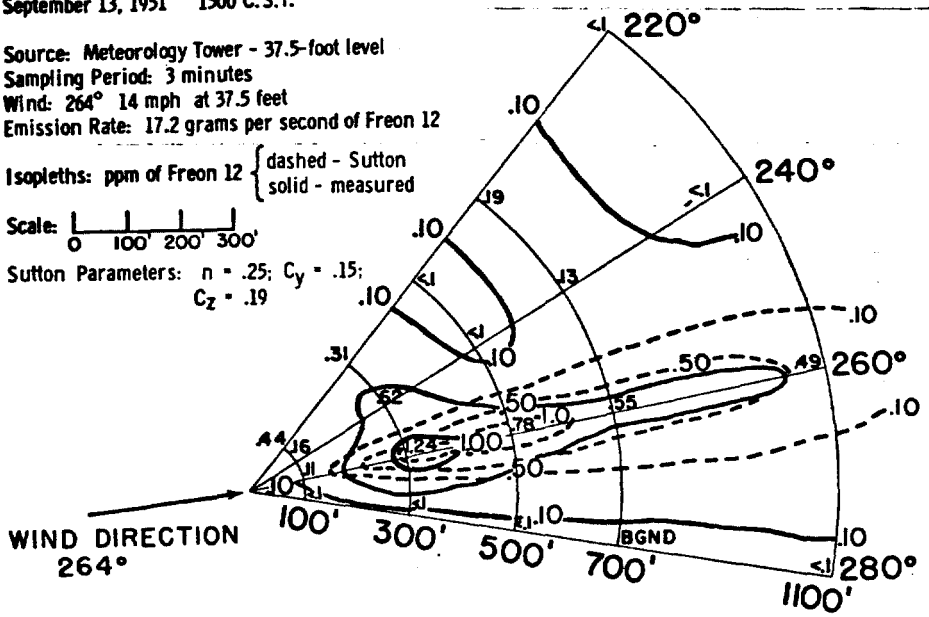


FIGURE 6

Argonne National Laboratory
Atmospheric Diffusion Test No. 7
September 13, 1951 1500 C.S.T.

Source: Meteorology Tower - 37.5-foot level
Sampling Period: 3 minutes
Wind: 264° 14 mph at 37.5 feet
Emission Rate: 17.2 grams per second of Freon 12

Isopleths: ppm of Freon 12 { dashed - Sutton
solid - measured

Sutton Parameters: n = .25; C_y = .50; C_z = .50

Scale: 0 100' 200' 300'

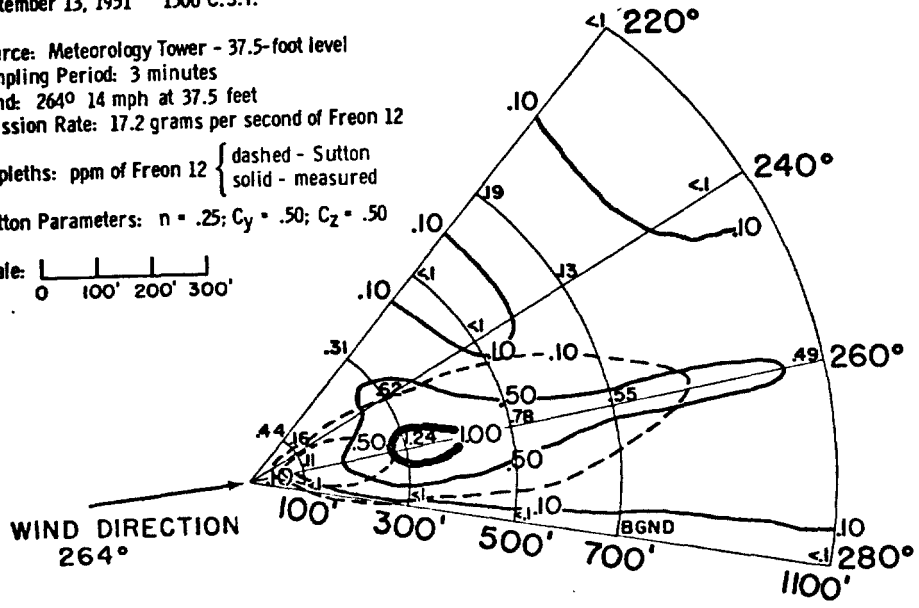
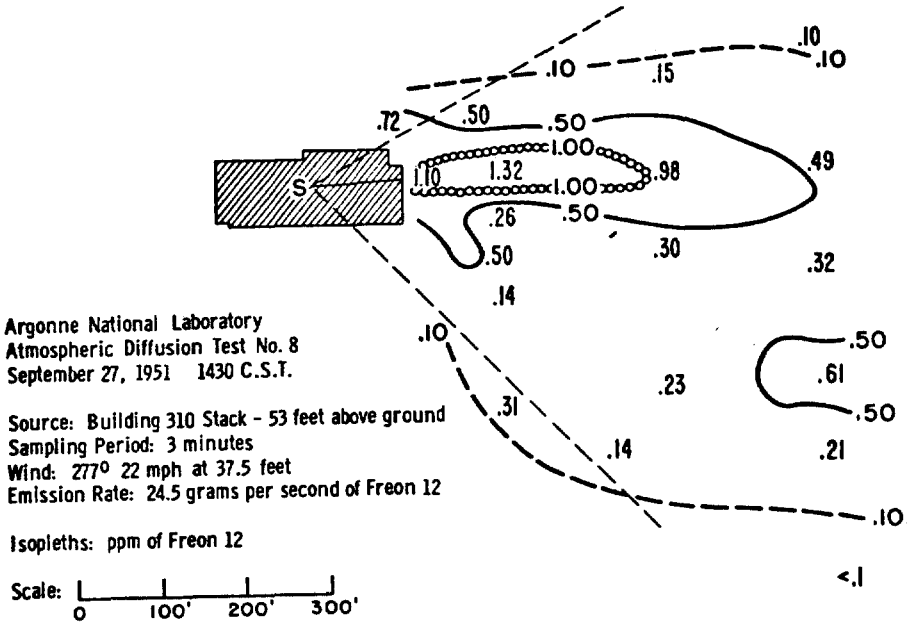


FIGURE 7



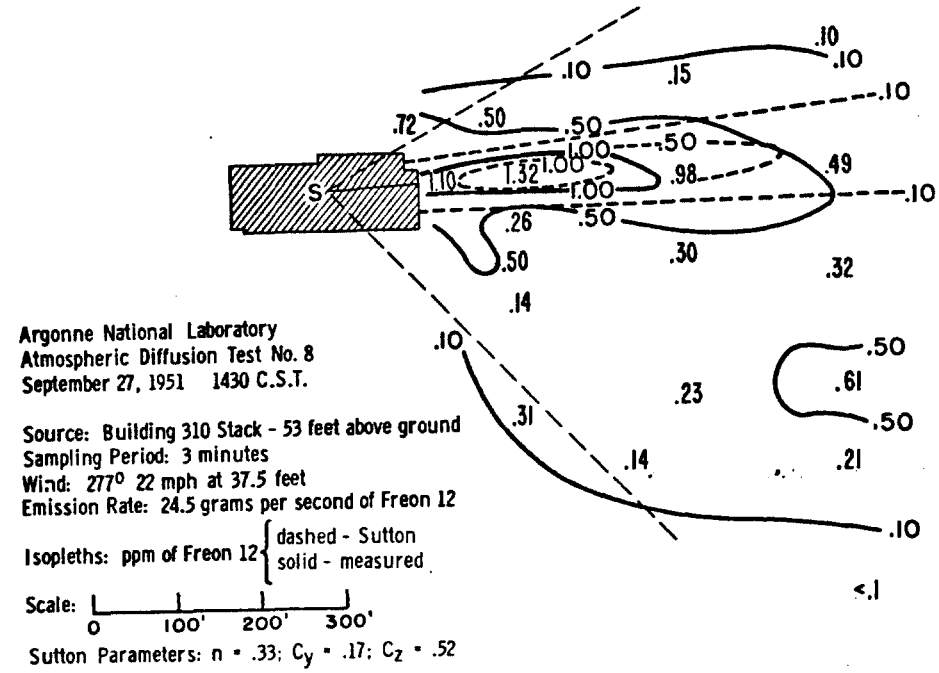
Argonne National Laboratory
Atmospheric Diffusion Test No. 8
September 27, 1951 1430 C.S.T.

Source: Building 310 Stack - 53 feet above ground
Sampling Period: 3 minutes
Wind: 277° 22 mph at 37.5 feet
Emission Rate: 24.5 grams per second of Freon 12

Isopleths: ppm of Freon 12

Scale: 0 100' 200' 300'

FIGURE 8



Argonne National Laboratory
Atmospheric Diffusion Test No. 8
September 27, 1951 1430 C.S.T.

Source: Building 310 Stack - 53 feet above ground
Sampling Period: 3 minutes
Wind: 277° 22 mph at 37.5 feet
Emission Rate: 24.5 grams per second of Freon 12

Isopleths: ppm of Freon 12 { dashed - Sutton
solid - measured

Scale: 0 100' 200' 300'

Sutton Parameters: n = .33; C_y = .17; C_z = .52

FIGURE 9

PHOTOGRAPHIC TECHNIQUES FOR MEASURING DIFFUSION PARAMETERS

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Argonne National Laboratory

Meteorological interest in air pollution is primarily concerned with the capacity of the atmosphere to dispose of contaminants. In line with this the meteorological group at Argonne has a dual program. One part of this program deals with climatological aspects of air pollution and the other part deals ultimately with the prediction of concentrations of contaminants. Our research efforts are directed towards a rational solution to this latter problem. In this respect we hope to accomplish several things. One of these is to test already existing hypotheses concerning diffusion for their validity and for the magnitude of certain parameters, or to formulate improvedhypotheses. Another goal is to make quantitative measurements of the entrainment of environmental air into smoke plumes and clouds. Since the Sutton hypothesis of diffusion is widely known and used, we are proceeding to test this first. At the same time, we hope to obtain usable values of the diffusion coefficients of his equations for interim use.

To accomplish these ends new photogrammetric techniques are used whereby oil fog which is generated into a 110-foot stack by an Army M-2 smoke generator is photographed. In one of these techniques, use is made of K-24 (Air Force) aerial survey cameras to take pairs of pictures at approximately 3.5 second intervals (Fig. 1). These cameras are located at opposite ends of a 400-foot baseline that is tangent to a circle of 80 feet radius, centered at the stack. The point of tangency, midway between the two cameras, is ideally directly under the smoke plume. The axes of the cameras are elevated so that the image of the top of the stack coincides

with a reference line ruled on glass in the focal plane. This horizontal line represents the vertical distance of 110 feet above the base of the stack. The two cameras are triggered simultaneously through an electrical circuit that is keyed by the controller at the base of the stack. Usually a series of twelve to fifteen exposures is made during given stack conditions, then the stack velocity is changed.

From these pairs of photographs measurements are made of the vertical dimensions of the smoke plume, of the height of rise and of the path of the center line. To make these measurements accurately, the meteorological group and personnel of Central Shops have jointly designed and constructed a three dimensional projector-plotter. Essentially, this machine reproduces to scale the photographic setup used in the field (Fig. 2). Two projectors are located at opposite ends of an 80-inch baseline. Between the projectors and normal to the line joining them is a translucent tracing paper screen mounted on a carriage so that the screen can be moved normal to its plane. The projectors are elevated at the same angles as the respective cameras, thereby eliminating the distortions due to the tilt of the cameras. Since the smoke plume ordinarily does not remain exactly halfway between the two cameras, the two images of a particular point on the plume will be coincident only when the plane of the screen is in a position relative to the two projectors similar to the location of the smoke plume relative to the two cameras. Thus, if horizontal distances parallel to the plane of the screen are x-distances, and vertical distances are z-distances, the position of the screen to the right or left of the midpoint of the projector baseline gives the y-distance, to scale, of the portion of the smoke plume that has the two images coincident. As the screen is moved over a horizontal table, the x y coordinates of any

position may, at will, be punched on a piece of tracing paper stretched over the table. The x z coordinates of any point are punched directly on the vertical translucent screen. Punching of coordinates is done by means of two needles that are actuated by solenoids. A cross-hair, through the intersection of which the x z needle operates, can be moved over the surface of the screen. All motions are made by means of reversible DC motors that are controlled from a common control point. Ordinarily all of the pairs corresponding to one set of stack conditions may be punched on the same pair of papers with individual frame images identified by colored pencil. Thus, with this photogrammetric technique, relatively precise entrainment measurements and diffusion measurements may be made. At the present time, one complete run of pictures has been punched onto tracing paper and some analysis has been made as a test of the projector-plotter. The system works quite well with certain limitations. One of which is that differences in density of the two films makes it difficult to determine exactly when the two images are coincident. As long as this difference in density can be compensated for by adjustments of the stop openings of the projector lenses, or lamp intensity, this limitation is negligible. However, it emphasizes the need for good control of the photographs during exposure and processing. In this respect, we have been well favored by the excellent work of Mr. G. A. Zerbe of the Meteorology Group and that of the photographic group of the Laboratory. Another limitation on this scheme is the angle between the smoke plume and the picture plane. As this angle approaches 45° the usable portion of the film diminishes.

Another limitation of this method when using black and white film is the poor contrast between white smoke and the clouds. A simple method of coloring the smoke output of the generator was developed by burning colored smoke grenades in the air-stream to the stack. Two red grenades will color the smoke a bright pink, which stands out quite clearly against white clouds when color film is used. Kodak Ektachrome Aerial film has a film speed high enough to permit taking color photographs under the adverse lighting conditions that occur beneath overcasts.

The second photographic technique used is that of making multiple exposures of the smoke plume (Fig. 1). Use is made of two cameras, the one directly under the stack is positioned so that the top section of the smokestack registers on the film; the second camera positioned crosswind from the smoke stack at a distance of about 1000 feet from the stack. The importance of having two simultaneous photographs of the smoke plume must be emphasized. With two pictures taken simultaneously from known positions, it is possible to make accurate measurements and one is not at the mercy of having made inadequate visual measurements at the time the picture was taken (Fig. 3). This multiple exposure technique was pioneered by Prof. Gordon H. Strom, with the meteorological wind tunnel at New York University. Strom worked with the Argonne meteorological group this past summer in developing this technique and the analytical methods of rectifying the measurements made on the films. Current practice is to make sixteen exposures at fifteen-second intervals with good success using Kodak Contrast Process Panchromatic film.

Current analysis of these multiple exposure films has been directed at testing the validity of the Sutton hypothesis. Sutton (QJRMS 73:p.267) gives an expression for the width of a cloud from a continuous point source and one that can be modified to give the vertical extent of a cloud from a continuous point source.

These equations are:

$$(1)\ \Delta y = 2\left(\ln \frac{100}{p}^{\frac{1}{2}}\right) C_y\ x^{(2-n)/2}$$

$$(2)\ \Delta z = 2\left(\ln \frac{100}{p}^{\frac{1}{2}}\right) C_z\ x^{(2-n)/2}$$

where:

Δy = width of cloud

Δz = thickness of cloud

p = percent of axial concentration

x = distance downwind from sources

C_y, C_z, n are diffusion coefficients.

The width or thickness versus the distance downwind plots as a straight line on log-log paper. The procedure follows:

1. Draw a smoothed outline of the smoke plume on the plan and profile films. Ideally, the outline obtained from the Sutton equations will be a smoothed outline.

2. Measure the vertical and horizontal extent of the plume outline as a function of distance downwind.

3. Rectify the above quantities to true space coordinates and plot on log-log paper. It will be seen that the points remote from the stack tend to fall on a straight line, while those near to the stack usually fall above the straight line. This appears to be due to two factors, (1) the source is not a true point source, and (2) the equations

do not allow for the apparent enhancement of the crosswind dimensions of the plume due to the rise of the plume above the top of the stack. This is particularly true of the profile dimensions. This non-linearity is corrected for by a trial determination of a constant distance, which when added to each of the observed x values, yields a straight line.

4. Determine the slope of the resulting line, and from it compute a value of n. In general, the profile line will yield one value of n and the plan line will yield another value of n. In some cases these values are quite close and in others there is a considerable disparity. Following the completed analysis of a sufficient number of these curves, it will be possible to determine whether or not the differences are statistically significant.

5. The intercept of the profile line determines a quantity from which the value of C_z can be computed. The plan line intercept gives a value from which the magnitude of C_y can be computed. To get numerical values for these parameters, it is necessary to assume that the visible outline of the plume corresponds to some constant fraction of the axial concentration. For convenience it is assumed that the outline of the visible plume has a concentration that is one-tenth of the axial concentration. Since the square root of the natural logarithm of the reciprocal of this number is the quantity which appears in the formulae choosing a value of one-hundredth would only decrease the magnitudes of the C's by a factor of 0.707 and making the outline concentration equal to the axial concentration would increase the quantities of 1.414 of the indicated values.

An important consideration in the foregoing method is the ability to accurately determine the outline of the plume, essentially a problem in the photographic quality. Experience based on the analysis of about

two dozen pairs of films demonstrates that in cases where the outline is well defined there is no difficulty in obtaining a straight line on log-log paper.

Prof. Strom and the writer have analyzed to date eighteen cases in which one could be confident of the outline of the smoke plume, thereby deriving a straight line on log-log paper by the addition of a constant to the downwind distances. From these lines, values of n_v, C_z, n_h and C_y have been obtained. Then from the laboratory's permanent meteorological instrumentation, simultaneous values of the wind speed ratio between 150 feet and 19 feet and the lapse rate between 6 feet and 144 feet were obtainable. Eighteen cases is too small a sample to give an adequate test of an hypothesis. However, a study of the correlations between certain of the parameters will help give some idea of what can be expected from this technique. To this end certain pairs of these data were plotted on scatter diagrams, thus computing the correlation coefficients for these pairs of parameters.

If the Sutton hypothesis is valid, one would expect the plan and the profile data to give the same values of the n's (Fig. 9). In this case, an ideal scatter-diagram would be simply a straight line of slope one passing through the origin. For the eighteen cases mentioned, which include both inversion and lapse conditions, the correlation coefficient between n_v and n_h is 0.94. This is statistically significant at the one percent level.

The magnitude of n is also supposed to be related to the lapse rate of temperature. In this connection, correlation coefficients were

computed for each of the above mentioned n's and the lapse rate between the 6 foot level and the 144 foot level (Fig. 7). For n_h this coefficient is 0.61 which is statistically significant at the one percent level. For n_v it is 0.42 and (Fig. 8) for the theoretical n it is 0.54; neither of these values is significant at the one percent level, but the value for the theoretical n is statistically significant at the five percent level.

Sutton has stated that the turbulence above 25 m is ordinarily isotropic. If this is generally true, the scatter-diagram of C_z versus C_y will give a straight line of slope one and passing through the origin. (Fig. 9). For these eighteen cases the correlation coefficient between the C's is 0.64 which is statistically significant at the one percent level. Neither set of C's had a statistically significant correlation coefficient when correlation with the lapse rate. The correlation coefficient for the C_z's was -0.01 and that for the C_y's was 0.45.

The analysis of these data to date is insufficient to warrant any conclusions as to the validity of any hypotheses. However, the results do indicate that is will be worthwhile to make a thorough analysis of all of the multiple exposure runs which are not available, the number being such that the results should be statistically significant. Sufficient data have been obtained to classify diffusion characteristics under stable and unstable conditions. Within these classes it may be possible to get meaningful subcategories based on wind speed and wind direction.

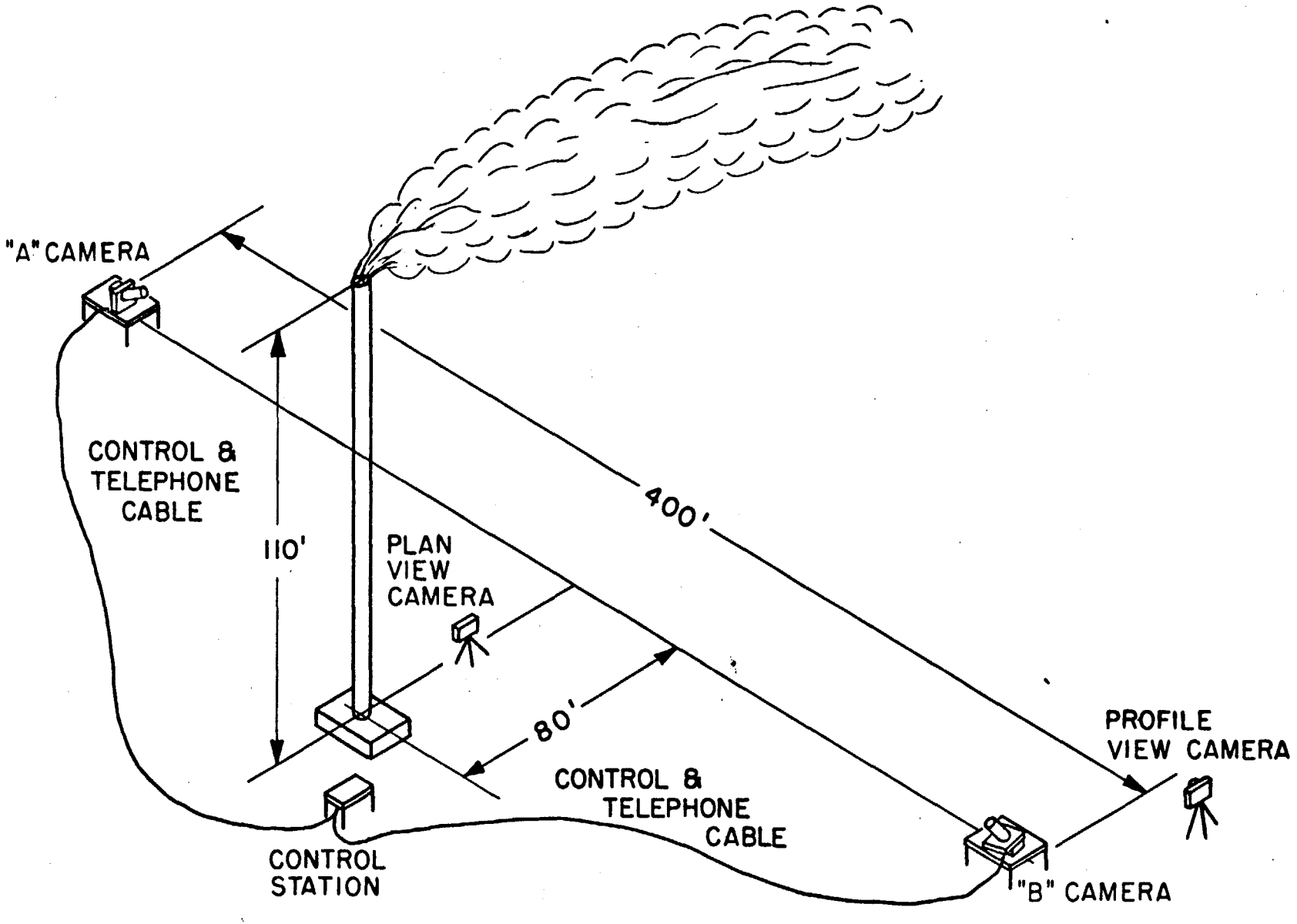

Fig. 1--Field Set-up for Use of K-24 Cameras.

Fig. 2--Photogrammetric Plotter.

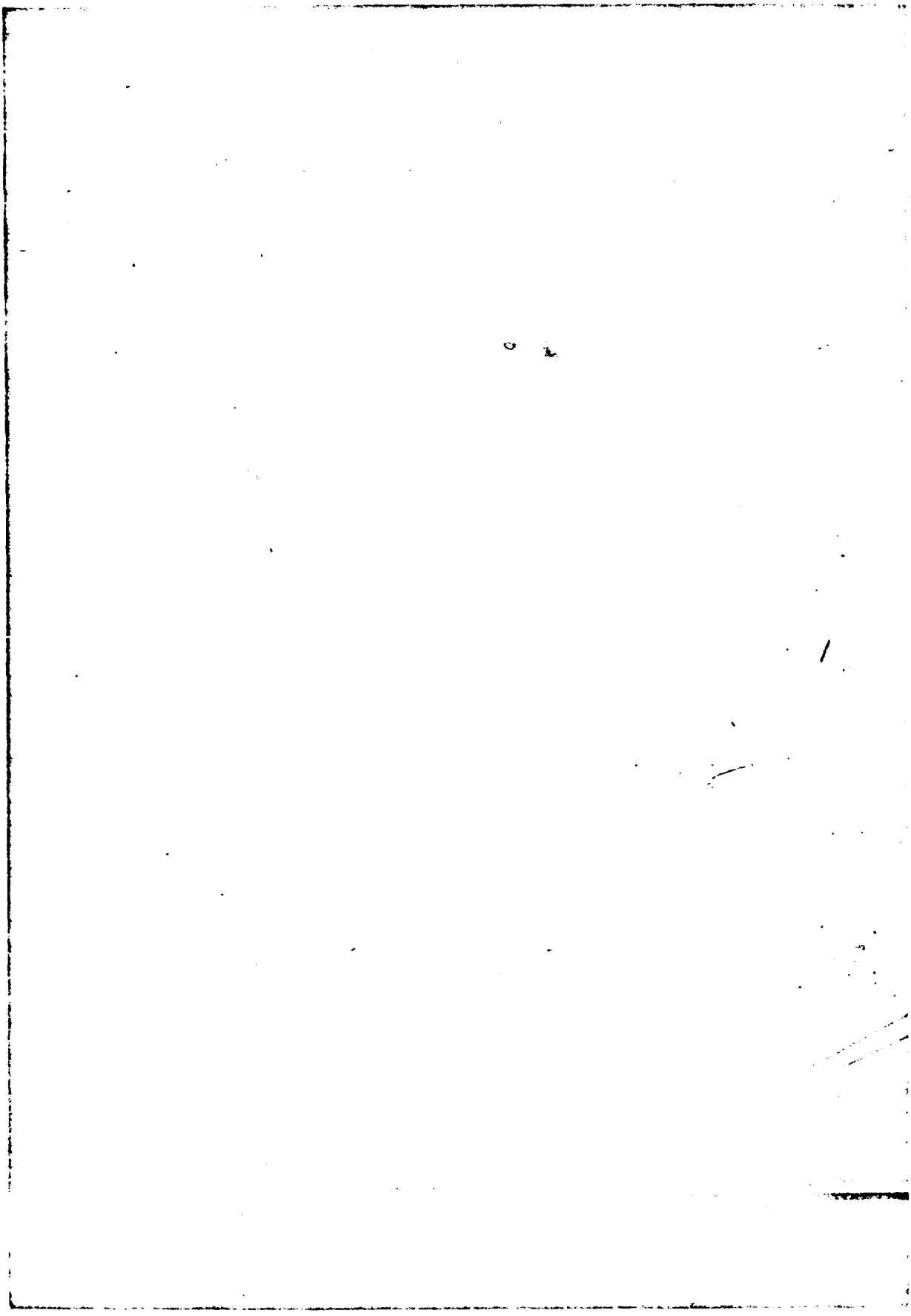

Fig. 3--Multiple Exposure Profile Picture.

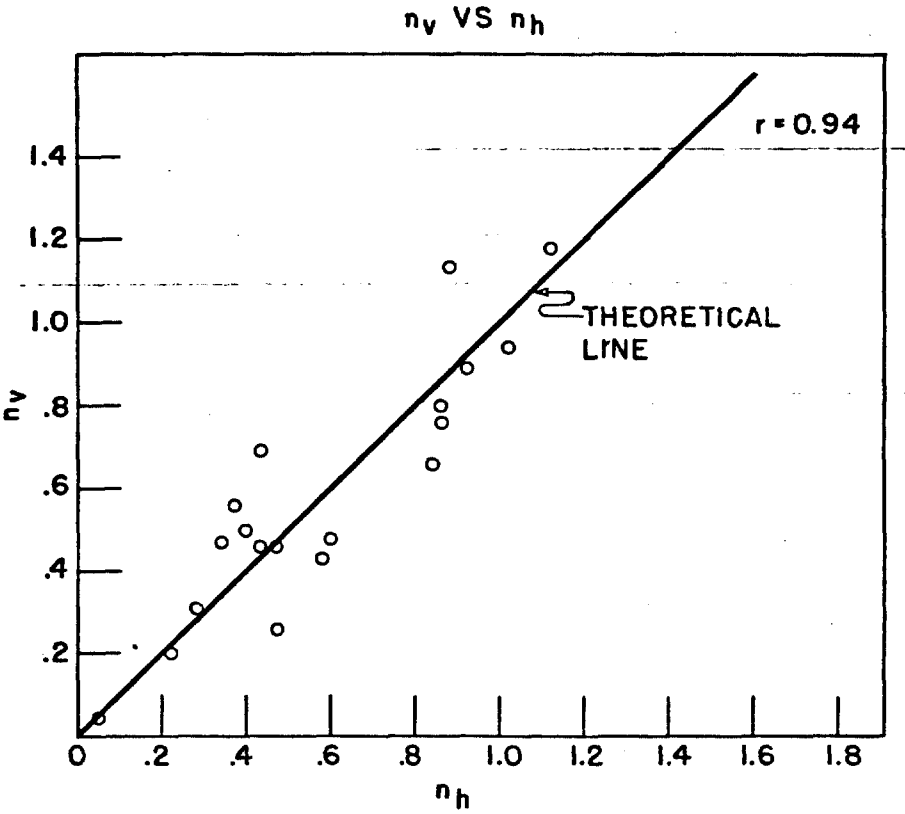

Fig. 4--n_v vs. n_h.

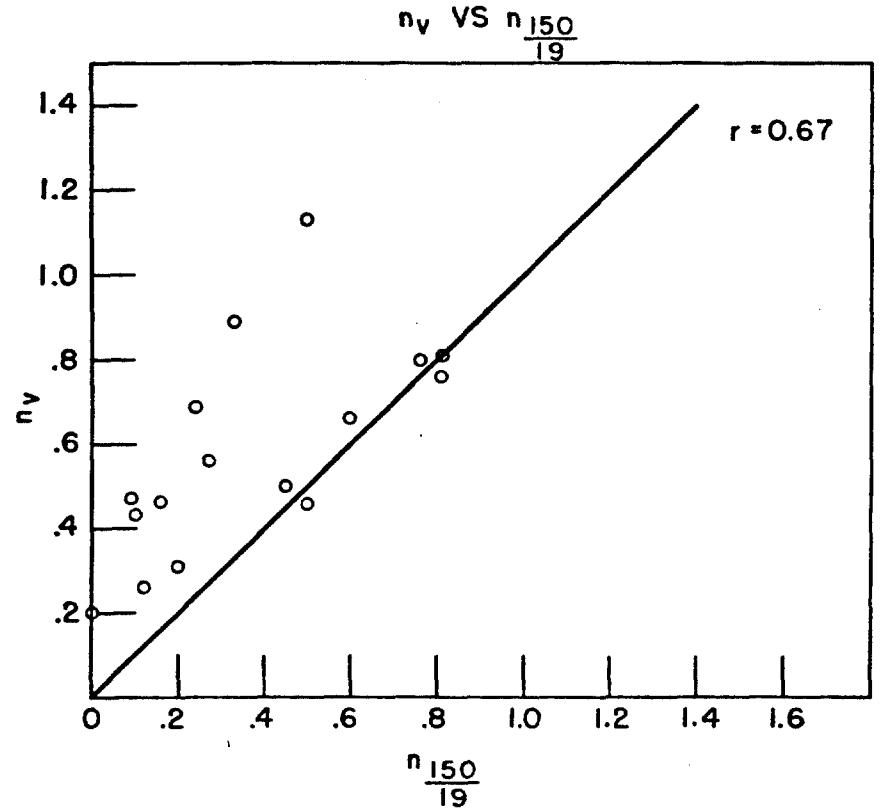

Fig. 5--Measured n_v vs. Theoretical n.

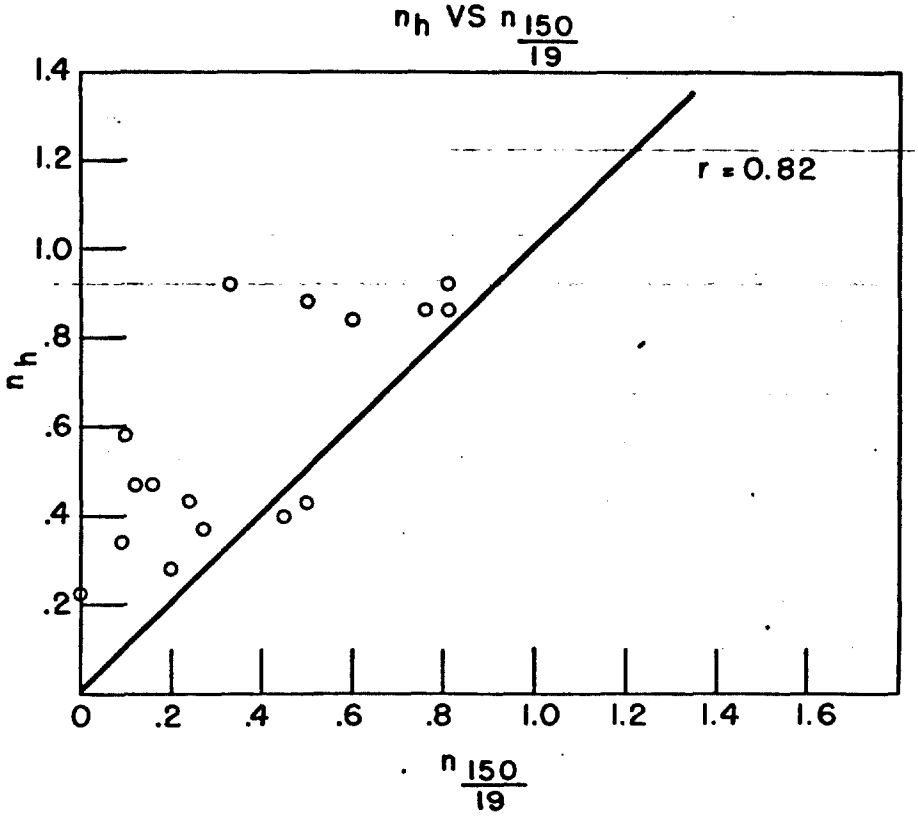

Fig. 6--Measured n_h vs. Theoretical n.

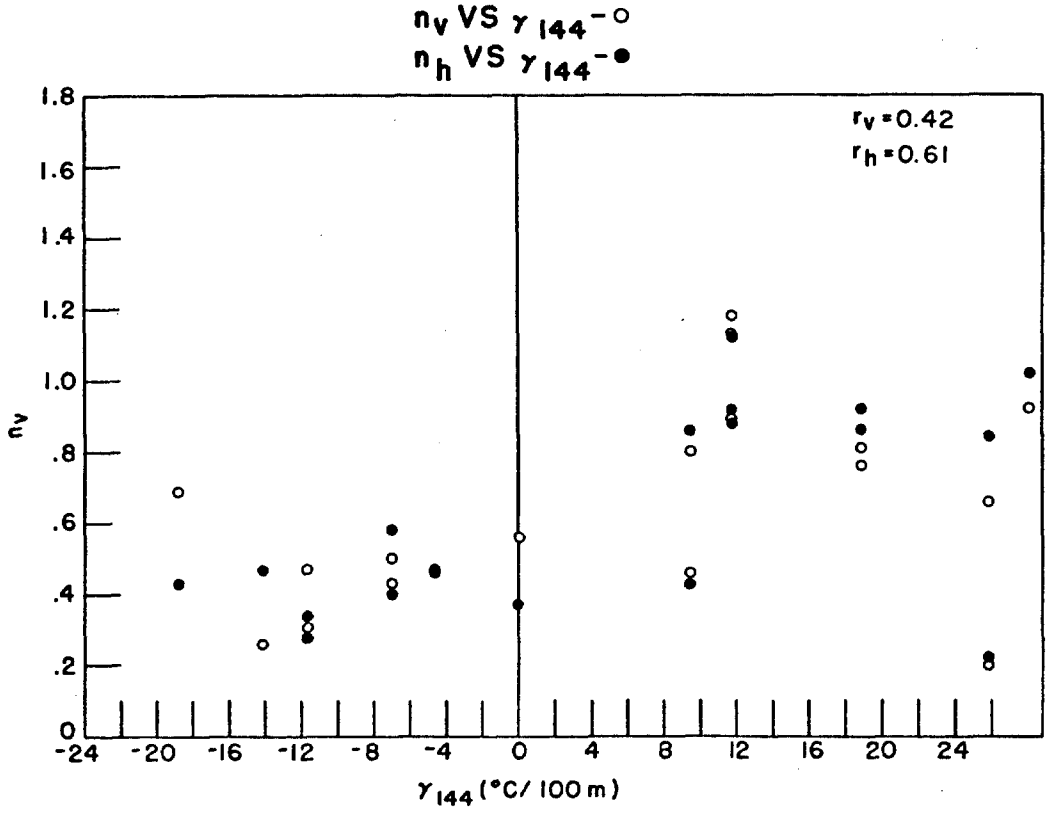

Fig. 7--Correlation of Measured n's with Lapse Rate.

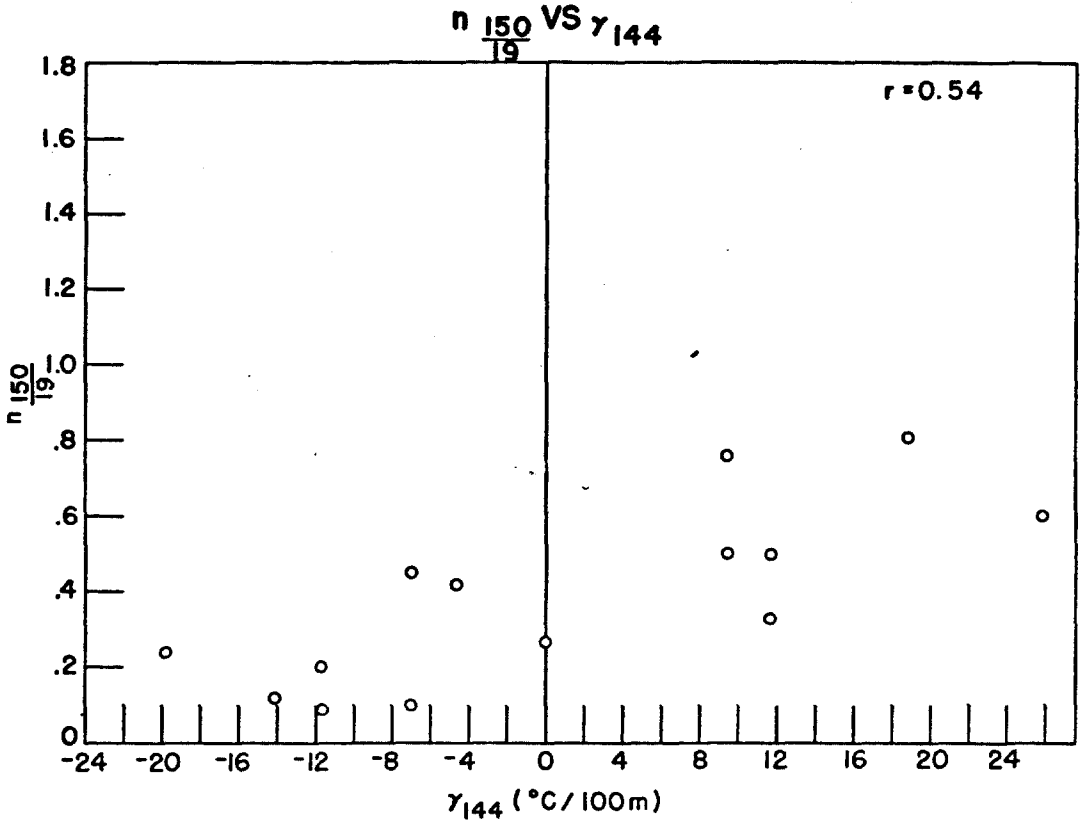

Fig. 8--Correlation of Theoretical n with Lapse Rate.

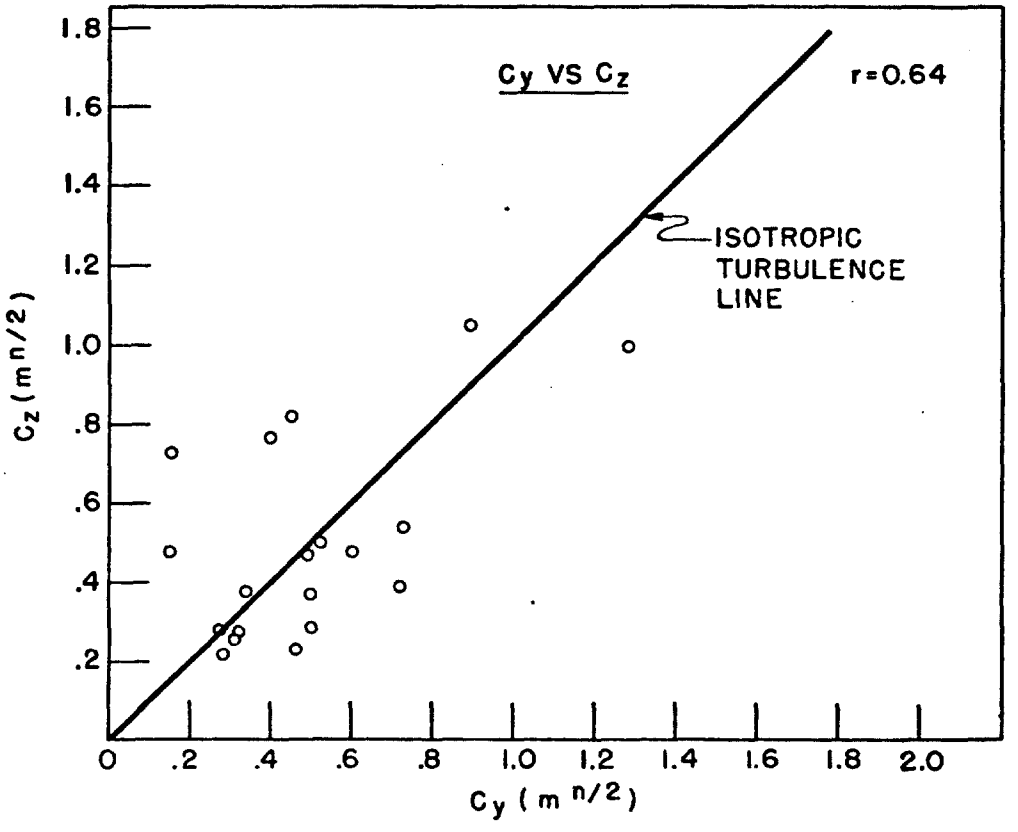

Fig. 9--Correlation of C_y and C_z.

RESEARCH AND DEVELOPMENT AT THE HARVARD AIR CLEANING LABORATORY

by

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In this brief introduction I will very briefly describe the activities of the Harvard Air Cleaning Laboratory since the Los Alamos seminar. As you know, our laboratory has five principal functions as listed below:

1. Research and development on air and gas cleaning problems
2. Evaluation of commercially developed equipment as requested by the Commission
3. Collection and collation of data on air and gas cleaning obtained by AEC facilities and contractors
4. Consultation services when requested by the Commission or its contractors
5. The training and professional education of AEC personnel.

The present Air Cleaning Seminars were an outgrowth of the last objective.

Of utmost importance to us has been research and development work and it continues to be of primary interest. During the time interval described above we have been studying the performance of high velocity filters for precleaning air, with regard to adhesive characteristics, and the effects of dust generation techniques upon their performance.

We have made rather extensive studies of the effect of electrostatic charge on fixed filter beds, some of which were reported at Los Alamos by Dr. Rossano and some of which will be reported here by Mr. Anderson. We recently published an article on the frictionally charged filter unit. This appears in the May issue of "Industrial and Engineering Chemistry" (1).

Our further studies on reverse-jet filters have been handicapped because the commercial equipment which was provided has not proved the optimum for evaluating the nature and characteristics of the deposited aerosol. It is this effect on performance we wish to delineate further.

We have also continued our investigations of isokinetic sampling probes and their influence on the measurement of aerosols as related to air cleaner performance.

We have also undertaken an investigation of the structural characteristics of filters under conditions of reverse air flow. In particular we wished to ascertain the effect of external sonic shock waves which might be imposed upon installed air cleaning equipment. Mr. Billings will present test results obtained on Dust-Stop and AEC type filters.

At AEC request we have been investigating the performance of the Bureau of Mines AEC incinerator in regard to the type of effluent produced and its effect on the proposed air and gas cleaning system.

We have also studied, in a pilot investigation, the performance of miniature cyclones with dimensions ranging from $\frac{1}{4}$ to 2 inches in diameter. We have evaluated, in a preliminary manner, the performance of a new type of electro-deposited screen known as Pyramid screen which may offer some promise as a roughing filter for precleaning of gases.

We have made preliminary studies of external voltage supplied electrified fiber filters, one type (Model K electrostatic - Western Precipitation Corporation) was described and has since appeared as an AEC document (2). Further studies have been made in the laboratory on two similar filters using electrified paper and glass fibers as made by another manufacturer. Results

of these will be issued in a report when studies are completed.

The performance of a new type of scrubbing device developed in France has been observed for the past few months at the request of the Commission. Mr. Edward Kristal will report on this later.

At the present time we have investigations continuing on a high-efficiency cyclone for possible use on fine particulates; on electrostatic filters; and on treated hair media (for high temperature resistance) which might have application as a roughing filter.

Our present fundamental studies, in addition to those given above, are directed towards ascertaining the forces which cause particles to adhere to fibers and surfaces. We are also conducting fundamental studies of electrostatic filters developed from fluidized beds. This provides a novel means of developing a collecting charge and simultaneously acting as a filter for aerosols.

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(1) Silverman, Leslie, Conners, Edward W., Jr., and Anderson, David M.: Mechanical Electrostatic Charging of Fabrics for Air Filters. Industrial and Engineering Chemistry, Volume 47, Number 5, May, 1955.

(2) Billings, Charles E., Dennis, Richard, and Silverman, Leslie: Performance of the Model K Electro-Polar Filter (Report of Laboratory Tests). USAEC NYO-1592, Harvard University, July 15, 1954.

A STUDY OF A NEW TYPE WET COLLECTOR

by

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SUMMARY

Performance tests were conducted on an experimental model of a new type wet collector known as the "Solivore". This unit (600 cfm capacity) consists of four, similar collection stages in series, each containing two spray generators, rated at 9 gpm and 7 psi, and a special Venturi tube. A special feature of this device is a spray generator which uses a rotating mechanical interrupter to disintegrate small liquid streams to produce a fine water spray.

Weight collection efficiencies were obtained with several aerosols for inlet dust loadings ranging from 0.02 to 2 grains per cubic foot, water rates of 6 to 12 gallons per minute per spray generator and for one, two and three stage operation. Efficiencies determined for a single stage varied from 99 per cent for fly ash to 22 per cent for iron oxide. Coarse and fine sulfuric acid mists were collected at efficiencies of 95 per cent and < 5 per cent, respectively. Collection efficiency for sulfur dioxide in low concentration (130 mg/m^3) was about 91 per cent with three stages.

Efficiency increased with multiple stages and with increasing water rate for a single stage.

Although the data obtained in this study may not apply exactly to larger scale equipment due to differences in design and operating conditions, they indicate performance characteristics comparable to several similar wet collectors. High efficiencies (above 99 per cent) are not obtained without high energy consumption.

Introduction

An experimental model of a new type wet dust collector, the "Solivore", is under study at the Harvard Air Cleaning Laboratory as part of the Atomic Energy Commission program of dust collecting equipment evaluation. The unit was developed by Ateliers Ventil, Lyon, France, and may be manufactured in this country by the Ventil Corporation, Harrisburg, Pennsylvania.

The "Solivore" wet collector consists of single or multiple series of stages, each containing a Venturi tube and two spray generators. Its principal collecting mechanism is the impingement of dust particles on water droplets which is enhanced by passing the saturated gas stream through a Venturi tube at high velocities (12,000 cfm throat velocity). This unit is not directly comparable to the Pease-Anthony Venturi scrubber since, in the latter device, water is atomized by the main gas stream at the Venturi throat. In the Solivore a water spray is introduced in a plenum prior to the Venturi. The pressure drop in a Venturi scrubber ranges from 10 to 30 inches of water (due to energy requirements of atomization) as compared to three inches of water per collection stage of the Solivore. The expansion of the gas stream taking place in the Venturi throat is stated by the manufacturer to produce a cooling effect (Joule-Thomson effect) with condensation resulting on the dust particles which serve as nuclei.

A special feature of this collector is the spray generating device which uses mechanical means rather than air or water pressure to produce a fine water spray.

This report describes results of tests with representative aerosols under a variety of operating conditions. Dust concentrations varied from 2 grains per 1000 cubic feet to 2 gr./cu.ft. and water rates from 6 to 12 gallons per minute per spray generator. Several combinations of spray generators were employed during multi-stage operation.

Description and Operation

Description

The experimental Solivore unit consists of four similar collection stages in series each stage containing one Venturi tube and two spray generators as shown in Figure 1. This is a schematic diagram of the experimental four stage Solivore collector. The spray is directed normal to the direction of air flow. Oversized spray generators were installed in the test unit since the manufacturer could not obtain smaller ones. Therefore, water rates were stated to be high with respect to air handling capacities in comparison with large commercial sized units. The spray generator consists of a fixed, circular manifold (11 in. diameter) having eight, relatively large orifices (3/16 inches in diameter) equally spaced on the periphery. When water is supplied, the resulting jets are intercepted continuously by sixteen bevelled vanes extending from a rapidly rotating disc (3300 rpm) located directly in front of the manifold. The spray generator in the test unit has a rated water capacity of 9 gpm at 7 psi and requires a 1 1/2 horsepower motor to energize the spinning disc, Figures 2 and 3. The outstanding advantage of this type spray generator in comparison with conventional hydraulic or pneumatic spray nozzles is its non-clogging feature. The use of large diameter orifices makes possible extensive recycling of spray water without requiring a special filtration system to remove suspended solids.

During laboratory testing two devices were used to remove entrained water droplets. For one and two stage operation an enlarged circular chamber containing six layers of a coarse "metex"* knitted wire screen was attached to the collector outlet. For three stage operation, a vertical riser was attached to the collector outlet so that the gas made an abrupt 90° turn upward upon leaving the collector. This arrangement served as the droplet eliminator.

* Metal Textile Corporation, Roselle, New Jersey

Collection Mechanisms

Collision between spray droplets and dust particles will occur in the plenum chamber. Some of these spray droplets will be removed by inertial forces before entering the Venturi tube. Some collisions will also occur as the aerosol approaches the Venturi throat, due to an increase in relative velocity between the larger particulates (dust and water droplets) and the accelerating gas stream. The velocity of smaller particles stays essentially the same as the gas velocity so that they pass through a zone of relatively slow moving large particles which increases the probability of capture by impaction. A temperature drop will occur during the expansion of the water saturated gas stream at the Venturi throat. However, our calculations show the temperature change based upon a Joule-Thomson expansion to be quite small. In addition, the short retention time during which dust particles can act as condensation nuclei in the area of supersaturation, appears to eliminate this mechanism as an important factor in collection.

Test Methods

Aerosol Generation

Several test aerosols were employed in this study. Fly ash, at concentrations greater than 0.2 grains per cubic foot, calcium carbonate, talc and vaporized silica aerosols were produced by redispersing the dry dust with the Harvard generator (1). In this device the dust is fed from a Syntron Vibrator onto a turntable (1 to 2 rpm). An adjustable wiping arm removes the excess dust from the turntable leaving a ribbon of any desired width along the circumference of the plate. A compressed air aspirator* operating at approximately 25 psi lifts the ribbon of dust from the turntable and ejects it into the inlet duct of the test system. For low dust loadings in the range of 20 gr. per 1000 cu.ft., the National Bureau of Standards dust generator was used. In this device dust is fed by gravity from a small storage hopper to a slowly rotating spur gear. Dust in the grooves is removed by an offset aspirating tube which ejects a steady

* 3/4 inch McDaniel water lifter with Venturi section, Walworth Company, New York, New York -- Cat. 47, 1947.

flow of dust into the test air stream. Sulfuric acid mist was generated by aspirating 2N H_2SO_4 with compressed air at 90 psi and impinging it against a baffle to remove coarse droplets (2).

A finer sulfuric acid mist was obtained by allowing drops of concentrated sulfuric acid to fall on a heated crucible which rapidly formed a fine sulfuric acid mist. A copper sulfate aerosol was generated by atomizing a ten per cent $CuSO_4$ solution with compressed air (100 psi) through a pneumatic nozzle. Large droplets settle out in an elutriating chamber while the finer fraction passes through a pipe heated to 500 to 600°F which produces anhydrous $CuSO_4$ microspheres.

Iron oxide fume was generated by burning undiluted iron pentacarbonyl in a high temperature air-butane flame. The iron pentacarbonyl is conveyed to the gas flame by entrainment in a nitrogen stream in order to eliminate fire and decomposition problems. This procedure for generating Fe_2O_3 is superior to the burning of iron powder since it eliminates the possibility of coarse, metallic iron particulates. A limitation of this technique is that loadings above 20 gr. per 1000 cu.ft. are difficult to obtain without introducing a potential fire and explosion hazard. Table I gives the size parameters for the dusts, fumes and mists used in this study.

Sampling Methods

Two separate sampling methods were employed to determine the dust concentration in the effluent gas stream. In the first method gross concentration was obtained by inserting into the effluent gas stream a sampling probe which led directly to the sampling device, that is, a pleated filter (3), paper thimble (4) or an impinger tube (5). In the second method, the amount of dry or unwetted material in the collector effluent was determined by inserting a settling bottle in the downstream sampling line to remove coarse droplets, greater than 10 microns.

The weight collection efficiency of the Solivore collector has been determined with representative aerosols for several typical dust loadings, several

water rates, and 1, 2, and 3 stage operation. Some data has also been obtained on the amount of wetted dust which has passed through a droplet eliminator compared to the gross amount of dust in the collector effluent.

Results

The Effect of Dust Loading Upon Weight Collection Efficiency

The effect of dust loading upon weight efficiency was observed for one stage operation with fly ash and calcium carbonate. Fly ash efficiencies (Table 2) increased from 99.0 to 99.4 per cent when the inlet dust concentration increased from 0.02 to 1.60 gr. per cu.ft. (an eighty fold increase in loading). With $CaCO_3$, an increase in efficiency from 88.2 to 93.4 per cent was observed for a six fold increase in dust loading (0.25 to 1.50 gr. per cu.ft.).

These data indicate that variations in inlet dust loading have little effect for aerosols collected at high efficiencies (fly ash). However, in terms of penetration, the outlet fly ash concentration is reduced 40 per cent (i.e. 1.0 to 0.6 per cent passage).

For finer aerosols such as $CaCO_3$ the increase in collection efficiency with dust loading becomes more significant (88 to 93 per cent). Increased retention with higher dust loadings is probably due to the greater opportunity for agglomeration which results from a higher particle count density.

The Effect of Water Rate Upon Weight Collection Efficiency

The per cent passage (100 per cent minus collection efficiency) for fly ash, $CuSO_4$ microspheres and coarse H_2SO_4 mist at 6, 9 and 12 gpm per spray generator was obtained for single stage operation, Figure 4 and Table 2a. All tests showed an inverse relationship between per cent passage and water rate within the range tested. The extent of this variation over the range of water rates studied depended largely upon the efficiency for a given aerosol at rated water flow per stage (18 gpm). For the aerosols tested, doubling the water rate caused a reduction of approximately 50 per cent in dust passage.

Wetted Dust Contained in Collector Effluent

By using the two procedures for effluent sampling previously described, it was possible to estimate the quantity of wetted dust (water droplets containing dust) in the effluent gas stream. The amount of dust contained by the water droplets may make a significant contribution to the total effluent loading at the sampling location as shown in Table 3. However, it is expected in commercial installation that only a very small amount of dust bearing water droplets (< 10 microns) would be present in the stack effluent due to their settling and inertial separation in the exit duct, fan and stack.

Effect of Particle Size on Collection Efficiency

Sulfuric acid mist was generated by two methods; impaction of a 2 normal solution on a baffle followed by elutriation and decomposition of acid in a heated crucible followed by water condensation on sulfur trioxide nuclei. The larger size ($mg = 4.0\ \mu$) generated by impaction, was collected by one stage of the Solivore at a collection efficiency of 95.5 per cent. The fine mist (submicron), formed by condensation, was collected by one stage at an efficiency of less than 5 per cent. These data show the wide range in collection efficiency that may be found when particle size is varied.

Multistage Operation of Solivore

Tests discussed so far have described only single stage operation of the Solivore collector, that is, one Venturi tube and two spray generators. Preliminary efficiency data for multistage operation with $CuSO_4$ and Fe_2O_3 aerosols are reported in Table 4. Although this phase of the investigation has not been completed, present tests indicate that the collection efficiency can be estimated by the log-penetration law when additional collection stages are added in series. Theoretically, the log-penetration law applies only to the collection of uniform aerosols (with respect to both size and composition) when two or more similar air cleaning devices are connected in series. Since neither copper sulfate nor

iron oxide particles as formed represented uniform aerosols, this relationship merely provides a convenient means for estimating multistage efficiency. In order for the second and third stage of the Solivore unit to be as efficient as the first stage, the effluent from any preceding stage must have undergone sufficient conditioning (through agglomeration, particle and water contact, and possibly condensation) to approach the size distribution of the original aerosol. In the absence of particle conditioning multistage operation of the Solivore unit would, of course, be impractical.

Effect of Droplet Eliminators Upon Over-all Collection Efficiency

Efficiency tests indicated that the Metex screen droplet eliminator contributed little to total dust removal (0.7 and 2.0 per cent collection efficiency for fly ash and coarse sulfuric acid mist, respectively) while removing approximately one gallon of water per hour from the collector effluent. The vertical riser, used in three stage operation, removed (by inertial separation) about the same amount of water droplets (1 gph) as the Metex screen.

When the last spray generator of the final collection stage was not operated, water droplet carry-over was reduced considerably. The data presented in Table 5 indicates that shutting off the final spray generator with single stage operation (a 50 per cent reduction in water rate) decreases the collection efficiency by less than 2 per cent.

Effect of Varying Number of Spray Generators on Collection Efficiency

A series of tests were undertaken to determine whether the Solivore unit could be operated with fewer spray generators (decreased water rate) without causing an appreciable change in collection efficiency. A 50 per cent reduction in water rate with a single Venturi tube showed a decrease in collection efficiency of about 2 per cent. Passage however, increased by as much as 50 per cent. Under two stage operation removal of the fourth spray generator, located downstream of the second Venturi tube decreased the water rate by 25 per cent and caused no

significant reduction in collection efficiency (Table 6). When either the second (lower) or third (upper) spray generators were shut off a significant reduction in collection was observed in comparison to normal two stage operation. Based upon a rated, two spray generator per stage, water demand in this case was reduced by 25 per cent. Collection efficiencies were reduced from about 32 to 20 per cent for iron oxide fume and from 98 to 86 per cent for copper sulfate microspheres. Results of these tests indicate that the number of water droplets present (total water volume) is an important factor in multistage operation. One spray generator between Venturi stages did not furnish sufficient droplets to bring about efficient contact with the small particles entering the second stage of the collector. Relatively high efficiencies for one stage operation were attributed to removal of the coarser fraction of the aerosol.

Application to Gases

Sulfur dioxide was selected for investigating the collection efficiency of the Solivore unit on gases as they exist in operations where iron fume and fly ash are formed. For an inlet gas concentration of 180 mg/m^3 and three stage operation of the Solivore a collection efficiency of 91.4 per cent was obtained. This high efficiency suggests that corrosion problems may result from extensive recycling of the acid spray water. As the percentage of sulfurous acid in the spray water increases, due to recycling, it is expected that the collection efficiency would be reduced.

Conclusions

It is difficult to compare several types of wet collectors since the available performance data are often based upon entirely different dust loadings and dissimilar operating conditions. For this reason comparisons between several units should not be interpreted too rigidly. Fortunately, collection efficiency data from a prior investigation by the Harvard Air Cleaning Laboratory on a Dynamic centrifugal wet collector (7) is available for some of the dusts and at loadings similar to those used for the Solivore study. The wet collector

studied (the Hydrovolute)* operated at 1000 cfm with a water rate of 6.5 gpm at 5 to 15 psi. A comparison of the collection efficiencies of the Hydrovolute and Solivore collectors for similar aerosols is shown in Table 7. The Solivore collector has a higher collection efficiency, but this is not achieved without an appreciable higher water rate. Collection efficiency data for a Pease-Anthony cyclonic scrubber (8), a Pease-Anthony Venturi Scrubber (8) and a Fog Filter (9) are also shown in Table 7.

Power requirements for one stage operation of the experimental model Solivore is estimated to be 0.1 HP for water delivery, 0.5 HP for air flow and 3 HP for spray generator operation, making a total of 3.6 HP. In comparison, a 600 cfm Venturi scrubber operating at a pressure loss of 20 inches of water is estimated to require 2 HP.

Since the experimental model does not conform completely either in geometric propertions or operating conditions to large scale designs, the results of laboratory tests should not be extrapolated freely until field test data are available.

* Buffalo Forge Company, Buffalo, New York

Table 1

Size Parameters for Test Aerosols

Material	Median Diameter Microns		Geometric Standard Deviation
	Count	Mass	
Resuspended			
Fly Ash	0.6	1.3	2.7
Vaporized Silica*	0.4	0.6	1.5
Talc	1.3	2.5	1.6
Calcium Carbonate	0.6	2.6	2.0
Sulfuric Acid Mist	4.0	13.8	1.9
Copper Sulfate Microspheres	0.48	0.744	1.46
Iron Oxide Fume	.03	0.6	2.0

Table 2**

Relationship between Inlet Dust Loading and Weight Collection Efficiency for One Stage Operation, a Water Rate of 9 gpm per Spray Generator and 600 cfm at Room Temperature

Aerosol	Inlet Dust Loading gr./cu.ft.	Weight Collection Efficiency %	Passage %
Fly Ash	0.02	99.0	1.0
	1.60	99.4	0.6
$CaCO_3$	0.25	88.2	11.8
	1.50	93.4	6.6

Table 2a

Relationship between Spray Generator Water Rate and Weight Collection Efficiency for One Stage Operation at 600 cfm and Room Temperature

Aerosol	Water gal/ 600 ft^3 of air	Inlet Dust Loading gr/cu.ft.	Weight Collection Efficiency %	Passage %
Fly Ash	6	0.2	99.2	0.8
	9	0.2	99.4	0.6
	12	0.2	99.6	0.4
$CuSO_4$	6	0.6/1000	78.9	21.1
	9	0.6/1000	85.0	15.0
	12	0.6/1000	90.2	9.8
H_2SO_4	6	2.5/1000	92.8	7.2
	9	2.5/1000	95.5	4.5
	12	2.5/1000	96.2	3.8

*Size data refer to freshly generated amorphous vaporized silica

**Date presented in these tables are based on a minimum of three experimental runs

Table 3

Effect of Sampling Method on Estimation of Effluent Loading (One Stage Only) for a Water Rate of 9 gpm per Spray Generator and 600 cfm of Air at Room Temperature

Aerosol	Inlet Loading	Outlet Loadings			Efficiency	
		Dry	Wetted	Total	Dry	Wet
					%	
Fly Ash	0.15	0.00086	0.00154	0.00240	99.4	98.4
Talc	1.5	0.0565	0.0270	0.0835	96.2	94.4
H_2SO_4 coarse mist*	0.0025	1.12×10^{-4}	2.70×10^{-4}	3.82×10^{-4}	95.5	84.7

"Dry" refers to dust passing settling bottle in sampling line

"Wet" refers to dust entrained in water droplets retained in settling bottle

Table 4

Stage Collection Efficiency of Solivore Unit for a Water Rate of 9 gpm per Spray Generator and Air Flow of 600 cfm at Room Temperature

No. Stages	1	2	3
Aerosol	percent	weight	collection
Fe_2O_3	20	32	
$CuSO_4$	85	98	99.5+

Table 5

Collection Efficiencies for One Stage Operation with Second Spray Generators On and Off, a Water Rate of 9 gpm per Spray Generator and an Air Flow Rate of 600 cfm at Room Temperature

Aerosol	Weight Collection Efficiency %		Passage %		Inlet Loading
	2 spray generators	1 spray generator	2 spray generators	1 spray generator	gr./ft^3
Fly Ash	99.4	98.7	.6	1.3	1.65
$CaCO_3$**	93.4	91.2	6.6	8.8	1.5
Talc**	96.2	94.4	3.8	5.6	1.5
Vaporized Silica**	96.3	97.6	3.7	3.3	1.0
H_2SO_4	95.5	94.0	4.5	6.0	2.5/1000

*No droplet eliminator in collector

**Efficiencies given are based on gross (wetted and dry dust) effluent samples

Table 6

Weight Collection Efficiencies for Various Combinations of Spray Generators during Two Stage Operation of the "Solivore" Unit at 9 gpm per spray generator and an Air Flow of 600 cfm at Room Temperature

Aerosol	Spray Generators Used*	Inlet Loading gr./1000 cu.ft.	Weight Collection Efficiency %
Iron Oxide Fume	1,2	10	19.9
	1,3	14	20.6
	1,2,3	10	30.1
	1,2,3,4	15	31.6
Copper Sulfate Microspheres	1,2	0.4	86.8
	1,2,3	0.4	98.0
	1,2,3,4	0.4	98.0

Table 7

Comparative Performance of Several Wet Collectors

Unit	Run No.	Aerosol	Loading Gr./cu.ft.**	Water Rate gal/1000cu.ft.	Spray Liquid	Water Pressure psi	Collec. Effic. %
SOLIVORE One Stage Operation	1	Fly Ash	1.65	30	water	7	99.6
	2	$CaCO_3$	1.5	30	water	7	93.4
	3	Talc	1.5	30	water	7	96.2
	4	Vaporized Silica	1.0	30	water	7	96.3
	5	Fe_2O_3	19/1000	30	water	7	21.8
	6	H_2SO_4 (mist-coarse)	2.5/1000	30	water	7	95.5
	7	H_2SO_4***		30	water	7	<5
	8	$CuSO_4$ (microspheres)	0.6/1000	30	water	7	85.0
Three Stage Operation	9	SO_2	180 mg/m^3	90	water	7	91.4
HYDROVOLUTE		Fly Ash	1	6.5	water	5-15	98.4
		Talc	1	6.5	water	5-15	77.1
		Vaporized Silica	1	6.5	water	5-15	94.0
		$CuSO_4$ (microspheres)	1	6.5	water	5-15	81.1
PEASE-ANTHONY CYCLONIC SCRUBBER		Fly Ash (2-5+μ)	.5-2.6	3-10	water		88-98.8
		SO_2	100-150 mg/m^3		water + weak alkali		94.5-96.8
PEASE-ANTHONY VENTURI SCRUBBER		Fe_2O_3 (.02-.50 μ)	1-6		caustic water		99
		Humidified SO_3, H_2SO_4 mist	10.6 mg/m^3	2-6	water		99.4
FOG FILTER		SO_2	230 mg/m^3	30****	caustic water	450	98.3
		Chamber process SO_2, SO_3, H_2SO_4	150 ppm	70	water	500	99

*Number refers to a specific spray generator and indicates its location relative to direction of air flow.

**Unless noted.

***Formed by evaporation and condensation of H_2SO_4 -fine particle size.

****Stated to be lower for larger unit.

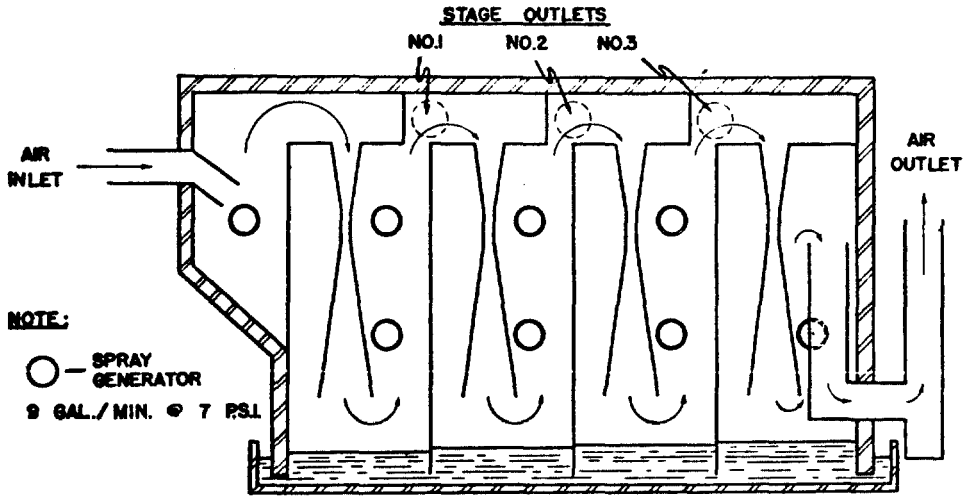

Fig. 1--Schematic Diagram of Experimental Four Stage "Solivore" Wet Collector.

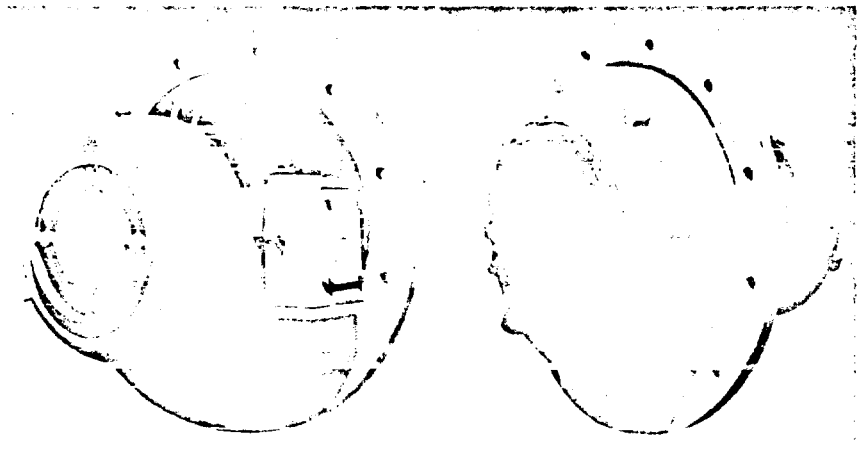

Fig. 2--Large Size Spray Generator.

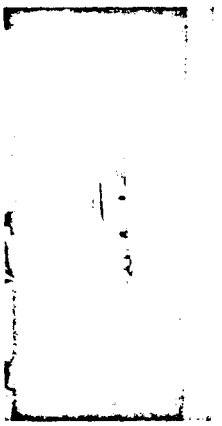

Fig. 3--Spray Generator in Operation.

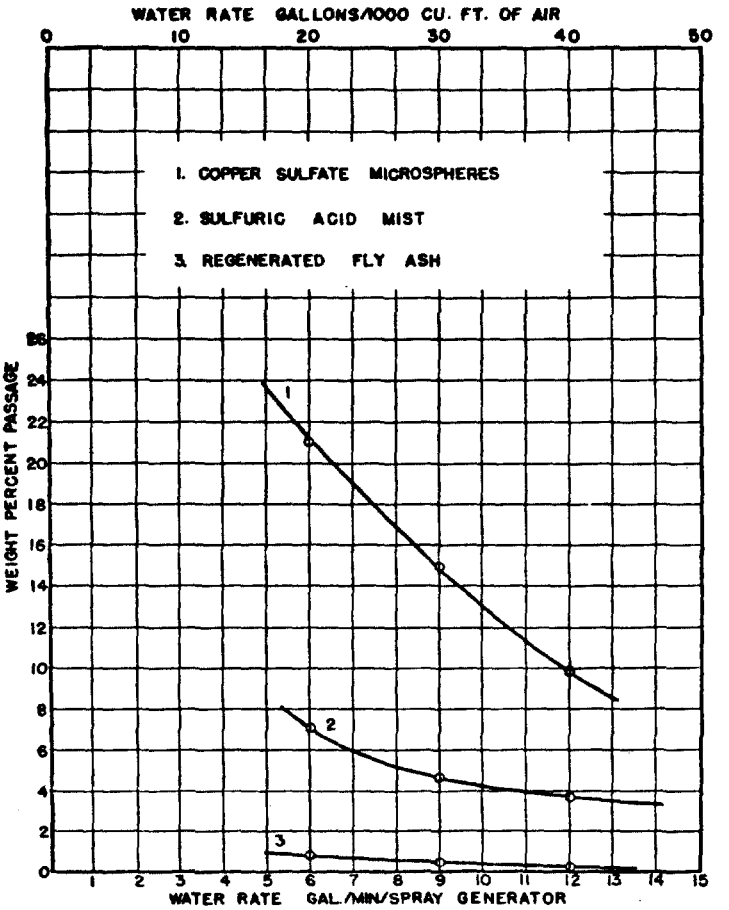

Fig. 4--Effect of Varying Water Rate on Percent Passage for One Stage "Solivore" Operation.

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GAS CLEANING STUDIES OF U. S. BUREAU OF MINES INCINERATORS

Stack Effluent Tests on BOMAEC-30 and BOMAEC-100 Incinerators

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SUMMARY

Representative stack samples were collected during seven incineration tests on the BOMAEC-30 incinerator and five tests on the BOMAEC-100 unit. Sawdust burnings were made in both incinerators to (1) compare their performance and (2) to evaluate the effect of design changes in the BOMAEC-30 unit. Office waste ranging in moisture content from 10 to 50 percent was burned in the incinerators to study combustion efficiency. Both units produced similar effluents when burning like charges and indicated the desirability of further improvements in combustion before design of final air cleaning systems. On a basis of sawdust tests the BOMAEC-100 incinerator yielded better overall combustion efficiency. Although the BOMAEC-30 appeared to do a better job in burning waste, the comparison is clouded by unavoidable differences in charge composition.

INTRODUCTION

At the request of the Division of Engineering, Atomic Energy Commission (Dr. Joseph A. Lieberman) arrangements were made to have the Harvard University Air Cleaning Laboratory conduct stack sampling and gas cleaner evaluation tests on two special incinerators developed by the Combustion Research Section, U. S. Bureau of Mines, Pittsburgh, Pa., the BOMAEC-30 unit, designed for the disposal of radioactive waste materials from hospitals and research laboratories and the BOMAEC-100 unit for similar disposal of somewhat larger volumes.

Stack sampling was conducted at the Bureau of Mines Combustion Research Laboratory, Pittsburgh, Pa., from November 29 through December 3, 1954 and June 8 through June 14, 1955 by staff members of the Harvard University Air Cleaning Laboratory. Incinerator operation and apparatus for supplying a continuous record of the combustion process was supervised by Mr. Cecil H. Schwartz of the Combustion Research Section.

The objectives of the first test program (1954) were (1) to establish air cleaning requirements for the BOMAEC-30 incinerator through the determination of concentration, size, and approximate composition of the incinerator effluent and (2) to evaluate the over-all performance of the originalair cleaning system consisting of a centrifugal section followed by glass filter bags.

Five sawdust incineration tests were made in which the quantity of charge, burning time, over-fire air flow rate and incineration temperature were essentially constant.

Analyses of combustion and sampling data for the BOMAEC-30 unit as first tested indicated a sooty effluent during the first fifteen to twenty minutes of the combustion cycle which caused rapid plugging

of glass filter bags. Condensation of volatile organic materials in the stack gas after passing through the glass bags produced tar droplets which could not have been filtered economically by an AEC absolute-type filter. Pressure loss through the glass bags increased rapidly during the first stages of combustion but remained constant during the last 20 to 30 minutes of operation, indicating that the organic constituents were the primary cause of bag plugging (Figure 1). The deposition of tars in the Ross tubular heat exchanger (which reduced cooling capacity) in conjunction with a fairly high pressure loss suggested that a simple spray tower might be substituted as a more effective means of precooling the stack gas.

As a result of these tests arrangements were made to increase the depth of the combustion chamber and adjust the air supply through changes in either slot width or air volume. The above modifications were based upon the following data: (a) the length to diameter ratio of the BOMAEC-30 combustion chamber was smaller and the Reynold's number through the air entry slots lower than those considered optimum in earlier studies on a smaller pilot plant incinerator (1).

The Air Cleaning Laboratory supplied a pneumatic spray nozzle which was installed in a spray cooling tower (in place of the present tubular heat exchanger). It was also agreed that typical waste charges should be prepared for the BOMAEC-30 unit in addition to sawdust charges so that a more realistic picture of field performance could be drawn.

The objectives of the second test series were (1) to determine whether any improvement in combustion would be realized through design changes in the BOMAEC-30 incinerator, (2) to determine

performance of the BOMAEC-30 unit in burning both rubbish and sawdust charges and (3) to determine the combustion characteristics with sawdust and rubbish and the composition and concentration of effluent gas from the BOMAEC-100 incinerator.

This report includes the results of seven combustion tests (five sawdust and two office waste charges) upon the BOMAEC-30 incinerator and five tests (three sawdust and two office waste charges) upon the BOMAEC-100 unit.

BOMAEC-30 INCINERATOR

A. Description

Figure 2 shows the original form of the BOMAEC-30 incineration and air cleaning equipment. Major design changes, based upon results of previous stack sampling, included an eighteen inch extension of the combustion chamber and a reduction in the width of the air entry slots from $\frac{1}{4}$ to 3/16 inches. No change was made in the position of the air preheat jacket, as shown in Figure 3, so that the preheating zone remained as in the original design. Minor changes in the location of the metering system for supply air have not been shown since they had no bearing upon incinerator performance.

A vertical 4 ft. by 6 in. diameter steel pipe with a pneumatic spray nozzle (Figure 3), directed concurrently, was substituted for the Ross heat exchanger employed in the original gas cooling system. Gas sampling points in the incinerator stack and at the spray tower exit were the same as in previous tests. Oxygen and carbon dioxide concentrations were measured upstream of the water spray system. Gas temperatures were measured in the same locations as in previous tests or as noted in Figure 3.

B. Physical Condition

Prior to testing, the incinerator outlet pipe was blown out to remove a small deposit of ash. No condensate or significant amount of ash or tarry residue appeared in the spray tower drain line. Substitution of the spray tower for the tubular heat exchanger permitted greater air flows than the original system. Glass bags were employed in most tests. Although bag pressure loss increased during each test to maximum values of approximately 9 inches of water, it was possible to maintain desired air flow rates throughout all tests.

STACK SAMPLING EQUIPMENT AND PROCEDURE

A. Stainless Steel Probes and Glass Filters

Particulate samples from the incinerator and spray tower outlet pipes were collected on 1½ inch diameter glass filter circles* supported in a stainless steel filter holder (constructed by machining flat, recessed surfaces on a standard 1" stainless steel union). A ½" diameter, 16" long, straight, steel probe was attached to the filter holder (Figure 4) and inserted in the incinerator outlet duct (Figure 3) so that the tip of the probe faced the gas stream. A similar holder and probe (9" long) was inserted in the tee fitting downstream of the spray tower (Figure 3). The gaseous effluent from the upstream filter holder was drawn through a 4', water cooled, condenser prior to passing through the flowmeter and sampling pump. Cooling was required to protect rubber fittings from high gas temperatures (1100 to 1500°F). Sampling rates were adjusted so that the entry velocities were nearly isokinetic by applying standard temperature and pressure corrections to the flowmeter calibrations. However, rapid filter plugging during some tests and uncontrollable variations in incinerator air flow caused some deviation from isokinetic sampling velocity.

B. Bacharach Stain Tests

Concurrent stain tests were made by the Bureau Combustion Research Laboratory on the incinerator stack gas with a Bacharach smoke indicator. Density of the smoke stains (which are on record at the Combustion Research Laboratory) showed excellent agreement with the appearance of samples collected upon the all-glass filters. No attempt was made during the current test series to sample the glass bag effluent. Bag pressure loss measurements and metering of total air flow were conducted as reported previously.

* Type 1106 B Glass Paper, Mine Safety Appliances Co., Pittsburgh, Pa.

SAMPLING AND TEST RESULTS - BOMAEC-30 INCINERATOR

A. Sawdust Charge

Eight combustion tests on the BOMAEC-30 incinerator (PH-7 through PH-14) were conducted as in the previous survey. Coarse sawdust was dumped into the combustion chamber, levelled by hand, and ignited with a kerosene soaked rag. Typical results (representing tests PH-7 to PH-11) for the combustion of 25 pound sawdust charges at rated air flow (approximately 60 cfm) are shown graphically in Figure 5. Although sawdust charges were smaller than those used in earlier tests (33 pounds) these data indicate that no important changes in effluent concentrations (0.1 to 0.5 gr./cu.ft. STP) or incineration temperatures (1400° - 1500°F) were produced by structural changes in the incinerator, i.e. lengthened combustion chamber and reduced air slot width.

Incinerator stack temperatures rose to slightly higher levels (1300° - 1500°F) due to increased air flow (approximately 10 percent more than in December tests) and a slight reduction in organic components was noted in the stack gas effluent during the first 10 minutes of operation. However, the change in combustible concentrations became insignificant when the periods of organic-free effluent were compared on a basis of total burning time. It should be noted that gas samples collected downstream of the spray cooling system (which showed a higher organic loading) furnished a more accurate picture of effluent composition since condensed tars, some of which passed through sampling filters in the volatile phase at high temperatures, were removed from the cooled gas.

An attempt to improve combustion efficiency through increased air flow, approximately 75 cfm, proved unsuccessful as shown by the

increased organic content of the ash (60 percent). This substantiated the results of past tests by the Combustion Research Laboratory where Bacharach smoke stains had been used to evaluate combustion efficiency. Stack temperature rose to a higher level (1700°F) and the total combustion period was reduced to 25 minutes. Increased combustible loadings were attributed to shortened particulate retention time and changed air flow distribution within the incinerator.

B. Waste Charge

Tests PH-12 and PH-13 represent the combustion of 60 pound charges of office waste consisting of miscellaneous paper, cardboard, and lunch refuse. Estimated moisture contents in tests PH-12 and PH-13 were 10 to 15 percent and 50 percent, respectively, on a dry basis. Combustion of the drier charge (10 to 15 percent moisture) followed the general temperature pattern of the sawdust charges although the average effluent loadings were higher (0.6 gr./cu.ft.) and contained much less combustible material (3 percent). The reduction of distillable combustibles in the charge (primarily cellulose and mineral fillers) accounted for the improved state of the stack effluent. Maximum bag pressure loss during this test was 8.6 inches as compared to 9.5 inches of water for sawdust runs.

A similar waste charge containing 50 percent moisture (Figure 6) showed unsatisfactory performance in that (1) ignition difficulties were experienced and (2) incineration temperatures did not climb to a high enough level to completely burn the entrained combustible materials. Average effluent loadings showed approximately 60 percent combustibles. Bag pressure loss, however, did not exceed the average value of 9.4 inches of water noted for sawdust. At the completion of this test some 16 pounds of ash and unburned charge remained in the incinerator.

BAG PRESSURE LOSS

Pressure loss through the glass bags reached fairly high values during each combustion test (9.5 inches of water). However, pressure loss reduced to approximately 1.8 inches of water at 60 cfm following bag shaking (25 raps) and did not appear to build up to higher base levels during successive tests. The glass bags were removed from the BOMAEC-30 unit at the end of the tests and shaken into a barrel to examine the deposited material. Nearly two pounds of fine ash were dislodged from the bags which indicated that the mechanical shaking mechanism may not be as effective as it should be. The surface of the bags did not show the heavy soot stain observed in previous tests.

SPRAY NOZZLE PERFORMANCE

The pneumatic atomizing nozzle* located in the cooling tower had sufficient capacity at maximum rated flow (9.7 gal./hr.) to reduce stack temperatures from 1400°F to 200°F when air flow rates did not exceed 55 to 65 cfm. However, maximum water rates were not employed in most tests since cooling to 400°F was considered adequate by Mr. Schwartz. It was noted that cooling capacity was exceeded only during test PH-14 when a high air flow rate was used (approximately 80 cfm) which elevated stack temperatures to 1700°F.

* Spraying Systems Company, Bellwood, Illinois
Nozzle 22B - Water pressure 10-60 psi; Air pressure 10-70 psi.

BOMAEC-100 INCINERATOR

A. Description

A schematic drawing of the BOMAEC-100 incinerator (Figure 7) shows the location of the stack sampling probe, the sampling points for the oxygen and carbon dioxide recorders and Bacharach smoke indicator, and the location of the thermocouples.

Supply air for these tests was delivered under positive pressure by a turbo-compressor and entered the combustion chamber through six tangential inlets. Hot gases were exhausted through the incinerator stack at the top of the unit. Although the effluent would, in practice, pass through filtration equipment, the hot gases were vented to an open hood since the primary purpose of the current tests was to evaluate stack gas particulate composition and concentration.

B. Physical Condition

Before any tests were conducted on this unit it was determined that no ash deposits existed in the combustion chamber and stack. According to Mr. Schwartz, incineration and recording apparatus were functioning properly and duplicated operating conditions of previous tests.

C. Stack Sampling Equipment and Procedure

Only incinerator stack samples were collected during tests on the BOMAEC-100 unit. Sampling apparatus was identical with that used in testing the BOMAEC-30 except for a 90° bend in the sampling probe which allowed it to face into the hot gas stream. Again, simultaneous stain tests were run by the Combustion Research Laboratory with a Bacharach smoke indicator. The incinerator air flow for these tests was metered cold at the compressor inlet. Since the flow meter and the compressor handled standard air, delivered volume was nearly constant during each test.

SAMPLING AND TEST RESULTS - BOMAEC-100 INCINERATOR

A. Sawdust Charge

Five combustion tests were conducted on the BOMAEC-100 incinerator (PH-15 through PH-19). The incinerator was charged by placing 20 separate, five pound cardboard containers of sawdust in the combustion chamber. The charge was then ignited by an auxiliary gas burner. Tests PH-15 and PH-18 were conducted at an air flow of 155 cfm (700 pounds per hour) and PH-16 at 193 cfm (870 pounds per hour). The inlet air was not preheated as in the BOMAEC-30 incinerator and the slight temperature rise was due to the heat of compression. The indicated burning period was decreased from approximately 80 minutes (test PH-18) to 60 minutes (test PH-16) by the increase in air flow. Incinerator stack temperatures rose to slightly over 1300°F in the low air flow tests and to 1500°F in the high air flow test. Oxygen concentrations in the stack gas fell to very low values, less than 0.5 percent, for the low air flow tests and to 0.5 percent for the high air flow tests. Conversely, the carbon dioxide curves showed maximum concentrations of about 18 percent for corresponding times. During the runs it was noted that sparks were emitted from the stack when total dust loadings were at maximum levels.

Stack loadings for these tests as obtained from the samples collected on all-glass filter circles are reported graphically along with the other operating data. Figure 8 (test PH-18) shows that for an air flow of 155 cfm the total dust loadings varied from 0.20 to 0.52 gr./cu.ft. while the combustible loadings varied from 0.0 to 0.20 gr./cu.ft. By increasing the air flow to 193 cfm the total dust concentrations ranged from 0.18 to 1.7 gr./cu.ft. while the combustible loadings varied from 0.0 to 0.45 gr./cu.ft. The high loading values

for the high air flow rate occurred at the end of the test after the oxygen concentration had returned to 21 percent; this may have been due to the entrainment of a large amount of partially burned material after the actual combustion had ceased.

It appeared that increased air flow did not improve combustion since total combustible effluent was increased. This confirms the results of similar tests on the BOMAEC-30 incinerator.

B. Waste Charge

Test PH-19 (Figure 9) represents the combustion of 112 pounds of office waste (20 percent moisture) at an air flow of 155 cfm (700 pounds per hour) and test PH-17 represents 101 pounds of office waste (10-15 percent moisture) at an air flow of 193 cfm (870 pounds per hour) in the BOMAEC-100 incinerator. The loose waste charge was dumped into the incinerator and ignited as before with an auxiliary gas burner. The estimated burning period was shortened by about 15 minutes with increased air flow. However, minimum oxygen concentrations were 2.5 percent at the low flow rate (155 cfm) in contrast to 0.4 percent at the high flow rate (193 cfm). Stack temperatures were consistent with reported oxygen concentrations in tests PH-19 and PH-17, i.e., the greater the temperature the lower the oxygen concentration. However, temperatures dropped below 1200°F for the last two-thirds of the runs. Reduced burning rate and greater excess oxygen in test PH-19 was attributed to possible differences in charge composition and bulk density. A series of violent smoke puffs were expelled from the incinerator stack for the first 5 minutes of both tests. Mr. Schwartz attributed this to rapid combustion of printers cleaning rags, film, or other highly volatile materials in the charge. The dust loadings, based upon stack samples, showed a great dependence on air flow. Test PH-19 (air flow 155 cfm) showed dust

loadings ranging from 0.5 to 1.2 gr./cu.ft. with an average value of approximately 0.9 gr./cu.ft. When the flow rate was increased to 193 cfm (test PH-17) the total loading rose to 5.9 gr./cu.ft. at one point and averaged approximately 2.0 gr./cu.ft. for the entire run. The average combustible loading was nearly three times greater when air flow rate was increased to 193 cfm from 155 cfm (0.27 to 0.78 gr./cu.ft.). These data conform to the performance of the BOMAEC-30 incinerator when recommended air flows were exceeded.

PERFORMANCE COMPARISON
BOMAEC-30 AND BOMAEC-100 INCINERATORS

Table I summarizes the comparative performance of the BOMAEC-30 and BOMAEC-100 incinerators for sawdust and waste burning. Columns 1, 2 and 3 indicate total weight of charge, air flow rate and ratio of air flow to charge, respectively; column 4, the burning rate in lbs./hr; columns 5 and 6, the stack emission in terms of total and combustible materials emitted in lbs./hr./lb. of charge; and column 7, the percent combustibles in the stack effluent.

Air flow rates in excess of those recommended by the Combustion Research Laboratory resulted in increased stack emission of both mineral and combustible materials although burning rates were increased by about 20 percent.

Over-all combustion efficiency of the BOMAEC-100 unit appeared better than that of the BOMAEC-30 unit with sawdust. Combustible loadings were equal to or less than those of the BOMAEC-30 unit, the air to charge ratio lower and the burning rate approximately 65 percent greater. However, waste combustion tests indicated a lower stack emission with the BOMAEC-30 unit at the expense of a lower burning rate and greater air to charge ratio.

A higher moisture content and possible variation in composition in the waste may have accounted for the increased stack emission in the case of rubbish charges in the BOMAEC-100 unit.

Based solely upon sawdust tests it appeared that the arrangement of air jets within the BOMAEC-100 unit may have been responsible for its improved combustion. It should be noted, however, that since no preheating of inlet air took place in the BOMAEC-100 incinerator, the combustion conditions should have been less favorable than in the BOMAEC-30 unit.

TABLE I

Comparative Performance of BOMAEC-30 and BOMAEC-100 Incinerators

Total Charge lbs.	Air Flow Rate cfm	Air to Charge Ratio cfm/lb.	Burning Rate lbs./hr.	Stack Emission Rate		Percent Combustibles in Stack Effluent
				Total lbs./hr./lb. of charge	Combustible lbs./hr./lb. of charge	
A. BOMAEC-30; SAWDUST CHARGE						
25	60	2.4	45	0.0033	0.0011	33.3
25	79	3.2	65	0.012	0.0075	62.3
B. BOMAEC-30; WASTE CHARGE (10-15% MOISTURE)						
60	63	1.05	33*	0.0043	0.00016	3.8
C. BOMAEC-30; WASTE CHARGE (50% MOISTURE)						
69	63	0.91	22*	0.0071	0.0047	66.2
D. BOMAEC-100; SAWDUST CHARGE						
100	155	1.55	75	0.0043	0.0011	25.2
100	193	1.93	100	0.012	0.0023	18.8
E. BOMAEC-100; WASTE CHARGE (10-20% MOISTURE)						
100	155	1.55	75	0.012	0.0035	29.4
112	193	1.72	124	0.030	0.011	37.4

* Burning rate based upon weight of dry charge completely burned.

CONCLUSIONS

A. BOMAEC-30 Incinerator

1. The substitution of a high pressure water spray* for the Ross heat exchanger provides better control of gas cooling and reduces the over-all pressure loss in the gas cleaning system.

2. Glass bags still do not constitute an effective gas pre-cleaner for AEC type absolute filters due to the presence of tar droplets and water vapor in the gas stream. Resistancewise, glass bags may be serviceable provided that sufficient fan capacity is available.

3. Increasing the height of the burning chamber and reducing the width of the air inlet slots makes no significant change in the concentration and physical nature of the stack effluent for sawdust combustion tests. Temperatures, oxygen concentrations and burning rates were essentially the same as in previous tests.

4. Increasing air flow rate shortens the overall burning time but produces higher stack loadings containing a greater percentage of combustibles. These data agree with past smoke stain tests of the Combustion Research Laboratory.

5. Burning of comparatively dry materials (10-15 percent moisture) or other cellulose type wastes results in a substantially lower emission of combustible materials than found for sawdust. However, the burning rate and uniformity of combustion is largely dependent upon the bulk density of the charge.

6. Burning of wet waste (50 percent moisture on a dry basis) which simulates the water content of some biological wastes, is unsatisfactory. The burning rate was low, stack temperatures were

* Spraying Systems Company, Bellwood, Illinois
Nozzle 22B; Water pressure, 10-60 psi; Air pressure, 10-70 psi.

below 1000°F for most of the test and the quantity of combustible material leaving the stack was about thirty times greater than that from low moisture content waste.

B. BOMAEC-100 Incinerator

1. Incomplete combustion of sawdust occurs during the first 10 to 20 minutes of tests conducted at rated air flow (155 cfm) due to oxygen deficiency and rapid distillation of volatiles. During the last half of each test, stack temperatures dropped to less than 1200°F, below which level combustion is not considered optimum.

2. The concentrations of combustible materials in the stack effluent present the same gas cleaning problems posed by the BOMAEC-30 incinerator.

3. Sawdust combustion in the BOMAEC-100 incinerator appears more efficient than in the BOMAEC-30 unit based upon (1) equal or slightly lower stack emissions, (2) lower air to charge ratio, and (3) increased burning rate. Better performance may have been due to differences in method of air introduction and in air flow pattern within the incinerator.

4. Combustion of office waste (16 - 20 percent moisture) is less efficient than that of sawdust. Combustible effluent loadings were about three times higher than those of sawdust and stack temperatures dropped below 1200° for the last two-thirds of each test.

5. Combustion of both sawdust and waste is not improved by increasing air flow, i.e. 193 cfm vs. 155 cfm (the recommended flow rate). Although burning rate was increased in both cases by about 30 percent, the total weight of combustible effluent was increased about five times for the same quantity of charge.

RECOMMENDATIONS

A. BOMAEC-30 Incinerator

1. Operational and constructional changes in the BOMAEC-30 incinerator merit further consideration since tests with wet rubbish (50 percent moisture content) indicate unsatisfactory combustion. Since increased air flow did not improve combustion it is suggested that a change in the number and arrangement of air inlets be considered.

2. Preliminary drying of wet charges should be investigated if no auxiliary burners are to be employed. Combustion temperatures with wet waste were far below the level required for complete burning of airborne particulates.

3. If no further mechanical improvements can be made, the intermittent use of an after-burner to maintain a 1200°-1400°F stack temperature still appears as a practical way to reduce combustible loadings.

4. Recommendations for a final gas cleaning system, assuming that present combustion conditions are optimum, remain as reported previously. Following passage through a spray cooler and reheating (to prevent further condensation of water) cooled gases can be filtered through a mineral wool roughing filter to remove a large percentage of the organic materials. Final gas cleaning units would again consist of glass bags followed by absolute filters.

B. BOMAEC-100 Incinerator

1. Recommendations to improve combustion in the BOMAEC-100 incinerator follow the same pattern as for the BOMAEC-30 unit. Since limited test data for both sawdust and waste combustion show reduced emission of combustibles at lower air flow rates, it seems reasonable to consider a further reduction in total air flow.

2. Gas cleaning equipment for the BOMAEC-100 incinerator must necessarily be comparable to that of the BOMAEC-30 unit.

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(1) R. C. Corey, L. A. Spano, C. H. Schwartz, and Harry Perry. "Experimental Study of Effects of Tangential Overfire Air on the Incineration of Combustible Wastes", Air Repair, vol. 3, no. 2, November, 1953.

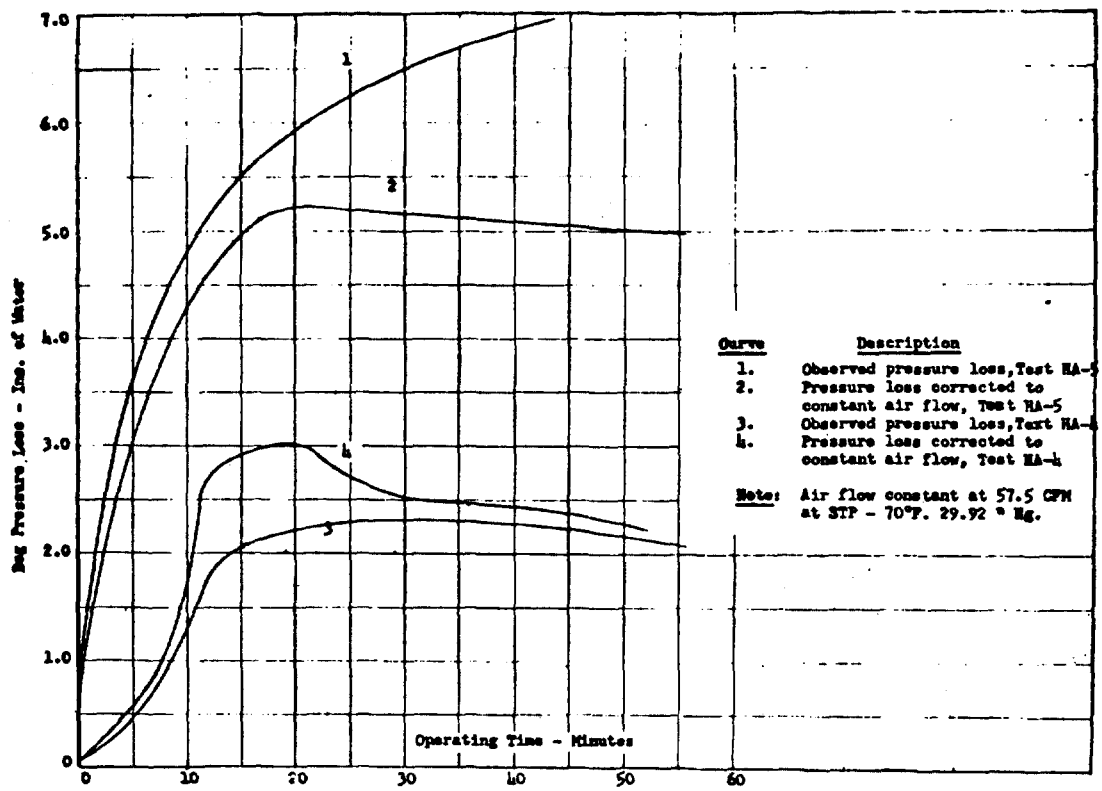


Fig. 1--Pressure Loss Increase Through Glass Bags During Incineration Tests.

FIGURE 2 - LEGEND

1. Incinerator (29" Inside Diameter, 29 1/2" High)
2. Air Inlet, Metered by 2" Orifice in 4" Pipe
3. Incinerator Inlet Static Pressure Tap
4. Sight Glass for Observing Combustion
5. Pre-Heat Air (Jacket) Temperature, Thermocouple Nos. 1 and 4
6. Incinerator Outlet Gas Temperature, Thermocouple No. 3
7. Incinerator Outlet Static Pressure Taps
8. Incinerator Outlet Sampling Probe
9. Gas Temperature Entering Heat Exchanger, Thermocouple No. 6
10. Inlet to Heat Exchanger Static Pressure Tap
11. Ross Heat Exchanger
12. Cooling Water Inlet and Outlet
13. Heat Exchanger Outlet Static Pressure Taps
14. Gas Sampling Tube to Oxygen Recorder
15. Gas Sampling Tube to Carbon Dioxide Recorder
16. Drain Plug, Condensate from Stack Gas
17. Heat Exchanger Sampling Probe
18. Bag House (Seven Glass Cloth Bags)
19. Final CC-6 Filter Housing (No Filters Used)
20. Buffalo Fan
21. Ash Drums (35 Gallon Size)
22. Sampling Probe to High Volume Sampler
23. Temperature After Fan, Thermocouple Nos. 2 and 5
24. Bag Pressure Loss Taps
25. Fan Static Pressure Tap

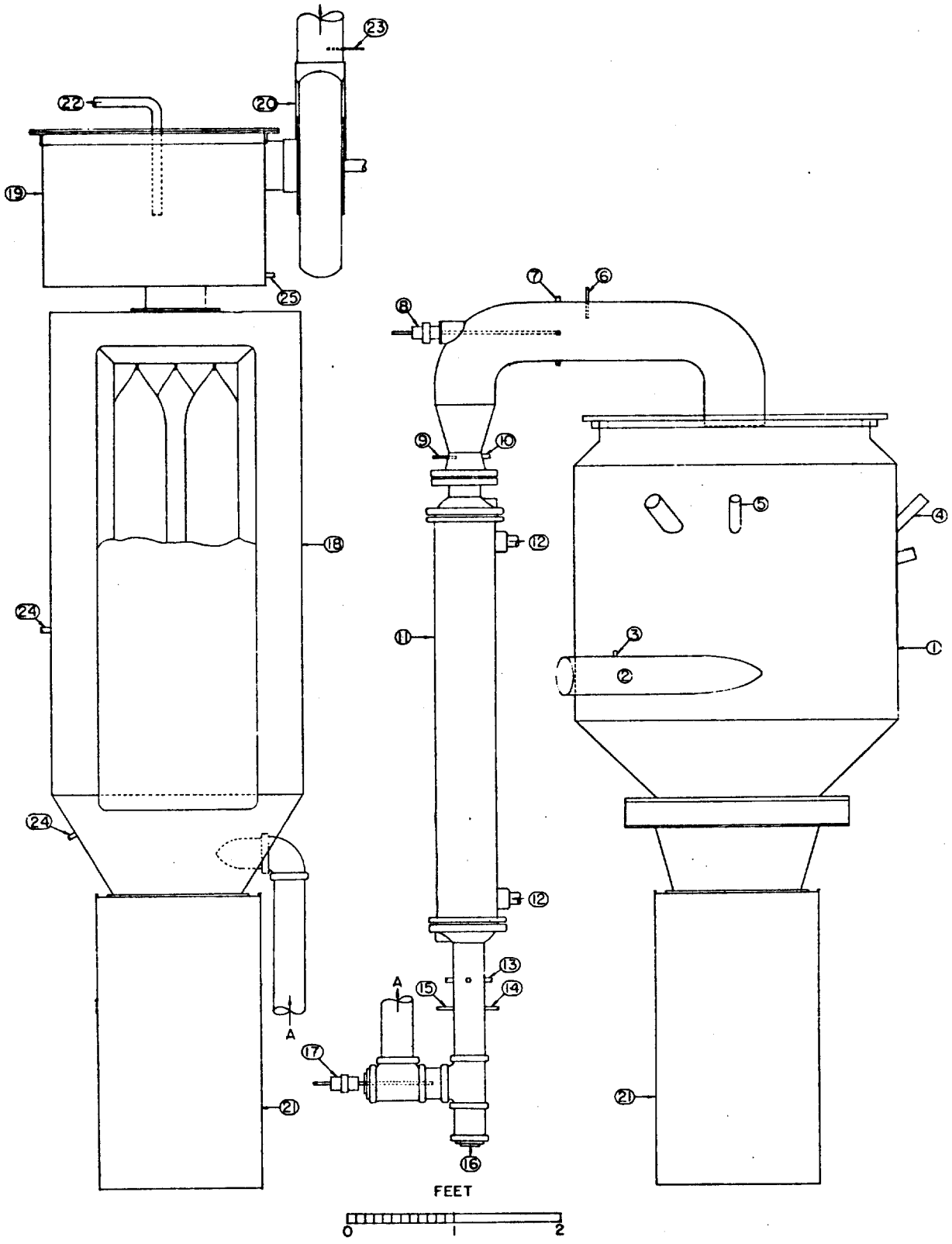


Fig. 2--Schematic Drawing of Institutional Incinerator (BOMAEC-30) Showing Sampling Points.

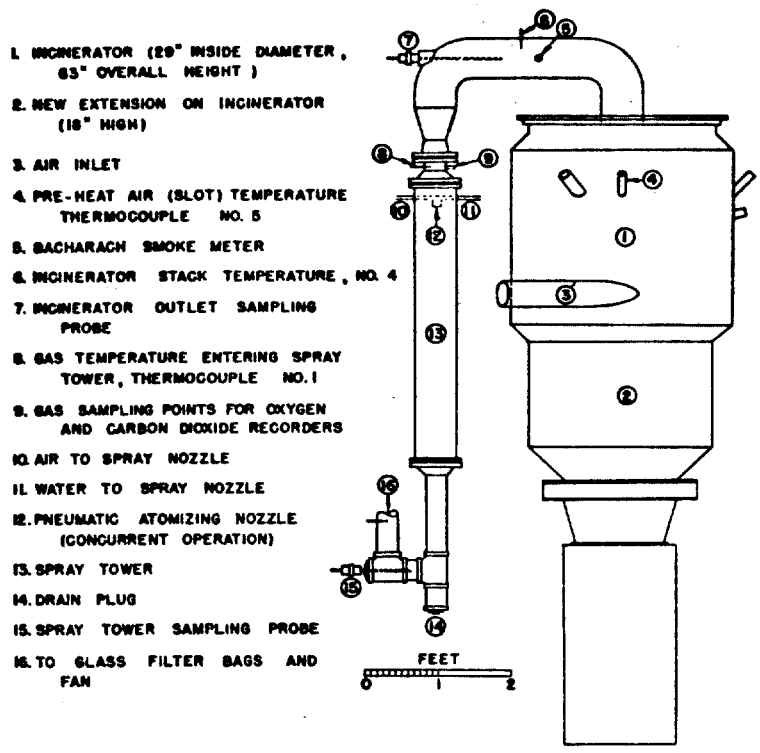
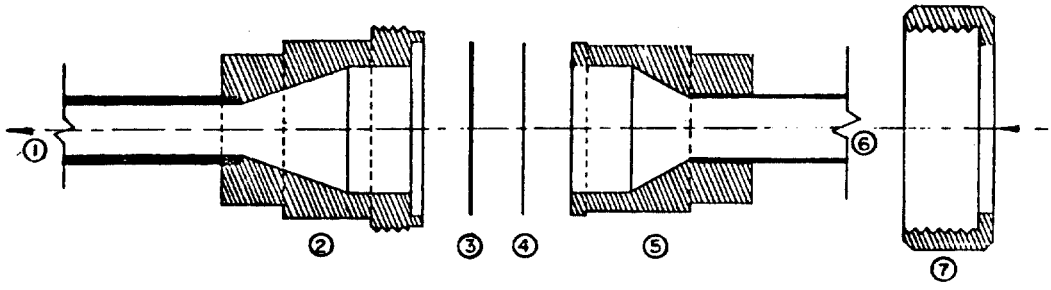


Fig. 3--Schematic Drawing of Revised Institutional Incinerator (BOMAEC-30) Showing Sampling Points.



1 TO FLOW METER AND PUMP
2 1" STD. STAINLESS STEEL UNION - REAR HALF
3 BACKER SCREEN
4 ALL GLASS FILTER CIRCLE
5 1" STD. STAINLESS STEEL UNION - FRONT HALF
6 SAMPLING PROBE EXTENSION
7 UNION NUT

INCHES
0 1 2 3 4

Fig. 4--Stainless Steel Sampling Probe and Holder for All Glass Filter Circles.

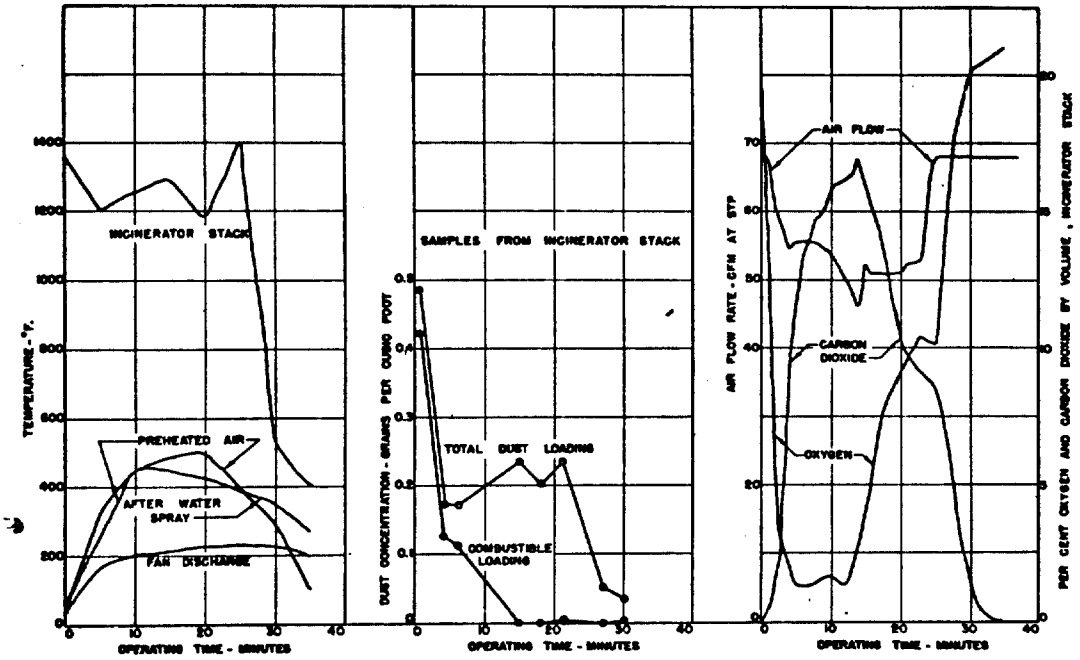


Fig. 5--Test Data, Test PH-8, 25 Lbs. Sawdust in BOMAEC-30.

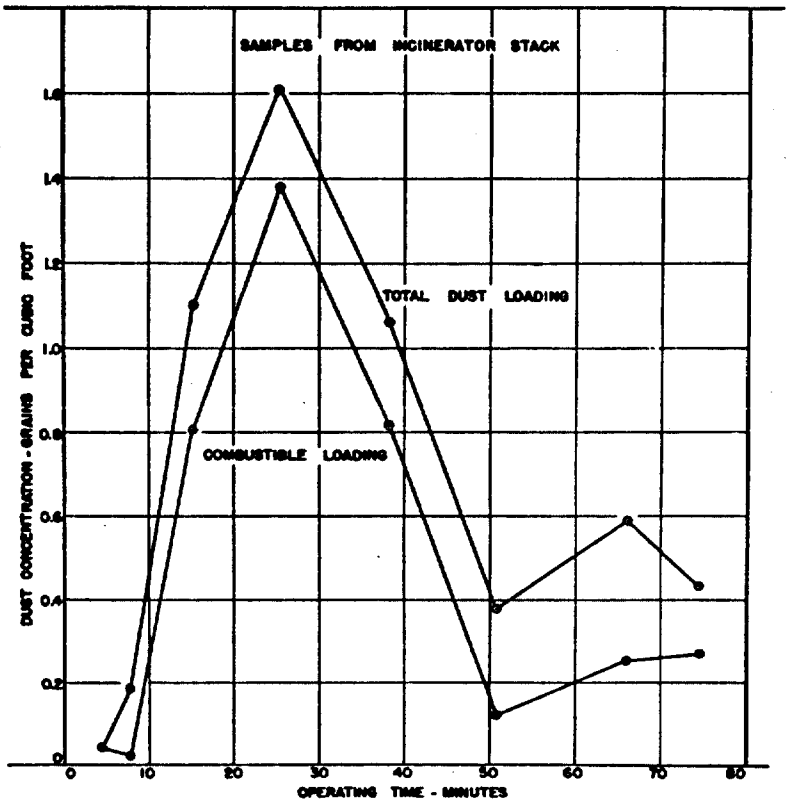


Fig. 6--Test Data, Test PH-13, 69 Lbs. Office Waste with 50% Moisture in BOMAEC-30.

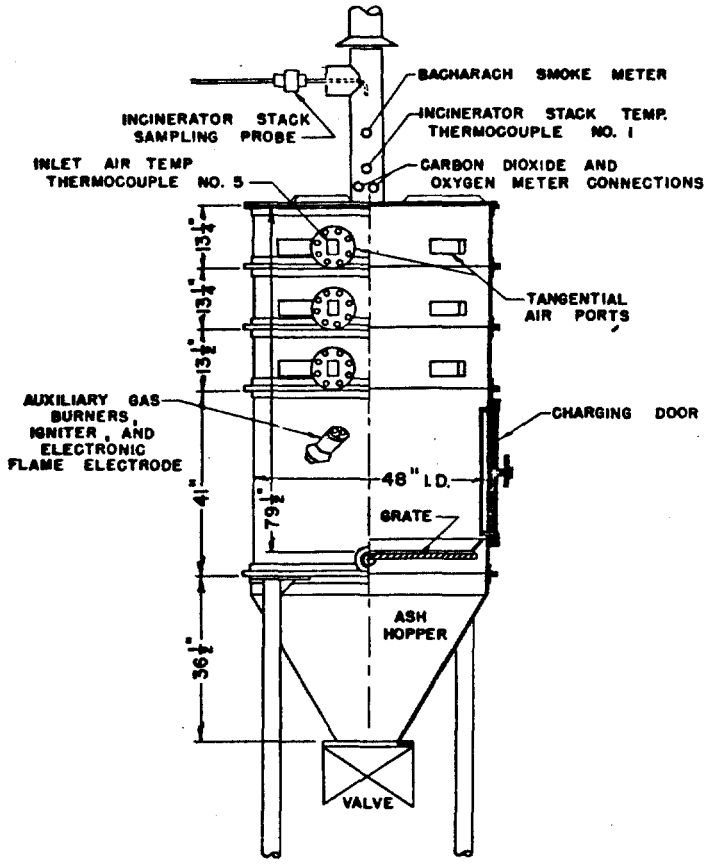


Fig. 7--Schematic Drawing of BOMAEC-100 Incinerator Showing Sampling Point.

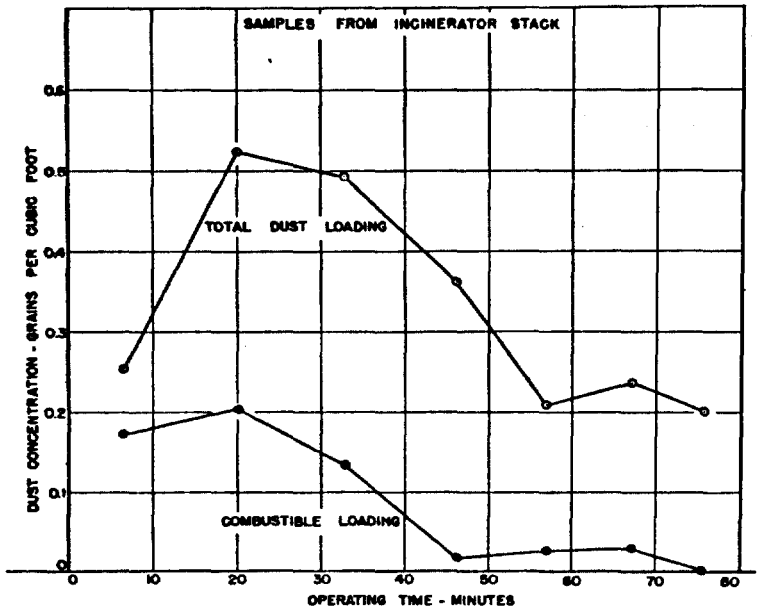


Fig. 8--Test Data, Test PH-18, 100 lbs. Sawdust in BOMAEC-100

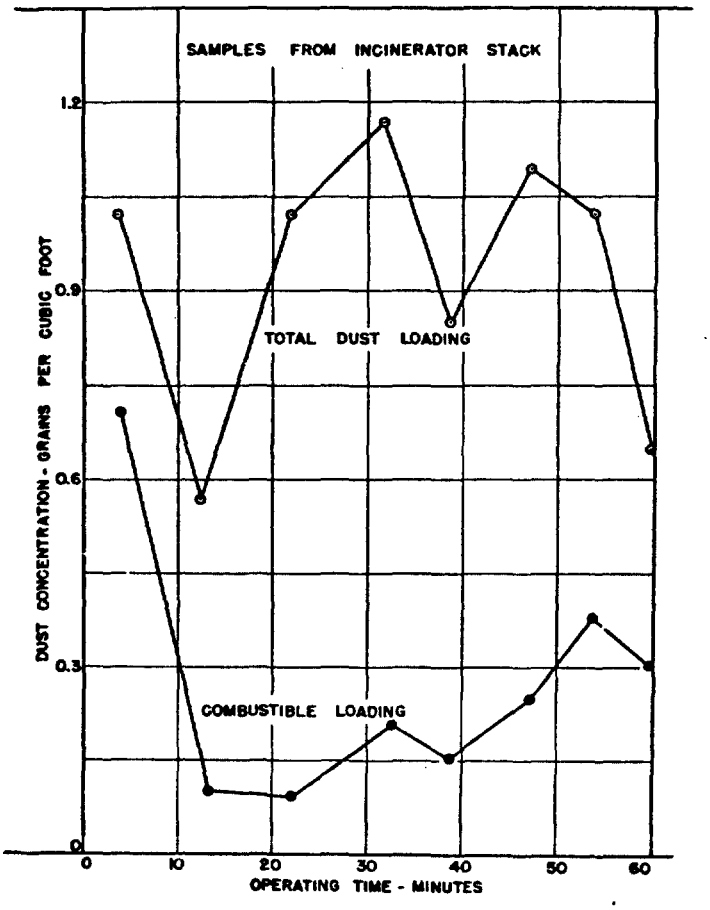


Fig. 9--Test PH-19, Office Waste, 15% Moisture, BOMAEC-100.

FURTHER STUDIES ON ELECTROSTATIC MECHANISMS OF AEROSOL FILTRATION

by

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INTRODUCTION

At the Harvard School of Public Health, research on electrostatic mechanisms of aerosol separation has proceeded along three main lines. Packed fibrous beds have been studied to obtain the relation between aerosol and fiber charge, and the improvement in inherent filtration, i.e. the electrostatic efficiency. Fabric media have been studied to relate apparent surface charge on the fabric and collection improvement. Some preliminary studies of a more basic nature have been made to define coulombic, dielectrophoretic, image, and space charge forces operating between parallel plane and irregular surfaces.

The initial studies on the first two phases have been completed. Detailed descriptions of the study on fibrous beds are available in NYO reports (1,2,3,4) and in the open literature (5). Results of the investigations on fabric media have now been published (7,9) and will be expanded in an NYO report soon to be released (8). The third phase of study, basic forces, is being completed and will be described in a separate NYO report. It is the purpose of this paper to summarize very briefly the completed studies, to describe the current phase of research, and to indicate proposed future studies.

SUMMARY OF COMPLETED STUDIES

A. Fibrous Bed Studies

At the third Air Cleaning Conference the effects of aerosol charge on the efficiency of an uncharged fiber bed were reported (6). The apparatus (Figure 1) was described, which consisted of a spinning disc aerosol generator (used for generating methylene blue spheres, MMD = 2.0 μ, σ_g = 1.3), a wire-cylinder ionizer for aerosol charging, a test filter section which also served as the aerosol and fiber charge measuring device by using the Faraday ice-pail principle, sampling probes, and a blower. The same apparatus was used for determining the effects of fiber charge on an uncharged aerosol and the combined effects of both aerosol and fiber charge.

Using packed 50 μ glass fibers as the uncharged filter it was found that efficiency increased systematically with aerosol charge reaching a maximum at a value 2×10^{-5} statcoulombs/gm. (2000 e/part.). These results were independent of aerosol polarity. Tests using a negatively charged 70 μ saran fiber bed and an uncharged aerosol showed that filter efficiency increased smoothly with fiber charge to over twice the initial value at a fiber surface charge of 0.3 statcoulombs/cm.^{2}. With the aerosol and filter charged to opposite polarities, efficiency increased more rapidly. At comparatively high fiber surface charge (0.7 statcoulombs/cm.^{2}) however, aerosol charge became unimportant and filter charge determined the efficiency almost exclusively. In addition this study included preliminary investigations of the effects of fiber size, filtration velocity, and packing density on electrostatic efficiency and related tests on the effective life

of a charged fiber filter. The concept of "self-charging" filters was investigated and results using filtered air, room air, and a methylene blue aerosol at loadings of 1.0 mg./M^3, with velocities up to 360 fpm, showed no measurable electrification of 70 μ saran fibers.

B. Fabric Media Studies

In this phase of the over-all program a device was constructed in which a mechanically charged fabric surface was employed as the filtering medium for atmospheric dust. Figure 2 shows the final unit as it was developed into a two-stage cleaner. This unit consists of a lucite box, D, perforated on two sides and mounted vertically between two lucite rollers, E. The fabric to be tested was sewn in the form of an endless belt, F, and placed over the rollers thus enclosing the box. A small electric motor geared to the bottom roller caused the belt to travel around the box and also drove a counter rotating paddle, C, covered with a fabric which served to charge the belt by a contact-separation mechanism. This assembly was enclosed in a Masonite box, G, one face of which was cut in grid form and covered with a fabric, A, the same as that covering the paddle. This fabric surface was charged by the action of a windshield wiper blade, B, covered with the same fabric as the belt. Air flow was through the screen and then through the belt. The unit was tested by sampling at three points, upstream, interstage, and downstream. Efficiencies were computed using the stain density of the dust on Whatman No. 41 filter paper. Fabric surface charge was measured by a charge pick-up probe, developed by this laboratory. Aerosol charge was not controlled and ranged from an estimated average net charge of <1.0 to 45 electron units (positive) per particle (as measured in a Faraday cage system).

The fabrics tested in this unit included wool, resin-wool, saran, and orlon, in various combinations. The basic uncharged efficiency on atmospheric dust of the two-stage unit could be doubled by mechanically charging the fabrics by contact with other suitable fabric surfaces. It was shown that the electrostatic mechanism introduced by mechanical charging was not quite as beneficial as that produced by the action of a resinous additive. However, mechanical charging was accomplished at no change in resistance. Moreover, the magnitude of the improvement from mechanical charging was by no means maximized in these tests. In addition particle charging by the charged first stage was shown to occur and to aid collection when the second stage was uncharged but was found to be unimportant when the second stage was charged to a sufficient magnitude. (This is essentially the same conclusion reached in the independent packed fiber bed study just discussed.) Other tests showed that the efficiency due to electrostatic effects was inversely related to filtering velocity and directly proportional to the apparent surface charge generated on the fabrics. The magnitude of this charge was shown to be dependent on the fabric composition, type of charging action, and absolute humidity.

FUNDAMENTAL RESEARCH

Throughout the previous investigations there was a need for a more basic understanding of the fundamental mechanisms of electrostatic capture with regard to aerosols such as atmospheric dust possessing only natural charges due to their generation, and moving in the streamline flow range as occurs in the motion past fibers in both packed beds and fabrics. The literature on electrostatic separation is, unfortunately, sparse in these two areas, most of it concerning aerosols of high charge moving in turbulence. Retention time in an electrostatic field, field strength, field configuration, and position of the collection surface with respect to the aerosol, required further investigation. Therefore a study was initiated with atmospheric dust moving in streamline flow using a vertical parallel-plate type condenser unit, directly charged (Figure 3). This is the simplest orientation which may be handled theoretically. The unit consisted of a rectangular Masonite channel of variable width, 16" long, and 18" deep. The inner faces of the channel were removable. In the following tests polished aluminum sheets, and plates covered with a layer of "Metlon", an aluminum-polyethylene woven cloth, were used as the collecting faces in the channel, producing uniform and non-uniform fields respectively. These collecting faces were charged directly with a 20 kv power supply and the field strength measured by plate voltage and capacitance. In the case of the non-uniform fields, the "apparent" field strength was measured, which was accurate except at very short distances from the cloth surfaces. Atmospheric dust was used as the test aerosol and samples up- and downstream were again measured by stain density. A statistical method of

averaging results was developed since many factors influence any one stain measurement and since an important variable, aerosol charge, varied during the tests.

For charged particles moving between two flat charged plates two forces were considered operating, field forces and image forces. The field force is derived from the definition of an electric field and is characterized by

$$F_C = \mathcal{E} Q_p \qquad \text{Equation (1)}$$

The image force is due to the decreased energy in the weakened field surrounding the particle when it is near a conducting body, regardless of the potential of the conducting body. It can be thought of as a coulombic force of attraction due to a mirror image of the charge in the conducting body and in the case of an infinite plane is characterized by (10)

$$F_I = \frac{Q_p^2}{4y^2} \qquad \text{Equation (2)}$$

Because the aerosol tested was considered to consist of approximately equal numbers of particles of opposite sign, space charge effects were neglected. Calculations also showed that for the plate spacings used, diffusional forces are negligible. Because of the vertical orientation of the unit, gravity effects can also be neglected. The equation of motion between these plates for particles in the Stokes' Law range is therefore

$$m \frac{dV_y}{dt} + \frac{6\pi\mu r V_y}{1+A(L/r)} - \mathcal{E} Q_p - \frac{Q_p^2}{4}\left[\frac{1}{y^2} - \frac{1}{(Y-y)^2}\right] = 0 \qquad \text{Equation (3)}$$

The first term is the inertia force, the second is the particle drag, the third is the field force, and the fourth is the force due to images of the charged particle in both plates. The fourth term is actually only an approximation since the image charges themselves induce images in the opposite plate and these images

in turn produce further images in an infinite series. The image force as written contains only the first terms of these infinite series and is a good approximation since each succeeding term decreases by the square of a distance which itself becomes infinite.

By integrating the fluid velocity distribution for streamline motion between parallel plates, and combining the result with the solution of Equation 3 for field forces operating alone, an equation can be written for the stopping distance x_s traveled by a particle starting at $t = 0$; from the position $x = 0$, $y = y$ (any particle just entering the area between the plates) and arriving at the point $x = x_s$, $y = 0$ (being caught on the plate at distance x_s) (11):

$$x_s = \frac{6\pi\mu r V_{avg}(3Y_y^2 - 2y^3)}{Y^2 Q_p[1+A(L/r)]} \qquad \text{Equation (4)}$$

The precipitating efficiency of such a parallel plate device is the fractional air volume swept clean in the distance x_s. Since the aerosol is considered to consist of equal numbers of particles of both signs the total efficiency is the ratio of the air volume entering the unit out to point y to the total air volume. Integrating the velocity distribution again the efficiency is, for a variable distance y

$$\eta = \frac{3Y_y^2 - 2y^3}{Y^3} \qquad \text{Equation (5)}$$

Using equation 4 to determine the limiting distance y for $x_s = X$, i.e. the total plate length, and combining with equation 5, the over-all efficiency is expressed by

$$\eta = \frac{X}{Y V_{avg}} \left[\frac{\varepsilon Q_p (1 + A (L/r))}{6\pi\mu r}\right], \eta \leq 1.0 \qquad \text{Equation (6)}$$

The term in brackets is the so-called plate migration velocity. This equation agrees in form with those given elsewhere (15).

This equation is of limited application since it refers only to the field force operating between parallel charged plates oriented perpendicularly, with air flow in streamline motion and a homogeneous aerosol of uniform size and charge distributions. In the experimental tests field forces do not occur alone nor are the charge and size distributions of the aerosol uniform. It will serve for comparison purposes, however.

The equation of motion for particles moving due to image forces operating alone could not be solved by any of the classical methods of differential equations. The use of finite differences was attempted but the number of steps required became prohibitive. Its solution is now being attempted using an electronic analog computer.

In an irregular field, as produced by a charged rough surface, the field gradient $\partial \mathcal{E}/\partial_y$ is not constant as between parallel plates but is a function of the distance from the surface. In such a field a third force, dielectrophoresis, becomes operative, and is characterized by (12).

$$F_D = K \frac{(K_1 - K)}{(K_1 + 2K)} \quad \frac{(D_p{}^3)}{(8)} \mathcal{E} \frac{\partial \mathcal{E}}{\partial y} \qquad \text{Equation (7)}$$

This force is due to induction and attraction of electric displacement charges within the particle which tends to produce a dipole and occurs whether the particle is charged or not. The differential equation describing motion due to this force is complicated and can only be written for particular geometric shapes and orientations, and definitely not for the heterogeneous fields produced in these investigations. It will be noted, however, that the force is independent of particle charge and increases with particle size.

Figure 4 represents tests to determine the effect upon efficiency of field strength at constant velocity and plate spacing. Curve 1 shows the effect of a uniform field. The relation is nearly linear up to a limiting field strength of approximately 13 dynes/statcoulomb after which a maximum efficiency, 80%, is reached. The heterogeneous field, Curve 2, shows a larger effect at the same apparent field strength due to the added dielectrophoretic force described in Equation 7 but also reaches a maximum at the same efficiency. This added efficiency is at no extra expenditure of power and shows the value of even a slightly heterogeneous field (See White (13), p. 936).

It will be noted that both curves shown an intercept at zero field strength. This is attributed to image forces which are now being investigated separately. Curve 3 is a plot of equation 6 starting at the intercept and using the previously measured average net Q_p of 25 electron charges. Since efficiency was measured with a stain technique rather than a count method, and since aerosol size and charge characteristics were variable, exact analytical comparisons of the data and the theory are not warranted. However, in spite of these limitations, it is obvious that an average Q_p of 25 e is notrealistic. Curve 4 is the theoretical count efficiency which most closely fits the experimental data and is for a uniform aerosol with an average Q_p of 0.4 e. The high measured charge is probably due to relatively few particles of high Q_p. The actual aerosol probably possesses a mean Q_p much nearer 0.4 e. The assymptotic efficiency of 80% is attributed to the removal of all charged particles which can significantly influence a stain density measurement.

Figure 4 reveals that at a low velocity a condenser-type apparatus will give high stain efficiencies on a naturally-charged aerosol

such as atmospheric dust without aerosol charging by ionization as in two-stage electrostatic precipitators. The field strength necessary for these high efficiencies (10 statvolts/cm.) is about 40% of that used in the second stage of the conventional two-stage precipitator (Westinghouse Precipitron). With a heterogeneous field the high efficiency (80%) is possible at even lower field strengths. For removal of uncharged particles (20% by stain for atmospheric dust) the heterogeneity must be more intense than that produced by an irregular semi-plane surface i.e. the field gradient $\partial E/\partial y$ must be greater for dielectrophoresis to become significant.

Figure 5 presents the results of tests to determine the effect of velocity and plate spacing on collection. Curve 1 is the experimentally determined relationship at E= 11.7 dynes/statcoulomb, Y = 4.44 cms.

Curve 3 shows the experimental values at the same field strength, 11.7 dynes/statcoulomb, but at a closer place spacing 1.91 cms. Both curves indicate that stain efficiency falls off rapidly with increasing velocity. For decreasing plate spacing this rate of fall-off becomes less rapid. At the same time image forces increase at a rate proportional to the square of the spacing (see equation 2). Therefore it appears that if plate spacing is further decreased high stain efficiencies will be obtained at velocities which will be more in line with practical values. The spacing must, of course, not approach values which will make pressure loss prohibitive.

Figure 6 presents the experimental results for the conditions of increased field strength, E = 17.9 dynes/statcoulomb, and Y = 1.91 cm. Superimposing Curve 1 of this figure on Curve 2 of Figure 5 it is found that the effect of increasing field strength is

significant above 150 fpm but below this velocity (and at this spacing) this 50% increase in field strength seems to affect the efficiency very little. This is to be expected since the difficult-to-assess areas are in the steep portions of these curves where efficiency is affected by velocity to the greatest extent. At low velocities the effect of field strength is actually considerable as was shown in Figure 4.

Curve 3 shows the effect of introducing a slight heterogeneity to the field form in the manner described previously. The results so closely parallel the uniform field that the two curves could actually be drawn as one. At low velocities, nevertheless, the effect of a slight heterogeneity is apparent as was shown in Figure 4. Curve 4 is a plot of results of tests where the field strength was zero, the "base-efficiency" of the unit. The points represent two plate spacings, 1.91 and 4.44 cms., between which no significant difference in results were noted. There is a wide spread in the data, and, in fact, above 50 fpm the curve could probably have been plotted at zero efficiency rather than at 5.0%. Below 50 fpm, however, there is a definite increase to a significant efficiency as velocity is decreased. This efficiency is attributed to image forces.

Curve 2 represents the theoretical curve of best fit using equation 6 and the image force efficiency from curve 4, i.e. $\eta_T = \eta_I + \eta_F$ where η_T is the total efficiency, η_I is the image force efficiency from the experimental curve 4, and η_F is the field force efficiency determined from equation 6. It is plotted only up to 200 fpm where flow becomes turbulent (based on a Reynolds number criterion of 2000) and where equation 6, therefore, ceases to apply. The shape of this curve is a slightly modified equilateral hyperbola. It is plotted for an average Q_p of 0.9 e

which is in the same order of magnitude as the Q_p determined from Figure 4. The limitations in the stain efficiency technique and the variability of aerosol properties prevent an analytical comparison of the curves, as mentioned above. Nevertheless curves 1 and 2 do possess some degree of similarity in shape.

Over-all conclusions from this study indicate: 1) high stain efficiencies on a naturally-charged aerosol are possible by using a condenser type apparatus at field strengths materially smaller than those normally used in the collecting stage of electrostatic precipitators; 2) low velocities and small plate spacings are necessary for optimum performance; 3) at low velocities a slight heterogeneity of the field form increases efficiency significantly at no increase in energy but a more intense field gradient than that produced by a rough plane surface is necessary to capture uncharged particles by dielectrophoresis; 4) also at low velocities image forces become important as a precipitating mechanism; 5) the average net Q_p of atmospheric dust appears to be in the order of one electron charge per particle (positive) but not all particles which influence a stain density measurement are charged, i.e. roughly 20% are uncharged.

CURRENT RESEARCH

The next line of study undertaken has been a more detailed investigation of image forces. This phase is currently in progress. The over-all purpose of the electrostatic studies at Harvard has been the optimum utilization of naturally occurring or mechanically produced electrostatic charges for air cleaning, thus doing away with power supplies and expensive auxiliary electrical equipment. As was shown above, significant image force effects are possible with naturally charged aerosols. Consequently a study has been initiated to investigate this mechanism in a fundamental manner. Determining the value of this separating force resolves essentially to the solution of the following differential equation written for the image force operating alone in a grounded parallel conducting plate channel at distances of less than Y/4, where Y is the plate spacing:

$$m \frac{dV_y}{dt} + \frac{6\pi\mu r V_y}{1+A(L/r)} - \frac{Q_p^2}{4y^2} = 0 \qquad \text{Equation (8)}$$

This is Equation 3 rewritten for the image force due to one plate alone for the condition where this force becomes controlling, i.e. where the force due to the other plate becomes negligible. In cases of collection by convex shaped targets such as fibers or spheres the image force will be less than that given by the third term of this equation (10). Concave shaped targets such as the inside wall of a hollow cylinder will produce an image force greater than the third term of this equation (14) but the representation of this force becomes more complicated. Therefore a parallel plate system was chosen as the case to be studied since the image force is of intermediate magnitude and can be represented in the simplest manner mathematically.

Equation 8 appears to be simple in form but unfortunately cannot be solved by classical mathematics. All obvious substitutions of variable reduce the equation to non-separable, first order, second degree, or non-separable, second order, third degree forms which cannot be solved. The use of operational calculus and the Picard method of general solutions to differential equations are also of no avail. A finite difference solution is possible but at distances of $y > 10^{-4}$ cm. the number of steps becomes prohibitive, e.g. for $y = 10^{-3}$ cm., the number of steps required is 10^{15}. A graphical method has been developed which may lead to a solution.

The validity of any deduced mathematical solution must necessarily be checked by experiment. Figure 7 is a schematic representation of the unit now being tested to determine the value of the image force experimentally. The aerosol generator, A, consists of a $3\frac{1}{2}$" diameter brass disc driven by a variable speed motor with a maximum speed of 3800 rpm. A 0.1% methylene blue in alcohol solution is fed from a constant head tank through a hypodermic needle onto the center of the disc and the aerosol is produced as droplets are centrifuged off the disc and the alcohol evaporates. The aerosol resulting consists of uniform solid spheres of 2.4 μ mass median diameter and a $\sigma_g = 1.3$. The aerosol is charged by an ion current produced in the wire and cylinder ionizing section, B. Ion currents are measured by a microammeter and voltages by a kilovoltmeter in parallel with the power supply. The upstream sample is drawn through a millipore filter E, mounted in a Faraday cage, D. Volume rates of flow are from 1 - 30 lpm. As the charged aerosol is caught by the millipore the net charge is measured by the induced voltage on an electrostatic voltmeter, the entire system capacitance being known. The concentration of

aerosol is measured colorimetrically by dissolving the sample and millipore in acetone. This upstream sample then gives the weight concentration and net charge of the aerosol which enters the test section, F. This section is constructed of two pieces of 18 gauge stainless steel which form a rectangular channel 36" long and 12" wide and of variable thickness. This conducting channel is grounded. On the center of one face of this channel 1" steel circles, G, have been punched out every 6 inches such that the smooth discs may be removed. As the aerosol traverses the test section it is hoped that sufficient aerosol will be deposited on the walls by the image force to give the gradient of concentration with length of path, by analyzing for the aerosol deposited on these sampling discs. The aerosol then passes to the downstream sampler, H, and is analyzed for weight concentration colorimetrically in the same way as the upstream sample, thus giving the over-all test section efficiency. Flow rates through H vary from 1 - 30 lpm thus varying the velocity in the test section. The entire flow through the unit passes through the sampling filters and therefore no external air mover is necessary. The dimensions of the test section have been so chosen to allow enough test aerosol for weight and charge analyses to move at the low velocities ($<$10 fpm) required to determine the effect of the image force.

At this point it should be noted that with a unipolar aerosol such as is produced by this test setup an additional space charge effect will occur simultaneously with the image force. Therefore, appropriate corrections will be made in the experimental results. No tests have yet been made with this unit.

PROPOSED RESEARCH

Several lines of study have been proposed for future work. The most promising appears to be the evaluation of the electrostatic properties of fluidized beds as they effect aerosol filtration. In particular the use of granular solids capable of triboelectrification appears reasonable., These particles would become charged by the natural collisions occurring as they become fluidized and would present naturally charged targets for aerosol capture by coulombic and dielectrophoretic forces in addition to the image forces due to the aerosol itself. This will be the next main line of study on electrostatic mechanisms at Harvard.

LEGEND

1. AEROSOL GENERATOR
2. STAIRMAND DISC
3. DIFFUSER SCREEN
4. IONIZER SECTION
5. SAMPLING SYSTEM
6. FILTER HOLDER - FARADAY CAGE
7. HI-VOL BLOWER
8. POWERSTAT UNIT
9. D.C. POWER SUPPLY
10. SHALLCROSS D.C. KILOVOLTMETER
11. MICROAMMETER
12. ELECTROSTATIC SHIELD
13. PSYCHROMETER

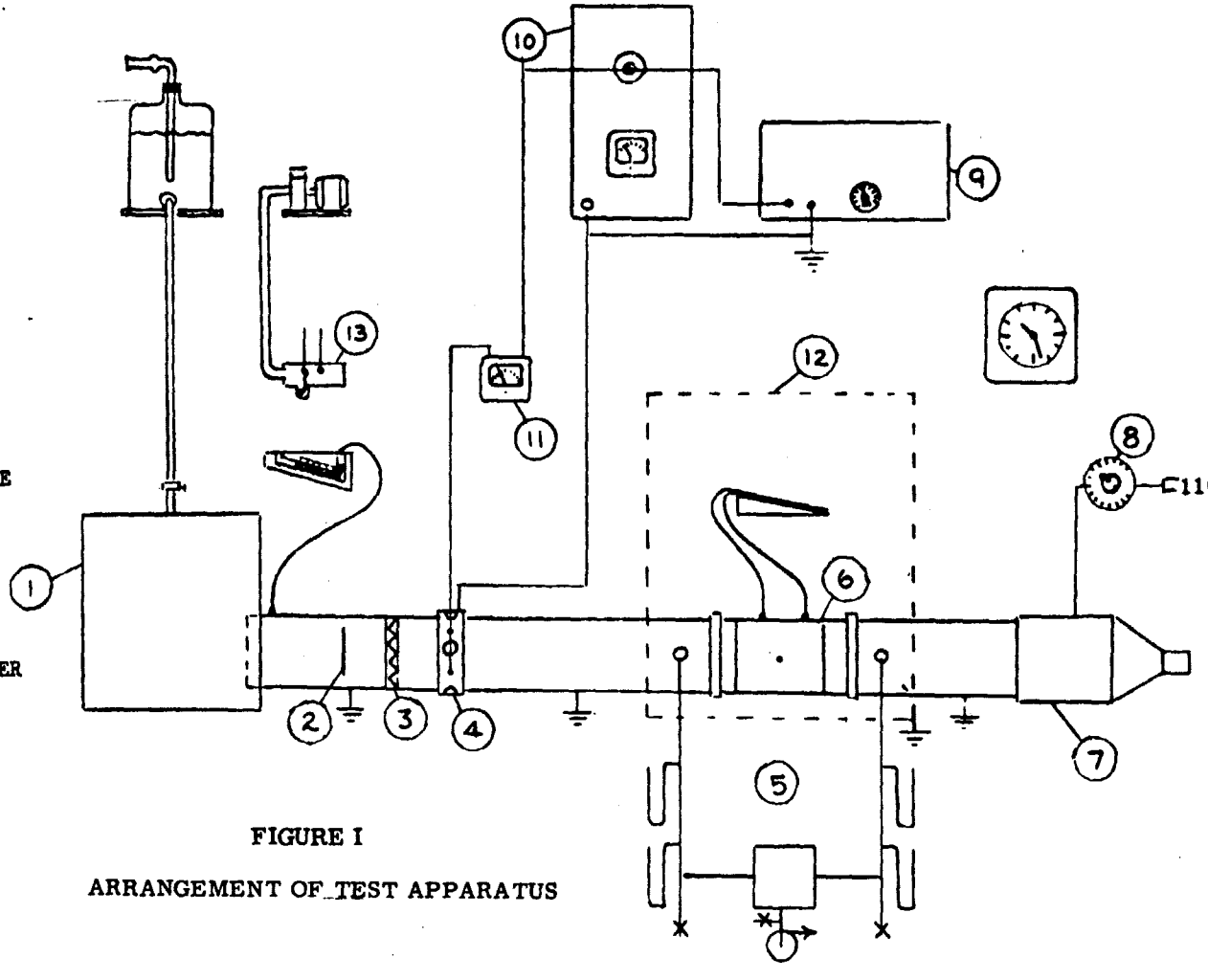
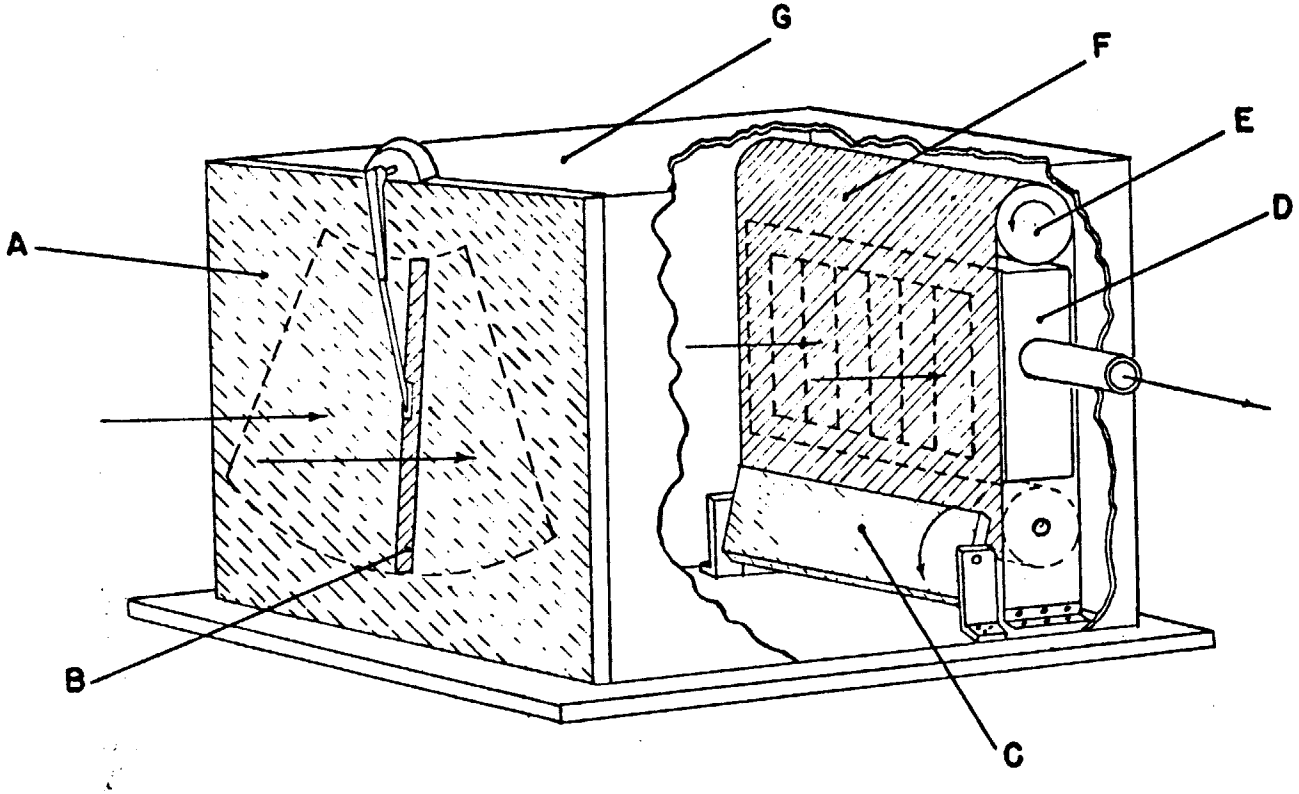


FIGURE I

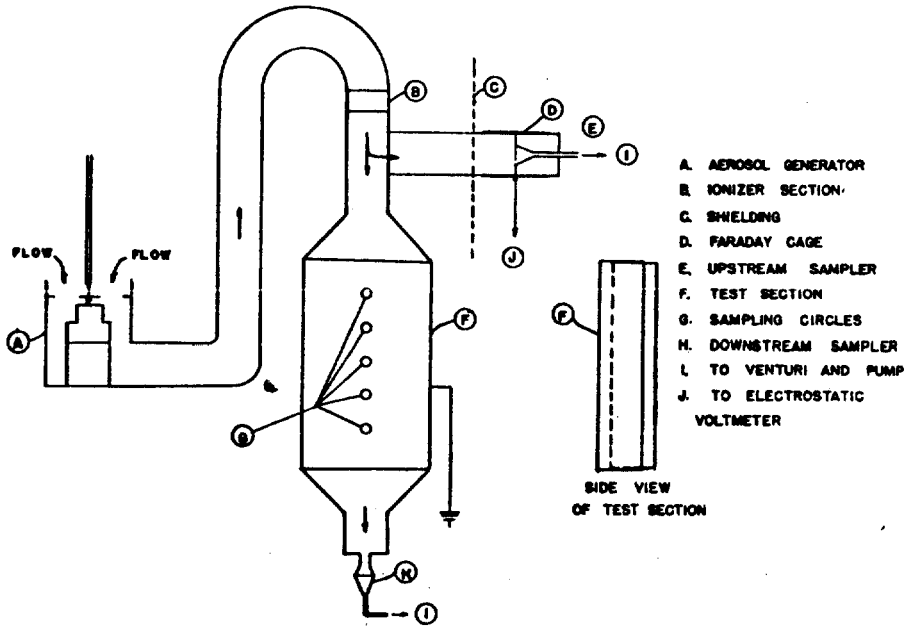
ARRANGEMENT OF TEST APPARATUS



A – FABRIC A SCREEN
B – FABRIC B COVERED WINDSHIELD WIPER BLADE
C – FABRIC A COVERED PADDLE
D – LUCITE BOX
E – LUCITE ROLLER
F – FABRIC B BELT
G – MASONITE BOX

FIGURE II

MECHANICALLY CHARGED FABRIC FILTER – TWO STAGE



SCHEMATIC ARRANGEMENT OF APPARATUS FOR IMAGE FORCE STUDY

FIGURE III

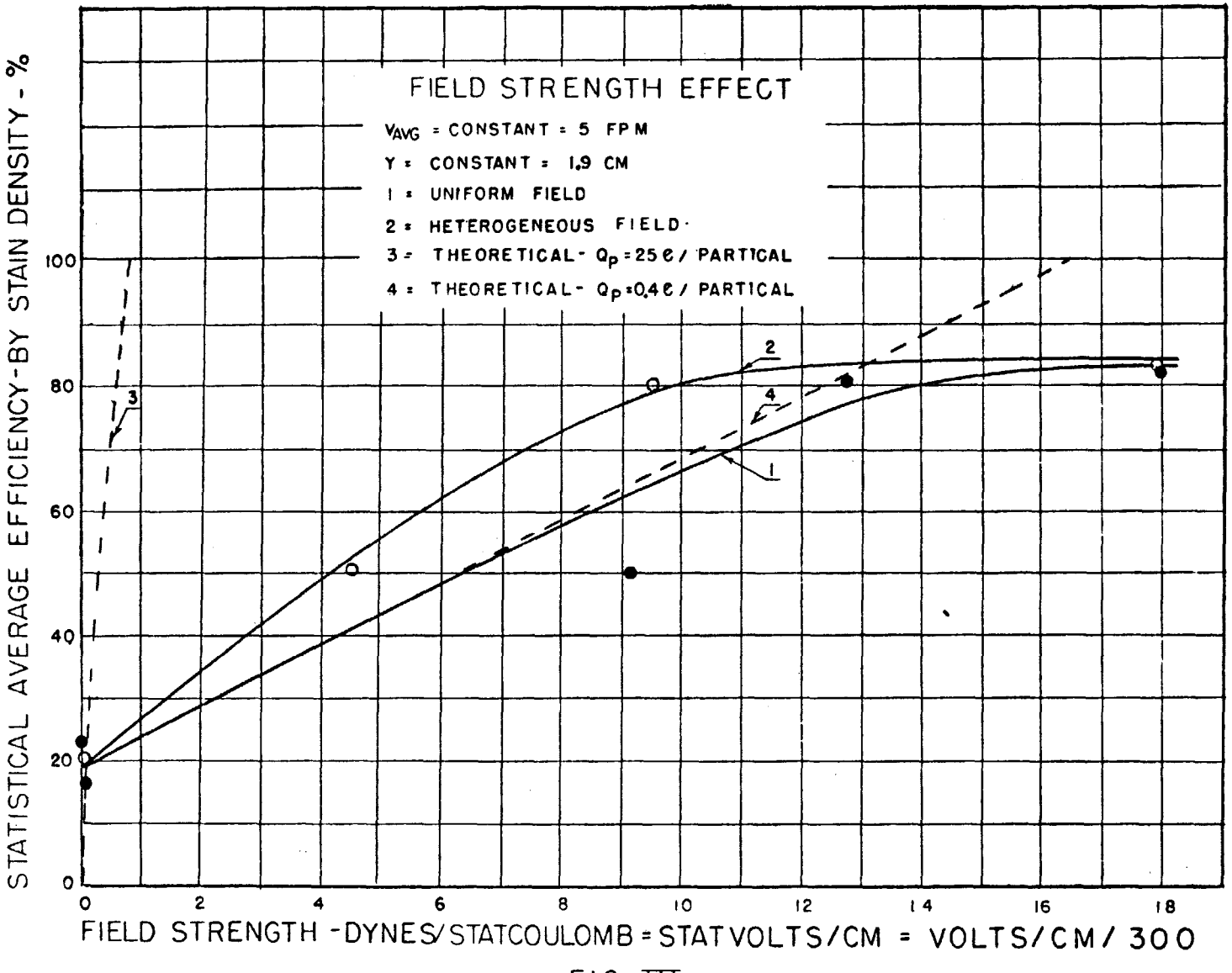

FIELD STRENGTH EFFECT
VAVG = CONSTANT = 5 FPM
Y = CONSTANT = 1.9 CM
1 = UNIFORM FIELD
2 = HETEROGENEOUS FIELD
3 = THEORETICAL - Qp = 25 e / PARTICAL
4 = THEORETICAL - Qp = 0.4 e / PARTICAL
STATISTICAL AVERAGE EFFICIENCY-BY STAIN DENSITY - %
0
20
40
60
80
100
0
2
4
6
8
10
12
14
16
18
FIELD STRENGTH - DYNES/STATCOULOMB = STATVOLTS/CM = VOLTS/CM / 300

FIG. IV

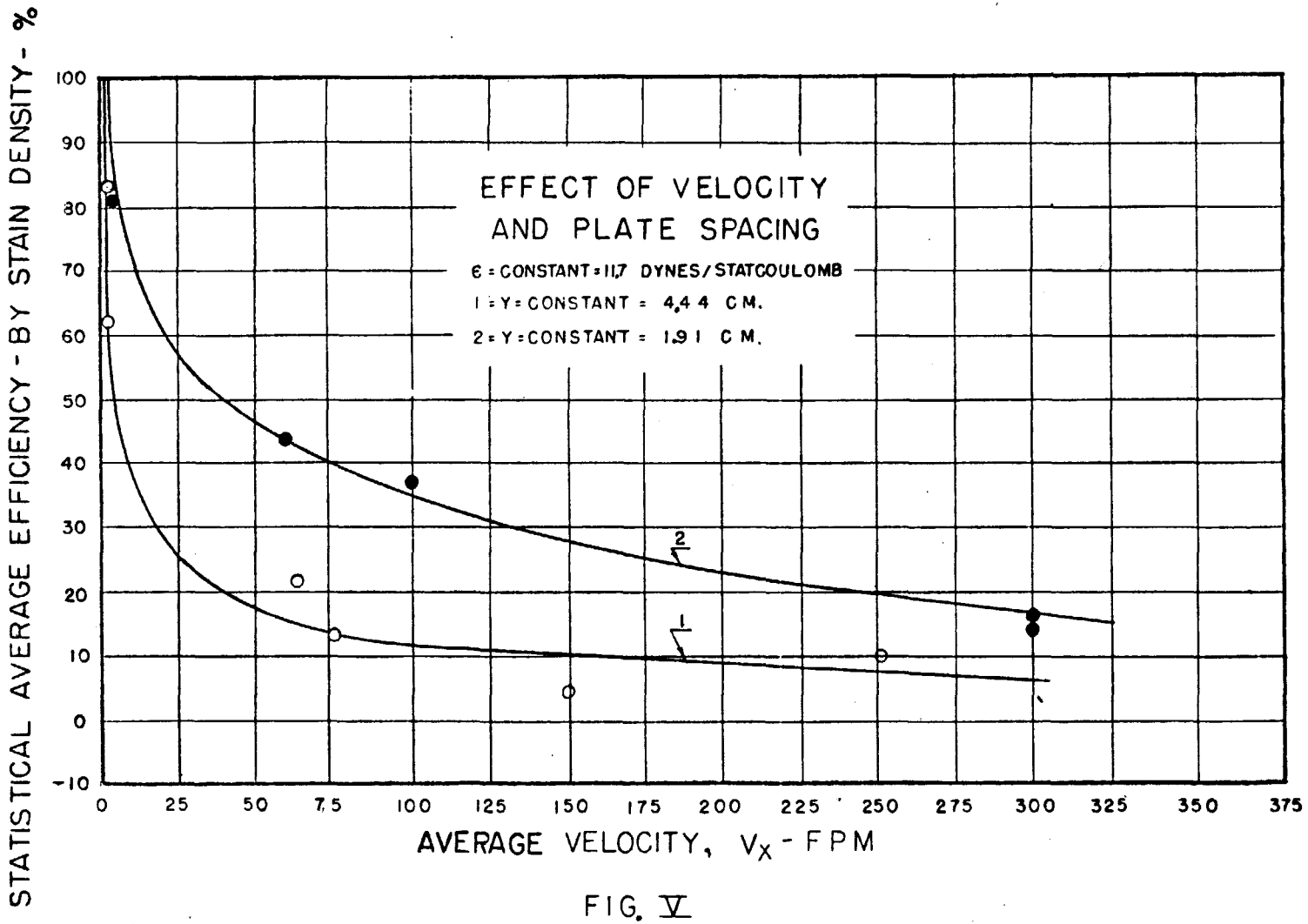

EFFECT OF VELOCITY
AND PLATE SPACING
ε = CONSTANT = 11.7 DYNES/STATCOULOMB
1 = Y = CONSTANT = 4.44 CM.
2 = Y = CONSTANT = 1.91 CM.
STATISTICAL AVERAGE EFFICIENCY - BY STAIN DENSITY - %
AVERAGE VELOCITY, V_X - FPM
100
90
80
70
60
50
40
30
20
10
0
-10
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
1
2

FIG. V

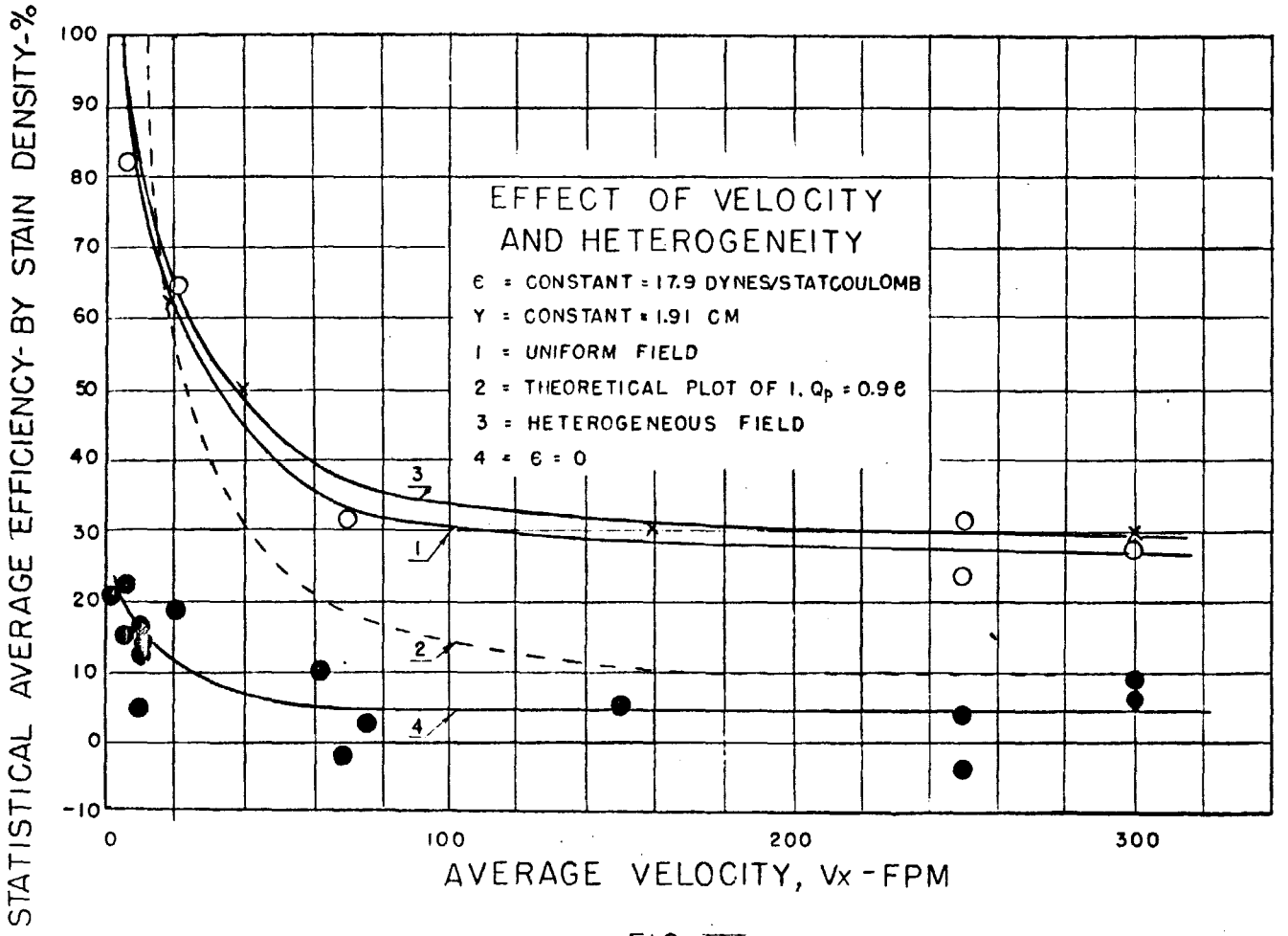
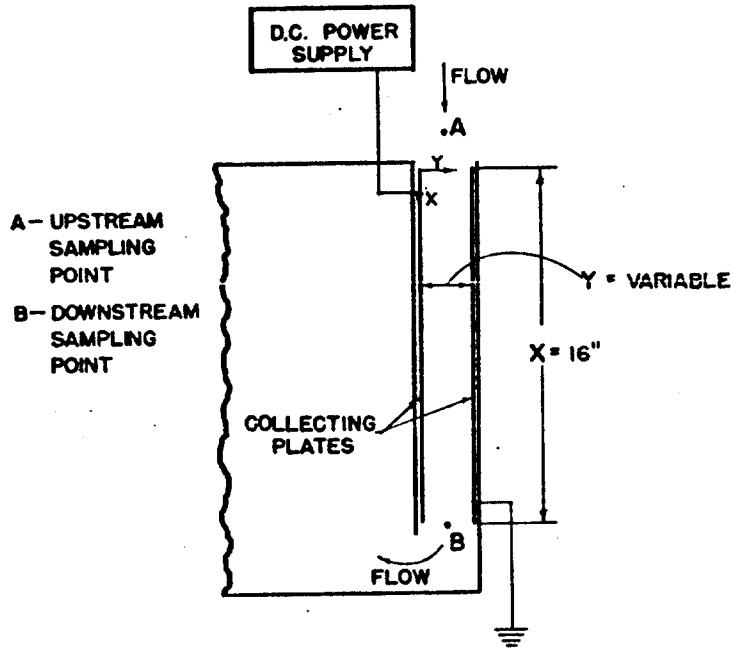

EFFECT OF VELOCITY
AND HETEROGENEITY
ε = CONSTANT = 17.9 DYNES/STATCOULOMB
Y = CONSTANT = 1.91 CM
1 = UNIFORM FIELD
2 = THEORETICAL PLOT OF 1. Q_p = 0.9 ε
3 = HETEROGENEOUS FIELD
4 = ε = 0
STATISTICAL AVERAGE EFFICIENCY- BY STAIN DENSITY-%
AVERAGE VELOCITY, Vx - FPM
100
90
80
70
60
50
40
30
20
10
0
-10
0
100
200
300

FIG. VI



SECTIONAL SCHEMATIC OF PARALLEL PLATE DEVICE FOR ATMOSPHERIC DUST

FIGURE VII

NOMENCLATURE*

A = Cunningham correction factor, dimensionless

F_C = coulombic force in an electrostatic field, dynes

F_D = dielectrophoretic force in a divergent electrostatic field, dynes

F_I = force due to an electric image, dynes

K = dielectric constant of fluid, dimensionless

K_1 = dielectric constant of particle, dimensionless

L = mean free path of air molecules, cm.

MMD = mass median diameter, microns

Q_p = particle charge, statcoulombs

V_{avg} = average fluid velocity parallel to plates, cm./sec.

V_y = velocity perpendicular to plates at point y, cm./sec.

X = length of plates in direction of flow, cm.

Y = plate spacing, cm.

m = mass of aerosol particle, gm.

r = radius of aerosol particle, cm.

x = distance along plates in direction of flow, cm.

x_s = stopping distance of particle starting at $x = 0$ and $y = y$ to point $x = x_s$, $y = 0$.

y = perpendicular distance from either plate, cm.

$\mathcal{E}$ = electrostatic field strength, dynes/statcoulomb

η = fractional portion of aerosol collected, dimensionless

σ_g = geometric standard deviation, dimensionless

μ = fluid viscosity, poises

* Unrationalized cgs system of units used

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HIGH TEMPERATURE FILTRATION STUDIES WITH MINERAL WOOL

by
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The research discussed below has been sponsored since 1953 by the American Iron and Steel Institute through its Subcommittee on Air Pollution Abatement. Although this study is primarily concerned with a solution to air pollution problems created in the open hearth steel making process, the results obtained may be successfully applied to problems in the AEC; particularly the cleaning of high temperature gases evolved from reactors and from incineration of radioactive waste materials. The degree of cleaning of open hearth gases is obviously not as severe as required by the AEC in most instances but the development of a low cost device could have application for some AEC problems. In many instances a roughing filter of the type to be discussed might be advantageously used when followed by a higher efficiency filter.

Particulate loadings are much higher in exhaust gases from the open hearth furnace than would ordinarily be expected from most AEC activities, ranging from less than 0.1 to greater than 2.0 grains per cubic foot (STP). The aerosol is composed of fine particles of iron oxide ($<0.1\ \mu$), created by the molten steel bath, contained in a high temperature gas stream (500 to 1500°F). The general aspects of steel process needs in gas cleaning indicate a cleaner which will prevent the obscuring of visibility and is low in both capital and operating costs. To date the only acceptable method for open hearth furnace fume removal has been electrostatic precipitation. Because of their cost, precipitators have only been applied where public relations demand the expenditure. About three tons of iron

oxide may be recovered from a typical 250 ton furnace (per heat) during the production of 750 to 900 tons of steel per 24 hour day. Recovery value is negligible but a nuisance problem is created since the fume is of such a fine size that it has high light obscuring properties. Some of it may subsequently agglomerate and produce some settled dust in the nearby neighborhood. The problem, then, consists of removing economically large quantities of fine particles from high gas volumes at high temperature.

The study has been divided into two phases. First, a study of agglomeration has been undertaken since freshly formed metallic fumes in high concentration can be shown to flocculate and aggregate rapidly. Knowing this fact it was conjectured that perhaps the particle size could be increased to a point where simpler collection methods might be applicable.

The second phase of the program is to develop a cleaner simple in principle, design and operation, capable of withstanding high temperatures continuously. Because it is low in cost and has proven successful on a laboratory basis for gas mask filters, we studied mineral or slag wool as a fibrous medium. This material is a by-product of the steel mill blast furnace, and is readily obtained in bulk since it is widely used for insulating purposes. It is produced by blowing or spinning molten slag (or rock) with steam or air into refractory fibers with a mean size of approximately 4 microns costing approximately $0.01 per pound.

Studies by the Chemical Warfare Service and others in World War II showed that special finer fibers could be made but these would be higher in cost.

The apparatus shown in Figure 1 was used to study filtration characteristics of layers of various thicknesses and densities of

commercial slag wool fibers formed into 6 inch diameter filter pads. An iron oxide fume was generated by burning iron powder in an air-oxygen-acetylene flame, or by feeding iron carbonyl vapor into the flame. An electron photomicrograph of fume particles is shown in Figure 2. Although these are from an actual open hearth furnace, the fume from burning iron carbonyl was found to be comparable in size. Resistance characteristics of the filters were determined as shown in Figure 3. It was found that the optimum thickness and density for a desired resistance of 2 inches of water is approximately 1 inch and 5 pounds per cubic foot, respectively. Figure 3 indicates that the resistance varies linearly with velocity and also increases with higher temperature due to the gas viscosity increase. The velocities to be used in slag wool filtration for steel industry gas cleaning purposes are far greater than those used in AEC applications except for precleaning. In order to minimize the size of equipment due to space limitations a filtration velocity of at least 100 feet per minute is necessary. A typical 250 ton open hearth furnace produces 25,000 cfm (STP) of gas which is increased to greater than 50,000 cfm at the temperatures existing in the open hearth (>500°F).

It was found from these and other laboratory studies that slag wool filters will collect from 80 to 95 per cent of the fine iron oxide fume, at temperatures of 500 to 1000°F, and at filtering velocities of 100 to 200 feet per minute.

Investigations of the effects of time and dust loading on the resistance of the filter have been made with the laboratory fume and also with actual furnace fumes in the field. These have indicated that the slag wool filter (of 1 inch thickness and 5 pounds per cubic foot packing density) will recover about 2.5 per cent of its initial weight per 1 inch rise in resistance. To keep the filter resistance

within reasonable power limits it should not exceed 4 inches of water. Its initial value is between 1 and 2 inches. For an allowable resistance rise of 2 inches of water, the filter will then collect 5 pounds of fume per 100 pounds of fiber. Higher recovery percentages were obtained in the field indicating that coarser material was present. This appreciably raised the weight of the collected fume per 100 pounds of fiber.

It was apparent that it would be uneconomical to use slag wool as a filter for one pass use. Studies were made with regard to washing and reclaiming the fiber. The method selected for washing also was ideal for re-establishing the filter. Laboratory studies (later confirmed in the field) have indicated that by washing and reusing the wool, approximately 8 to 10 re-uses could be made before the fiber was no longer satisfactory. This increases utilization to about 50 pounds of fume per 100 pounds of fiber. In practice it is best to add 10 per cent new fiber in each wash cycle. This replaces the fiber reduced to brokem fragments by the recycling. The iron oxide fume, slag wool shot and broken fibers were easily removed in the washing, the rejected material settling to the bottom of a decantation tank.

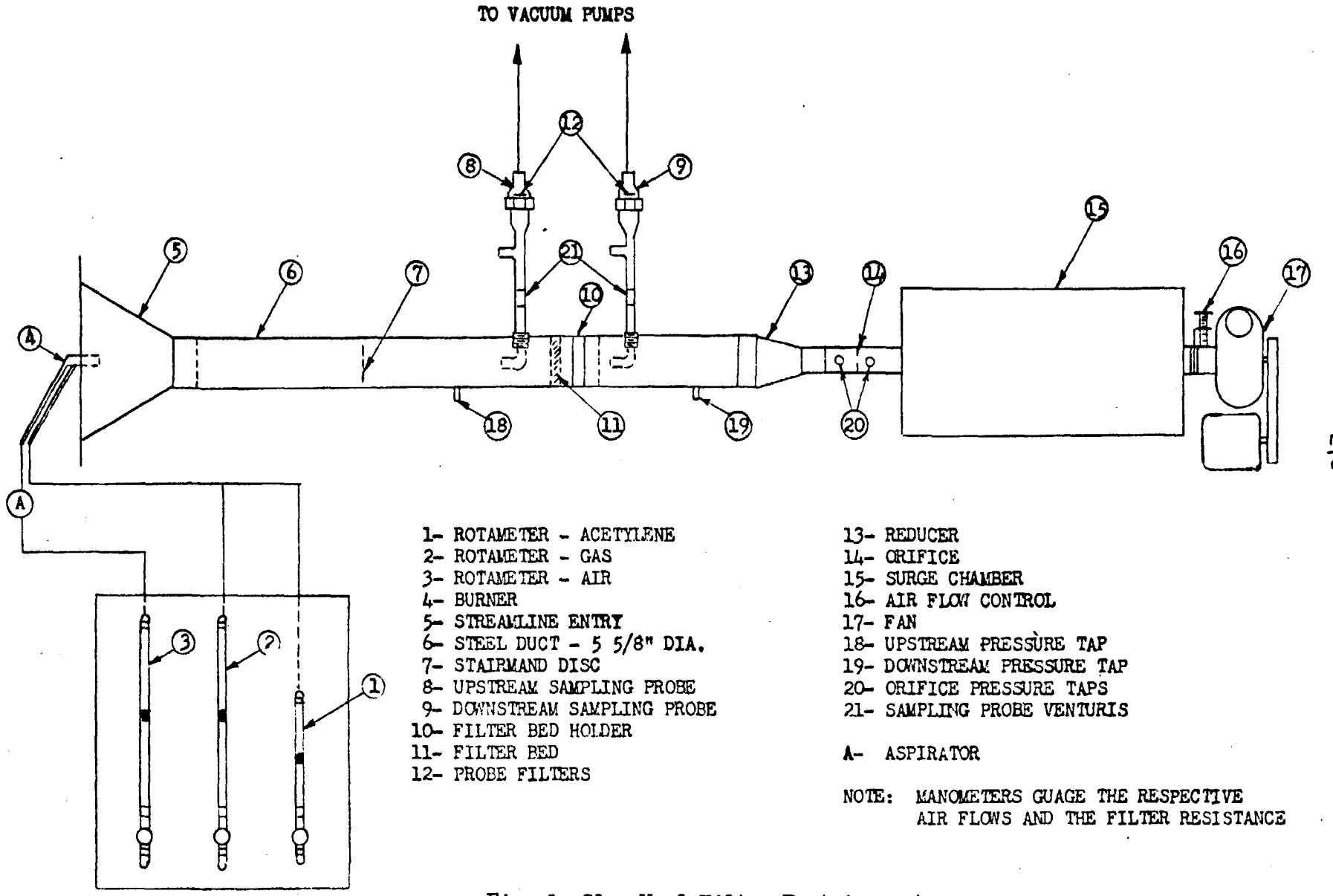
Figure 4 shows the basic principle of the continuous slag wool filter developed at Harvard. The fibrous material forms a continuous filter pad which is passed through the furnace gases and removes the fume. The collected fume and slag wool are discharged into a wash tank where it is prepared for re-use. A pilot unit has been developed based on this design with a capacity of approximately 500 cubic feet of gas per minute. During the past winter, the method has been successfully tested on a typical open hearth furnace at a steel mill. Another filter is being constructed incorporating design changes suggested by the initial pilot unit.

The possibility of causing the fine iron oxide particles to

agglomerate to a larger size is being investigated. A longer path is provided by passing the gas through a rotating screw flight. Additional turbulent and thermal forces can be controlled by counter-rotating the screw and cooling the walls and shaft. With diffusion this should enhance the coagulation to a certain extent. The screw can also be provided with hoppers to take advantage of whatever inertial collection occurs. Present studies are concerned with developing air flow equations to predict the pressure loss characteristics of screws under various cooling and rotational conditions. Background efficiency data have also been obtained on iron oxide fume. Methods for measuring aerosol agglomeration are currently being investigated.

It is expected that a combination of the agglomeration and filtration techniques indicated above will lead to a compact gas cleaning unit to effectively remove 90 to 95 per cent of fine metal oxide fumes at low cost.

Additional information on this project has been published at greater length and is available upon request.



1- ROTAMETER - ACETYLENE
2- ROTAMETER - GAS
3- ROTAMETER - AIR
4- BURNER
5- STREAMLINE ENTRY
6- STEEL DUCT - 5 5/8" DIA.
7- STAIRMAND DISC
8- UPSTREAM SAMPLING PROBE
9- DOWNSTREAM SAMPLING PROBE
10- FILTER BED HOLDER
11- FILTER BED
12- PROBE FILTERS
13- REDUCER
14- ORIFICE
15- SURGE CHAMBER
16- AIR FLOW CONTROL
17- FAN
18- UPSTREAM PRESSURE TAP
19- DOWNSTREAM PRESSURE TAP
20- ORIFICE PRESSURE TAPS
21- SAMPLING PROBE VENTURIS

A- ASPIRATOR

NOTE: MANOMETERS GUAGE THE RESPECTIVE AIR FLOWS AND THE FILTER RESISTANCE

Fig. 1--Slag Wool Filter Test Apparatus.

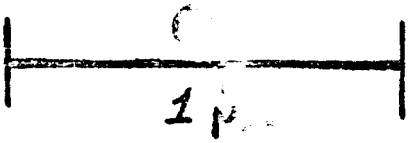


Fig. 2--Electron Photomicrograph of Hot Metal Open Hearth Furnace Fume, Taken before Waste Heat Boiler (X50,000).

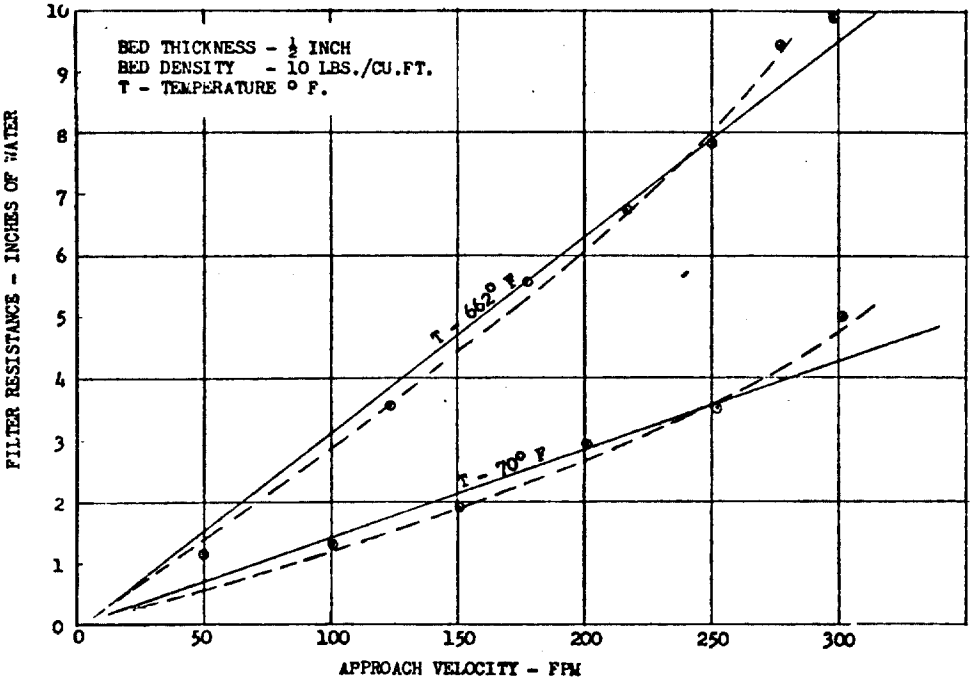


Fig. 3--Effect of Temperature on Filter Resistance.

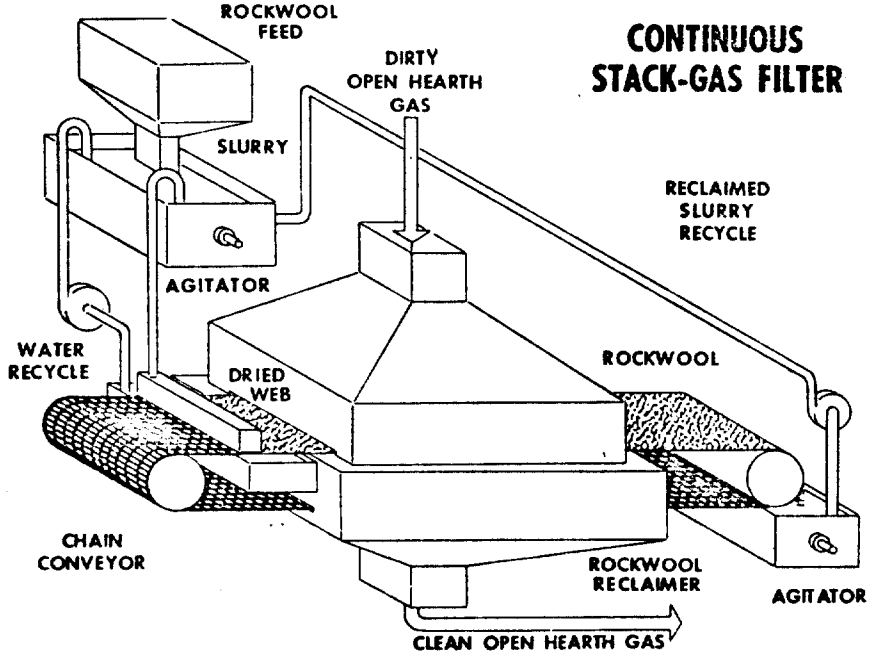


Fig. 4--Schematic Drawing of Continuous Slag Wool Stack Gas Filter Unit Showing Principle of Method.

BLAST EFFECTS ON AIR CLEANING EQUIPMENT - Results of Filter Tests

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SUMMARY

This report summarizes results of studies of the effect of shock waves impressed on air filters in a direction opposite to normal air flow.

Moderate damage to Dust-Stop prefilters occurs at shock over-pressures greater than one inch of mercury, severe damage occurring at pressures greater than three inches of mercury. At one inch over-pressure large amounts of dust are removed from the filter but physical damage is slight. Pleated A.B.C. No. 1 filters (24 x 24 x 6 inch) were found to sustain moderate damage at a pressure of six inches of mercury and a pressure of ten inches caused complete destruction. Pressures of five inches of mercury or less caused no apparent physical damage. A filter with perforated aluminum plates nailed to both faces had no additional strength to resist blast pressure.

Reentrainment studies have indicated large amounts of dust will be dislodged from a filter by the action of a shock wave.

This study was made under Contract No. AT(30-1)841 between the U. S. Atomic Energy Commission and Harvard University. Opinions expressed are those of the authors and do not necessarily represent the views of the U. S. Atomic Energy Commission.

At the request of the Division of Engineering, U.S. Atomic Energy Commission, Washington, D. C. an investigation into the effects of shock waves on air cleaning devices has been undertaken at the Harvard University Air Cleaning Laboratory. Major objectives of this study are:

1. To determine what structural damage occurs to air cleaning devices when they are subjected to a shock wave in a direction opposite to normal air flow;

2. To determine how much captured dust may be reentrained from the air cleaner and its connecting ductwork by the blast effect;

3. To develop inexpensive methods for reducing damage and minimizing reentrainment.

This report discusses expected damage to Dust-Stop roughing filters and A.E.C. No. 1 filters (and reentrainment of dust from A.E.C. No. 1 filters) at various blast over-pressure levels.

1. Test Equipment

A 20 inch diameter shock tube has been constructed with a transition to and from a 24 x 24 inch square section to provide for location of test equipment as shown in Figure 1. The shock tube is attached to a 20 inch diameter air lock on an 8 foot diameter by 10 foot long compression chamber. A steel ring and clamp at the inner face of the lock hold layers of brown Kraft wrapping paper which burst at predetermined tank pressures. Rupture of this paper disc creates

a shock wave which is propagated down the tube to the test section. The wave is dissipated in a pressure relief chamber at the end of the tube (about 20 feet from the test area) by a double layer cinder block wall. The pressure is relieved through a perforated wall of the relief chamber. Over-pressures are recorded by a sensitive bellows placed in the wall of the tube just prior (6 inches) to the test section. A mirror mounted on the rear of the bellows deflects a light beam and the trace is recorded on photo-sensitive paper.

Before testing a filter, a number of layers of paper were ruptured to determine the magnitude of the wave produced. From this calibration, which varies somewhat due to weather conditions, a reliable estimate could be made of the strength of the shock wave to be impressed on the filter. With a filter in place the over-pressure is substantially increased at the test section as indicated by shock wave theory.

2. Test Results

a. Blast Damage

Initial tests were made on damage to Dust-Stop pre-filters at various over-pressure levels. These are 20 x 20 x 2 inch Fiberglas mats held in a cardboard frame with light gage metal retaining screens on each face. The results of this series are presented in Table 1, tests 1 to 5. These filters will not withstand over-pressures greater than about one inch of mercury without sustaining some damage. Pressures near 3 inches of mercury caused complete failure

and the Fiberglas media was carried down the tube into the receiving chamber. It was observed that substantial dust was reentrained from the filter even though structural damage was slight at lower pressure levels.

Several 24 x 24 x 6 inch "absolute" type (A.E.C. No. 1) pleated space filters were tested for damage levels in the same manner (Table 2). Slight structural damage occurs when over-pressures reach about 6 inches of mercury. Complete failure occurs at pressures of 10 inches of mercury. Typical failure is shown in Figures 2 and 3. Three filters (tests 10, 11, and 12) were tested to determine air flow characteristics before and after blast, and also to check mechanical strength of perforated aluminum plates nailed to both faces (as supplied by manufacturer in some cases.) A standard 24 x 24 x 6 inch filter tested at 6.2 inches of mercury over-pressure showed moderatedamage. The pleats were pushed away from the blast about 1/4 inch over about one-half the face area. Air flow resistance (at rated 500 cubic feet per minute) fell from an initial value of 0.80 inches of water to 0.76 inches of water after testing. The same test conditions (test 11) applied to a filter with perforated aluminum plates on both faces showed about the same amount of damage. The filter media and the rear plate were pushed back about one inch over about one-third of the area as shown in Figure 4. Air flow resistance fell from 1.30 (initially) to 1.06 inches of water after test. A third filter tested at 4.3 inches of mercury (test 12) showed no physical damage but its resistance

was decreased from 0.88 to 0.80 inches of water by the test. It is concluded that moderate to severe damage will be sustained by 24 x 24 x 6 inch pleated "absolute" (A.E.C. No. 1) filters at blast over-pressures greater than 5 inches of mercury. Filters subjected to moderate over-pressures may suffer some damage but may be suitable in emergency disaster situations.

b. Dust Reentrainment

Additional tests have been made on 24 x 24 x 6 inch and 12 inch pleated "absolute" type (A.E.C. No. 1) filters to determine the amount of dust displaced by sub-damage level blast waves. This study is presented in detail in Table 3. The 6 inch filter held about one-half pound of dust (Calcium Carbonate) for an increase of one inch in resistance at rated air flow (500 cubic feet per minute). The 12 inch filter held about one pound of dust for a one inch resistance rise at rated flow (1000 cubic feet per minute). These values were found to check approximately with data presented by Mr. Walter Smith (of Arthur D. Little Inc.), at the Third Air Cleaning Seminar at Los Alamos. Filters were loaded to various degrees with a known amount of dust and subjected to over-pressures of 4 (for 6 inch) to 5 (for 12 inch) inches of mercury. With one exception (noted in Table 3, test 14) no physical damage was apparent from these tests.

It is concluded that at over-pressures just below damage levels (1) filters loaded to 100% capacity lose about 90% of this dust, and (2) filters loaded to 10% of capacity lose about 40% of this dust. The dust was carried down the shock tube and into the pressure relief chamber, and in fact,

was dispersed quite generally all over the testing area. High-volume air samples taken in the shock tube about 2 feet behind the test filter, and at the outlet of the tube into the relief chamber indicated air concentrations ranging from 18 to 20 grains per cubic foot for the 12 inch filter when fully loaded (tests 19 and 20) to no measurable amount when filters were loaded to 10% of capacity. A calculated value of air concentration based on pressure rise in the compression chamber before rupture of the diaphragm indicated air concentrations as high as 68 grains per cubic foot are possible. Large amounts of air-borne dust are produced by blast wave effects on loaded filters. The pressures (4 to 5 inches of mercury) used in this test series correspond to a distance of 6000 to 8000 feet from ground zero of a nominal atomic bomb. Blast wave duration time was of the same order of magnitude for this distance from ground zero, about 0.8 to 1 second.

c. Further Investigations

Further study is underway to determine the reentrainment from pleated filters at lower over-pressures. Damage levels for 24 x 24 x 12 inch filters will be determined. These studies have suggested some inexpensive methods for increasing damage levels for filters, and these will be investigated.

TABLE 1

Shock Tube Tests of "Dust-Stop" Fiberglas Prefilters - Failure Pressure

Test No.	Number of Sheets in Diaphragm	Diaphragm Rupture Pressure "Hg	Remarks
1	4	6	Complete failure. Both screens and Fiberglas carried down tube to receiving chamber.
2	2	3	Complete failure. Both screens remained attached to the filter frame but the Fiberglas was carried down the tube about 12'.
3	1	1.5	Partial failure. Downstream screen bent away from blast slightly. Large quantity of fly ash reentrained and carried into pressure relief chamber.
4	3	4.5	Complete failure. Upstream (blast side) screen remained in place, downstream screen and Fiberglas carried down into receiving chamber.
5	3	6	Complete failure. No large pieces of Fiberglas remained impinged on cinder block wall and some penetrated through two layers. Most complete destruction.

TABLE 2

Shock Tube Tests of AEC "Absolute" Type (No. 1) Pleated Filters[a] - Failure Pressure

Test No.	Diaphragm Rupture Pressure "Hg	Measured Pressure at Filter "Hg	Pressure Trace Characteristics		Filter Resistance[b] in. w.g.		Remarks
			No. Cycles	Time to Return to Zero	Initial	Final	
5	5.0	8.3	1	0.80	-	-	No apparent damage.
6	10.0	>20.0	3	1.45	-	-	Complete failure (same filter as Test 5).
7	4.2	6.3	1	0.72	-	-	No apparent damage.
8	5.4	11.8	1	0.89	-	-	Partial failure over 1/3 of area. Pleats pushed back 1/4" (same filter as test 7).
9	5.0	12.4	2.5	1.22	-	-	Complete failure (same filter as Tests 7 and 8).
10	6.2	14.0	1	0.86	0.80	0.76	Partial failure, rear pushed back 1/4"
11	6.4	12.2	1	2.86	1.30	1.06	Partial failure, perforated aluminum plates nailed to each face. Rear plate pushed back by pleats about 1".
12	4.3	9.0	1	0.92	0.88	0.80	No apparent damage.
13	12.0	>20.0	1.5	0.86	-	-	Complete failure (same filter as Test 12).

a. 24" x 24" x 6" b. At 500 cfm

TABLE 3. Shock Tube Tests of AEC "Absolute" Type (No. 1) Pleated Filters - Reentrainment Study

Test No.	Filter Size[a] In.	psig Diaphragm Rupture	psig Measured at Filter	Pressure Trace Characteristics: No. Cycles	Pressure Trace Characteristics: Time to Return to Zero, sec.	Filter Resistance[b] in. w.g.: Clean	Filter Resistance[b] in. w.g.: Loaded	Filter Load: Grams	Filter Load: %	Load Removed: Grams	Load Removed: %	Air Concentration, Grains/cu.ft.: 2" from Filter	Air Concentration, Grains/cu.ft.: Outlet of Tube	Air Concentration, Grains/cu.ft.: Theoretical	Remarks
14A	-	5.3	5.7	3.5	1.49	-	-	-	-	-	-	-	-	-	Calibration
14B	6	3.4	-	-	-	0.90	1.69	206	100	114	55	1.2	1.6	29	Test, partial failure pleats moved back ¼".
15A	-	3.6	4.5	3.5	1.53	-	-	-	-	-	-	-	-	-	Calibration
15B	6	3.6	-	-	-	-	-	-	-	-	-	-	-	-	Test to recheck 14B no apparent damage
16A	-	3.6	4.5	3.5	1.42	-	-	-	-	-	-	-	-	-	Calibration
16B	6	3.4	5.2	1	0.66	0.79	1.57	155	78	152	98	5.5	4.1	39	Test, no damage
17A	-	3.6	5.2	3.5	1.47	-	-	-	-	-	-	-	-	-	Calibration
17B	6	3.7	5.8	1	0.72	0.77	1.15	126	56	74	59	3.4	1.4	16	Test
18A	-	3.5	3.8	3	1.23	-	-	-	-	-	-	-	-	-	Calibration
18B	6	3.8	9.5	1	0.55	0.84	0.92	26	10	8	32	0	0	1.8	Test
19A	-	4.6	6.9	3.5	1.47	-	-	-	-	-	-	-	-	-	Calibration
19B	12	5.0	8.8	1	0.79	0.97	1.92	429	100	359	84	17	9.9	62	Test
20A	-	5.3	6.0	3	1.29	-	-	-	-	-	-	-	-	-	Calibration
20B	12	5.1	7.4	1	0.71	0.99	1.91	417	100	396	95	20	7.2	68	Test
21A	-	4.5	5.9	3.5	1.52	-	-	-	-	-	-	-	-	-	Calibration
21B	12	4.7	9.4	1	0.76	1.04	1.12	39	8	20	51	0	0	3.4	Test

[a] 24" x 24" x depth shown

[b] At rated volume of 500 cfm for 6" and 1000 cfm for 12"

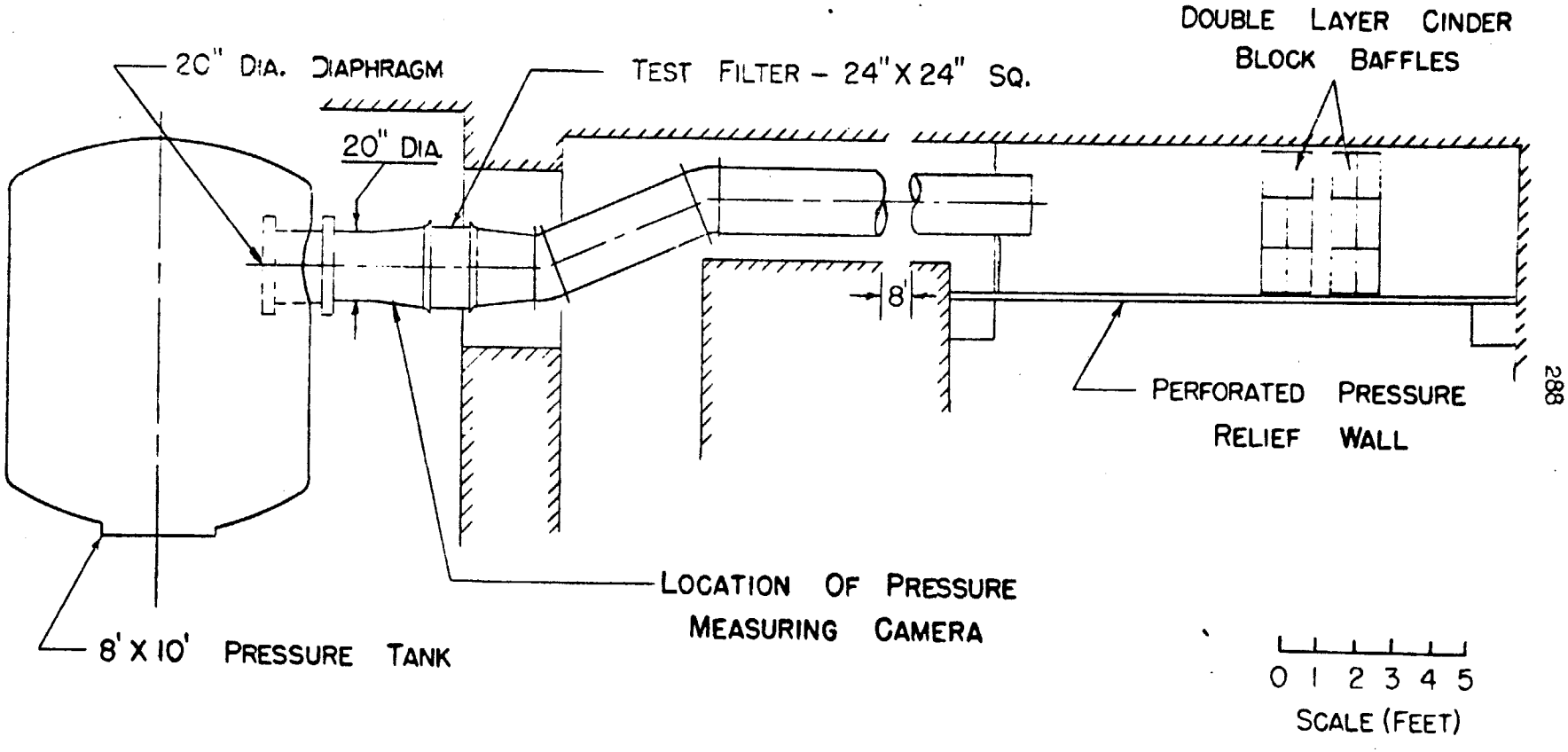

Figure 1. Experimental Shock Tube - Plan View

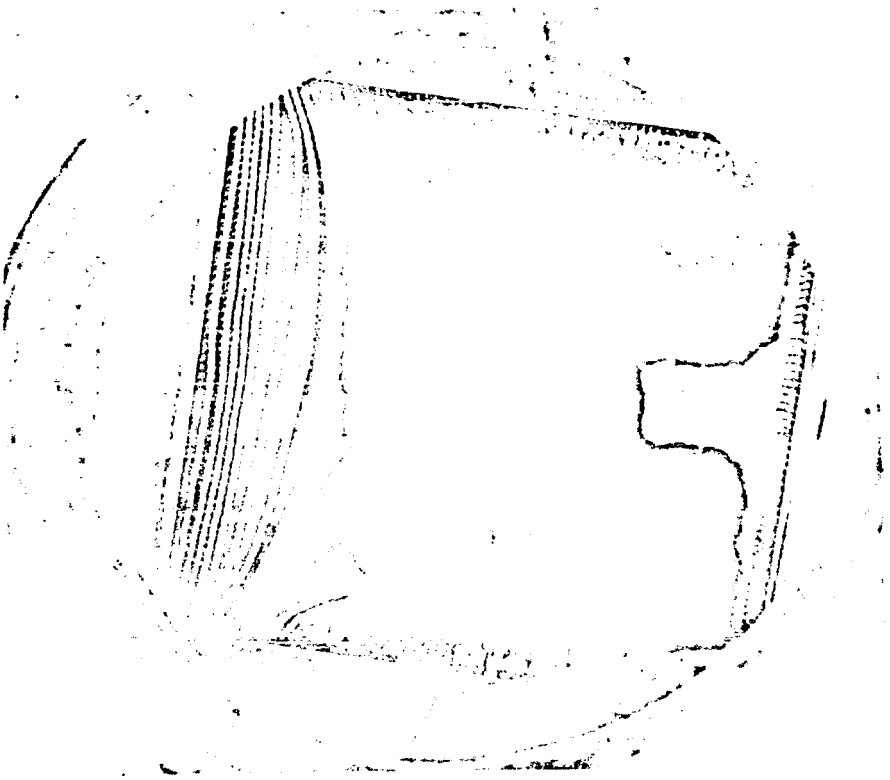

Figure 2. Pleated Paper Filter Showing Failure-Frame In Test Location In Shock Tube

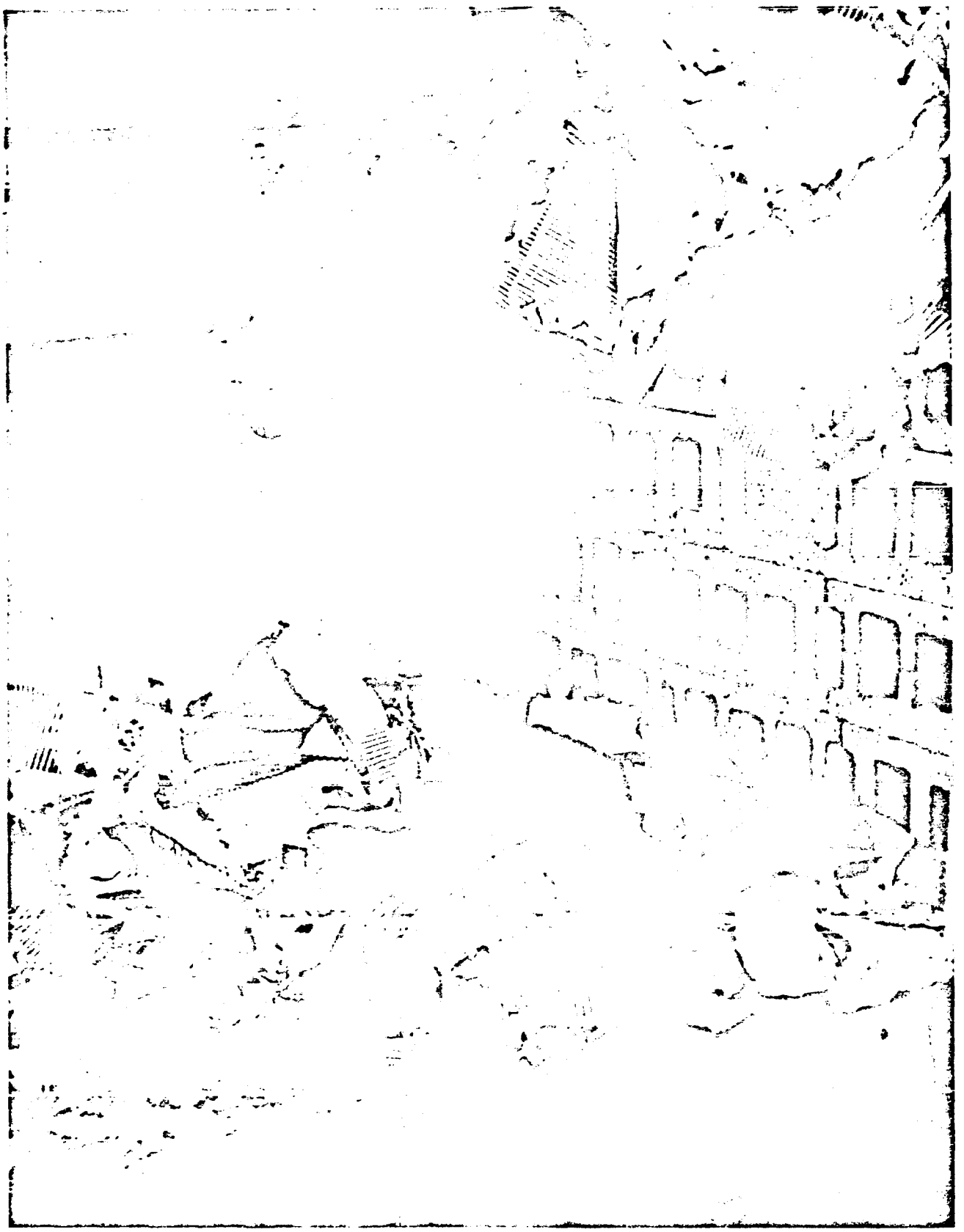

Figure 3. Pleated Paper Filter Showing Failure- Receiving Area

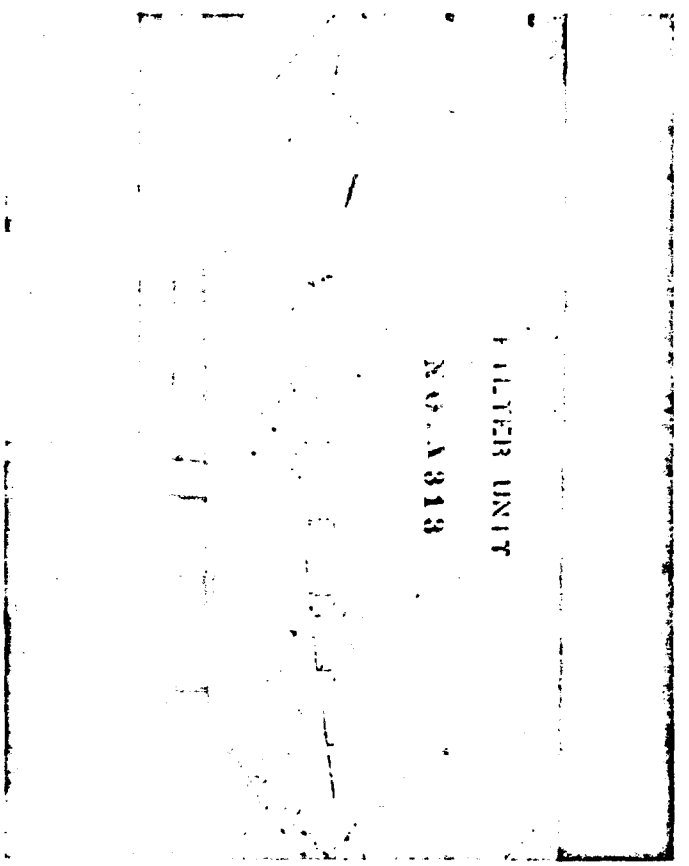

Figure 4. Pleated Paper Filter With Aluminum Plates- Partial Failure

PROPERTIES OF AEROSOL AGGLOMERATES

W. J. Scheffy

The process of coagulation in aerosols of both liquid and solid particles has been widely studied. The effects of various factors on the rate of coagulation have been investigated. Less work has been done on the nature of the agglomerated particles formed in the process. Coalescence of drops presents no problem in this respect. But the properties of solid agglomerates differ greatly from those of the pure solid particles and, furthermore, vary widely with agglomerate size, circumstances of formation and other factors. The density and drag diameter are particularly important in many methods of air sampling or cleaning. Measurements with a jet impactor, for instance, yield a quantity which can be converted into a size distribution only if the density of the particles is known. This quantity is the impaction parameter

$$\Psi = CD^2 \rho v_o / 18 \mu D_c$$

a dimensionless measure of the ratio of the particle inertia to the resistant force of the fluid on the particle (7). It has been shown that collection efficiency for various impactors and conditions, within certain limits, has a unique relationship to Ψ, so that substitution of the known quantities into the expression for Ψ gives a characteristic particle diameter for one impactor stage. With a cascade impactor the size distribution of an aerosol may be obtained. If ρ is unknown, all that is obtained is a distribution of the quantity $CD^2\rho$, which, incidentally, is directly proportional to the free fall terminal velocity. This quantity is enough for some purposes, but not for an idea of the actual size of the airborne particles.

The fact that the density of solid agglomerates varies extremely from the normal solid density is to be expected, and early work with smoke particles proves it. Whytlaw-Gray and Patterson found particle densities lower than ten per cent of the normal solid value (9). In the present work the method used by these observers and others (1) has been extended to the measurement of drag diameters and densities for agglomerates of a number of substances. The experiments are simply an adaptation of Millikan's oil-drop measurements of the electronic charge (6). The velocities of a particle in free fall and rising under an electrical force are measured by observation with a low-power microscope, using a dark field and an eyepiece scale. Such data for one particle are sufficient to calculate two of the three variables involved: particle drag diameter, particle mass, and the value of the electronic charge. In the original experiments with oil drops the density of the particle was that of the pure liquid, so the particle size and the electronic charge could be obtained. Since the value of the electronic charge is now fairly well established, it can be used to determine both the other variables when they are unknown, as in the case of agglomerates.

The Millikan cell used was a standard model built for the Central Scientific Company. The plate spacing was three millimeters, with battery voltages ranging from 90 to 270, depending on the average particle mass of the aerosol used. By a number of precautions, such as filtering the light from the source and keeping the room temperature constant, convection and photophoretic effects were reduced to very low levels even without a constant-temperature bath surrounding

the cell. The particles were introduced into the cell by spraying from an aspirator or from a glass nebulizer which, although made for solutions or liquid suspensions, was found quite useful for dry powders. For one particle the free fall velocity and from five to ten different velocities of rise under the electric field were measured, the different electrical velocities corresponding to different particle charges. The calculations require these velocities for various charges because, although the magnitude of one electronic charge is known, it cannot be said a priori how many unit charges the particle has. The numbers of electrons corresponding to the various observed velocities can only be deduced by comparison of the velocities; the smallest observed difference between two velocities then corresponds to a difference of one electronic charge, if enough measurements have been made.

The equations involved are simple force balances. Both in free fall and in rise under the electric field a terminal velocity is reached in a matter of microseconds; the sum of the forces acting on the particle is then zero. In the first case,

$$mg = 3\pi\mu Dv_g/C \qquad (1)$$

If the particle is rising in the electric field,

$$neX - mg = 3\pi\mu Dv_e/C \qquad (2)$$

The two unknowns D and m can be obtained from these two independent equations. It should be noted that the D calculated here is actually the drag diameter, defined by Hawksley (4) as the value of D which satisfies the Stokes law of resistance. It is perhaps also noteworthy that the mass of the particle can be obtained without assuming anything

about the resistant force except that it is proportional to the velocity and has the same form with or without the electrical force acting. For, by dividing (1) by (2) and rearranging, we obtain

$$m = neXv_g/g(v_e+v_g)$$

All the coefficients of v_g and v_e cancel in the division. The calculation of D, of course, requires the explicit form of Stokes' law, and much of the scatter in the data is attributable to this approximation. When D and m are known, an approximate density can be calculated.

As a check of the method and apparatus, uniform Dow polystyrene spheres were measured. The diameter of the spheres was known very accurately from electron microscope observations by the manufacturer. The standard deviations for 0.514 and 1.171 micron spheres were 0.011 and 0.013 micron, respectively. The average error in the density of these spheres determined by the method above was less than five per cent. The deviations are probably due to convection, the difficulties of observation introduced by Brownian motion, and the uncertainty of the values of the Cunningham slip correction to Stokes' law. Several choices are possible for the Cunningham correction; those used here were based on experiments (2, 5, 8) with particles including sizes of the same order of magnitude as the mean free path of the gas molecules, the range of interest in this work.

Dispersal of more concentrated suspensions of the polystyrene produced agglomerates containing from two to thirty single spheres for the 0.514 micron particles, and up to 500 for another latex of 0.132

diameter spheres. Photomicrographs revealed two types of aggregate: spheroidal clumps and chains of moderate length. For agglomerates of uniformly sized particles of known mass, the number of particles per agglomerate can be easily ascertained by dividing the two masses. In this way four of the 0.514 micron agglomerates were shown to be doublets, and five of them triplets. The doublets all had drag diameters between 0.67 and 0.73 micron, the triplets between 0.80 and 0.84 micron. The exact significance of these values might be found by calculations similar to that of Faxen (3), who obtained a theoretical Stokes diameter for symmetrical doublets falling with their line of centers in a vertical position.

Table 1 shows all the substances measured, with their normal solid densities and the range of apparent densities of the agglomerates, calculated from the experimentally determined drag diameter and mass. Only for the polystyrene and the aluminum oxide were the primary particles homogeneous in size. The results have been plotted on log paper in the form $CD^2\rho$ versus mass (Figures 1 to 5). The equation of the lines is*

$$CD^2\rho = m^B$$

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*Note added January 18, 1956

The discovery of an error in the calculations indicates that this equation should read

$$CD^2\rho = Am^B,$$

where A varies from about 1.1 to 2.2 for the substances used. Also, B varies so widely among these substances and otheres subsequently measured that the use of an average value is no longer justified. The range of variation of B is approximately 0.3 to 0.67. Figures 1 to 10 are still useful for showing the directions and orders of magnitude of the differences in behavior.

The solid line on each graph is the best line through the data for that substance. The dashed line represents the equation when the average value of B (0.644) for all the substances is used. The average deviation of the experimentally determined massfrom this line is 32 per cent. The degree to which all the materials fit the same line is a measure of the similarity of both the densities and shapes of their agglomerates. In other words, it is a measure of the constancy of the relationship between mass and drag diameter for various real particles.

Figures 6 to 9 show the data obtained by previous observers (1,9) calculated in the same manner. The average equation

$$CD^2\rho = m^{0.644}$$

thus may be said to hold, within the deviation noted, for materials with a range of normal density from 1.05 to 19.3 g./cc. and a range of primary particle size from 0.02 to 0.5 micron, dispersed in the manner of these experiments.

The behavior of particularly abnormal agglomerates is indicated by the curve for camphor smoke particles, which are well known to have a very open branched-chain structure (Figure 10). The data here fall 90 per cent below the average line; it may be significant that the slope is not greatly different. A tendency toward this type of behavior should be shown by agglomerates formed in the presence of excess electric charges, which promote chain formation.

As has been noted, the wide scatter of the data may be attributed to the wide variations in the overall shape of the agglomerates even of one substance. The smaller constant deviations shown by each material, however, are probably due to real differences

in the packing of primary particles in an agglomerate. There is no obvious correlation between these uniform deviations and any common properties of the substances, such as density, primary particle size, crystal habit, etc. The effect is of course a composite of more than one such factor. Further experiments are being carried out to shed light on the problem, particularly on the relationship of crystal form and surface structure to the packing.

Referring to the first problem discussed, size distributions of airborne agglomerates, the graph of $CD^2\rho$ versus mass may be used with the jet impactor to obtain drag diameter distributions for such aerosols. From the $CD^2\rho$ distribution measured by the impactor the distribution of particle masses can be obtained simply by reference to the curve. Allowance may be made for any available information on the general shape of the particles. Then m can be substituted into

$$CD^2\rho = 6mC/\pi D = 6m(1 + 2A\lambda/D)/\pi D$$

to obtain D. A limitation is that the primary particles must not be so inhomogeneous that agglomerates widely different in size can have the same mass.

Acknowledgement

Most of the experiments and calculations in this work were performed by H. Herzig.

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Nomenclature

A	Factor in Cunningham correction, dimensionless
B	Exponent in empirical equation, dimensionless
C	$= 1 + \frac{2A\lambda}{D}$, Cunningham slip correction, dimensionless
D	Drag diameter of particle, cm.
D_c	Characteristic dimension of collector in jet impactor, cm.
e	Electronic charge, electrostatic units
g	Acceleration of gravity, cm./sec.^{2}
m	Mass of particle, gm.
n	Number of charge units on particle
v_o	Velocity of air flow in jet impactor, cm./sec.
v_e	Terminal velocity of particle under electrical force, cm./sec.
v_g	Terminal velocity of particle in free fall, cm./sec.
X	Electric field strength, electrostatic units/cm.
λ	Mean free path of air molecules, cm.
μ	Viscosity of air, gm./cm. sec.
π	3.1416
ρ	Density of particle, gm./cc.
ψ	$= \frac{CD^2\rho v_o}{18\mu D_c}$, impaction parameter, dimensionless

Table 1

Substance	Normal Density, g./cc.	Primary Particle Size, microns	Apparent Density of Agglomerates, g./cc.
Polystyrene	1.05	0.132	0.26-0.76
Polystyrene	1.05	0.514	0.15-0.97
Aluminum	2.70	less than 1	0.14-1.94
Aluminum oxide	3.99	0.02	0.14-1.45
Zinc oxide	5.61	0.05-0.1	0.86-2.50
Zinc	7.14	less than 1	0.57-3.27
Carbon (camphor smoke)	2.25		0.0091-0.0480

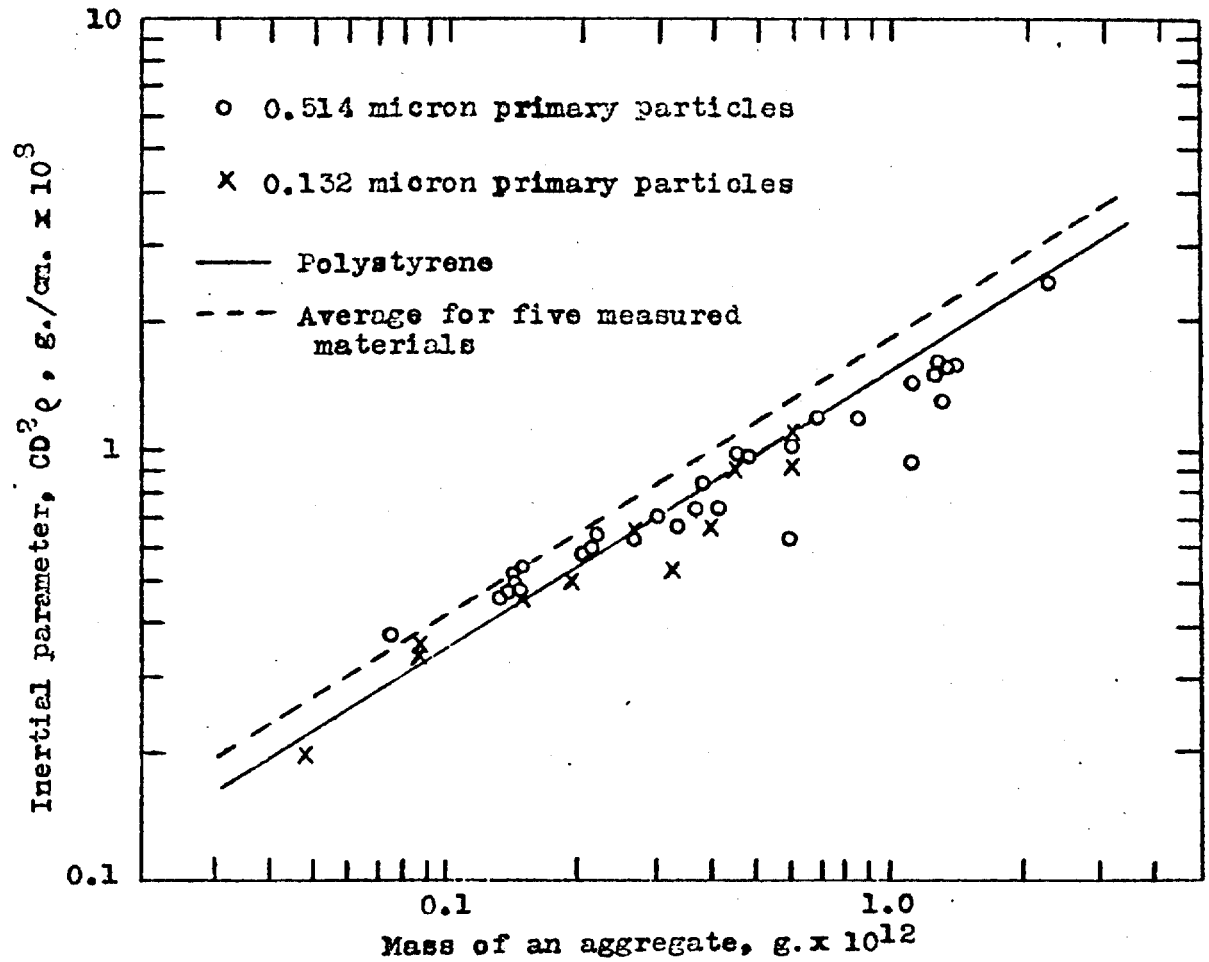

Figure 1. Relationship between mass and inertial parameter for polystyrene aggregates

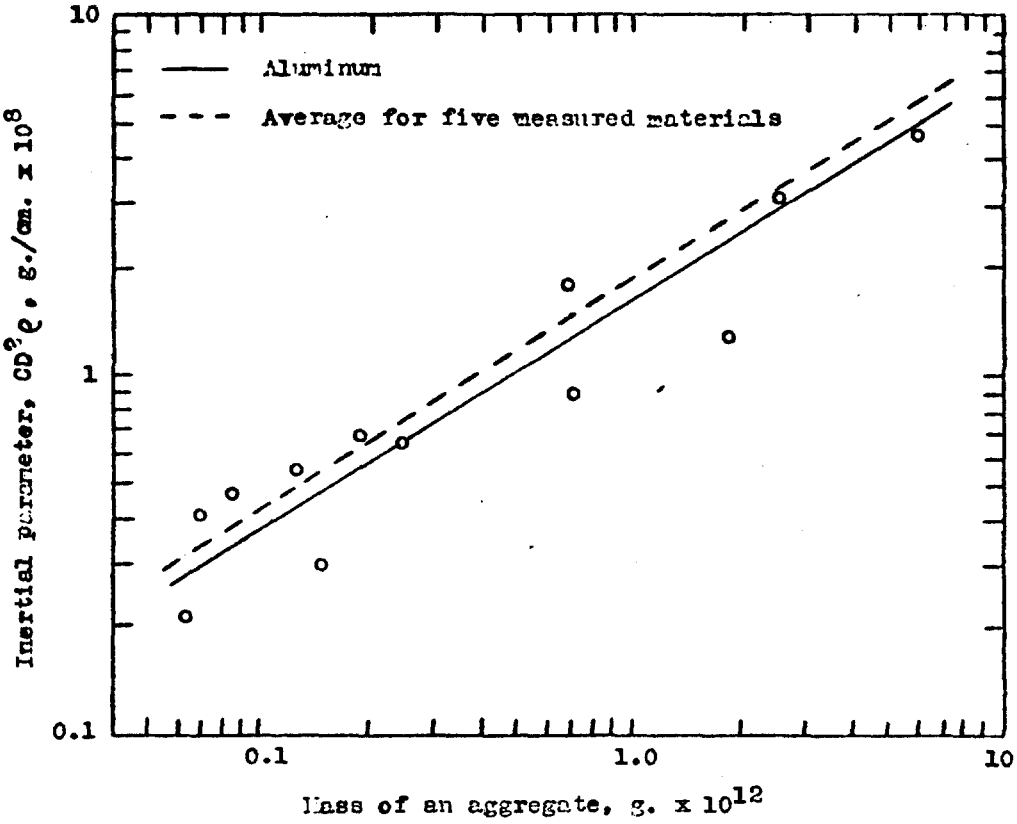

Figure 2. Relationship between mass and inertial parameter for aluminum aggregates

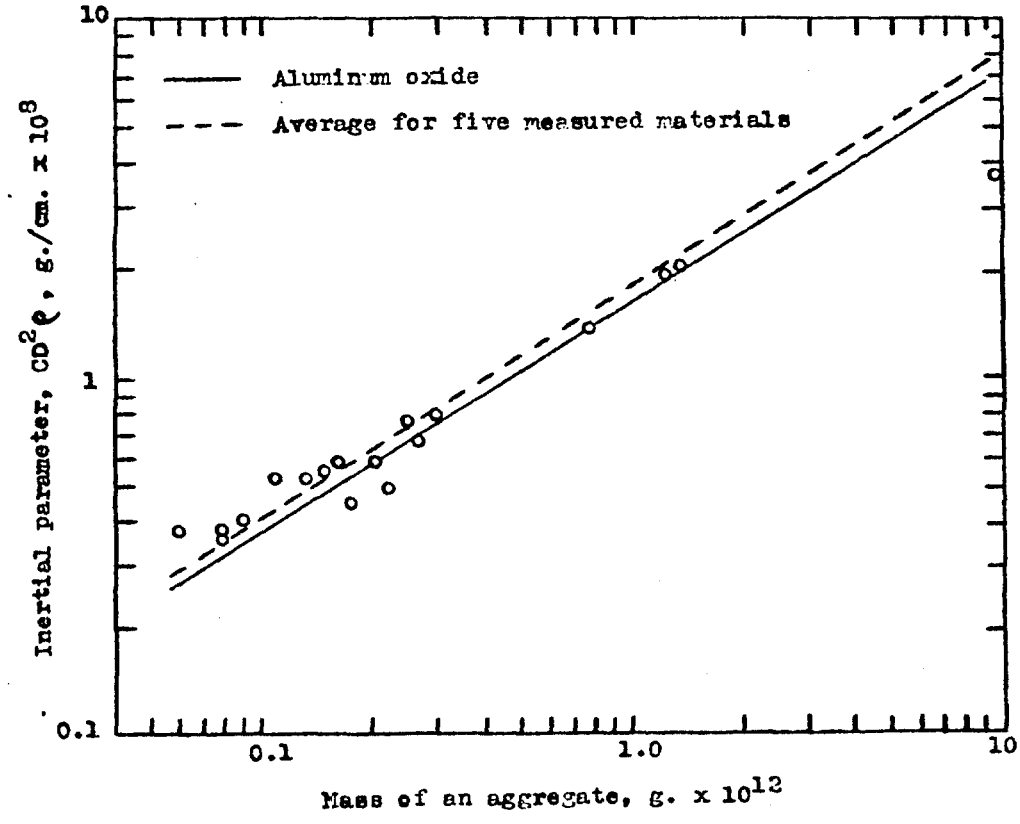

Figure 3. Relationship between mass and inertial parameter for aluminum oxide aggregates

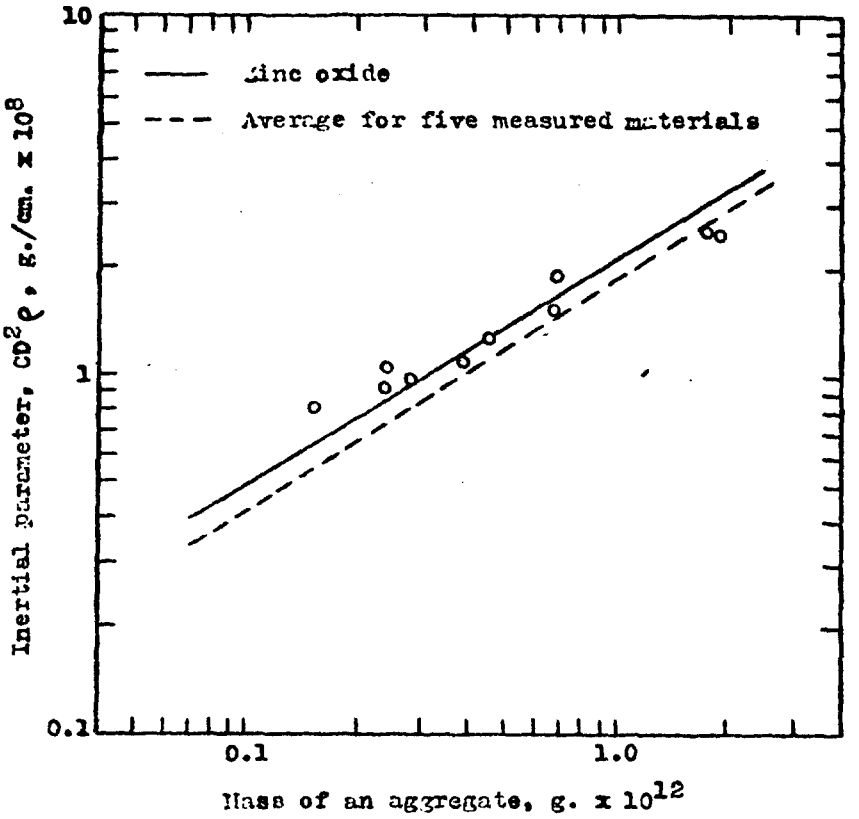

Figure 4. Relationship between mass and inertial parameter for zinc oxide aggregates

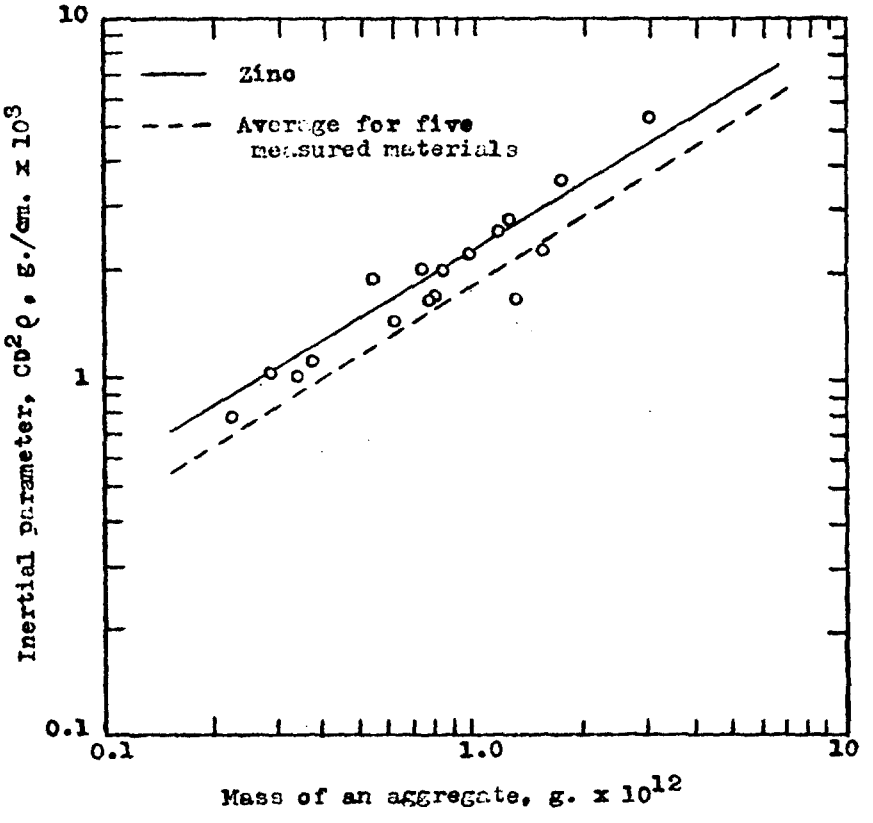

Figure 5. Relationship between mass and inertial parameter for zinc aggregates

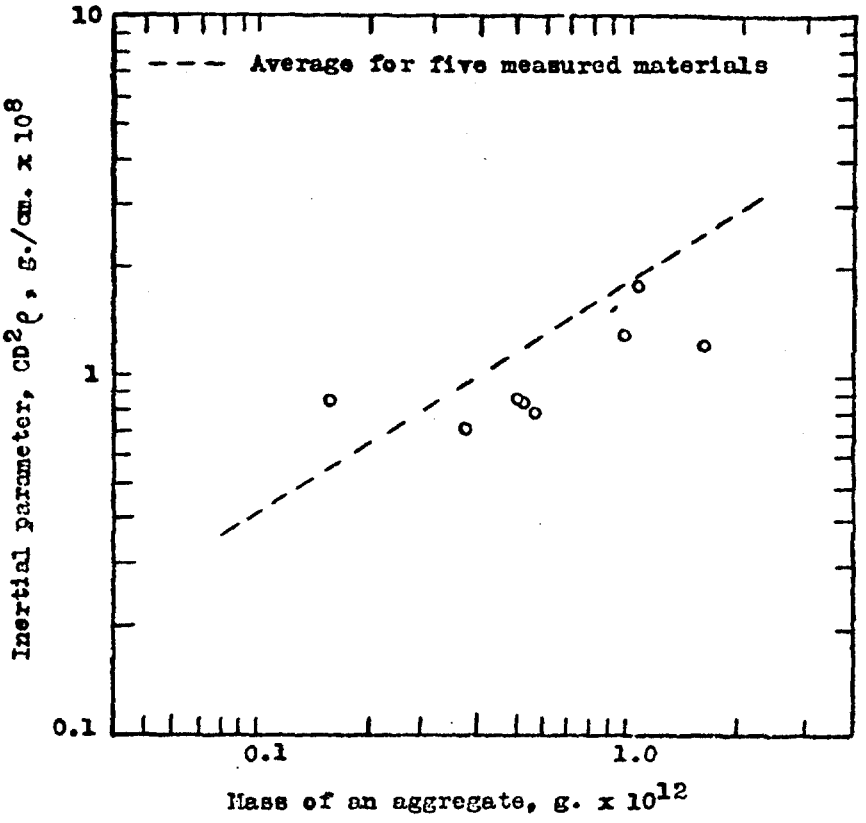

Figure 6. Relationship between mass and inertial parameter for cadmium oxide aggregates (18)

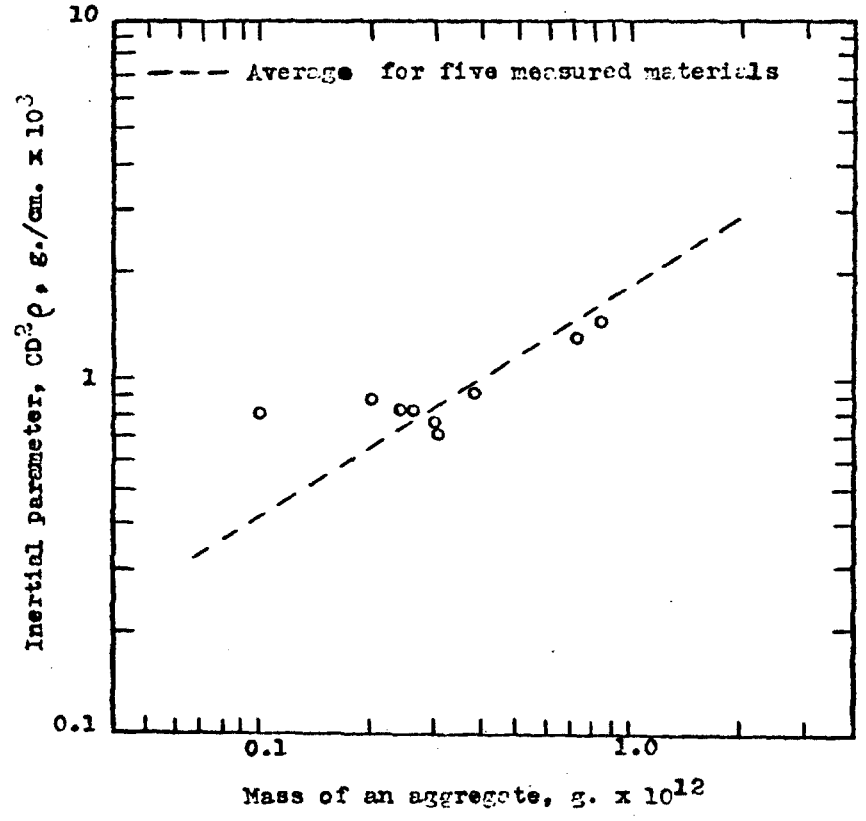

Figure 7. Relationship between mass and inertial parameter for silver aggregates (18)

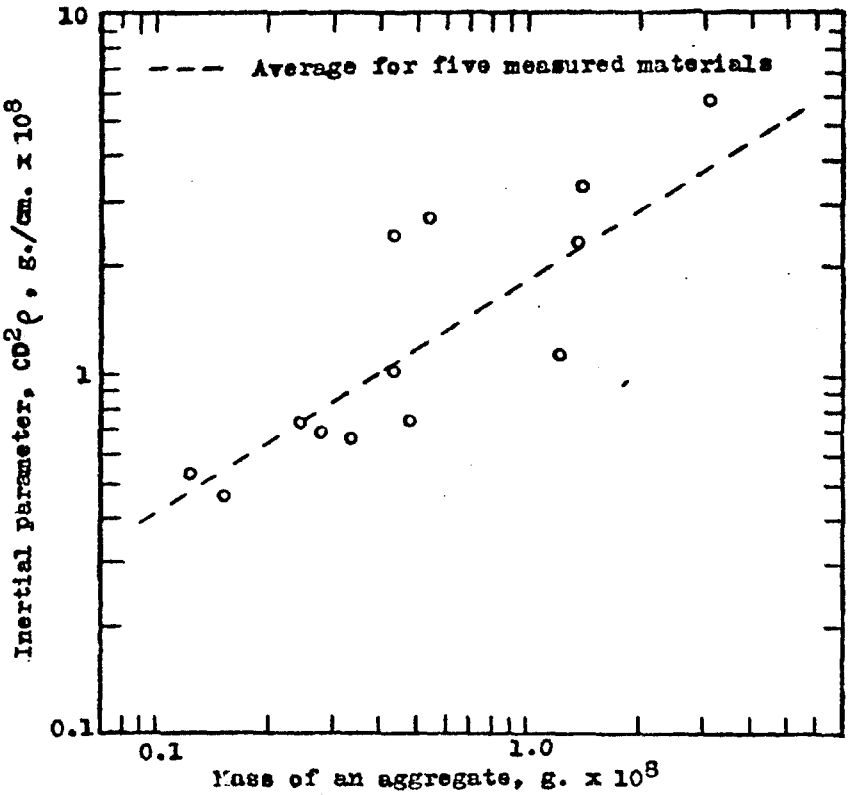

Figure 8. Relationship between mass and inertial parameter for gold aggregates (18)

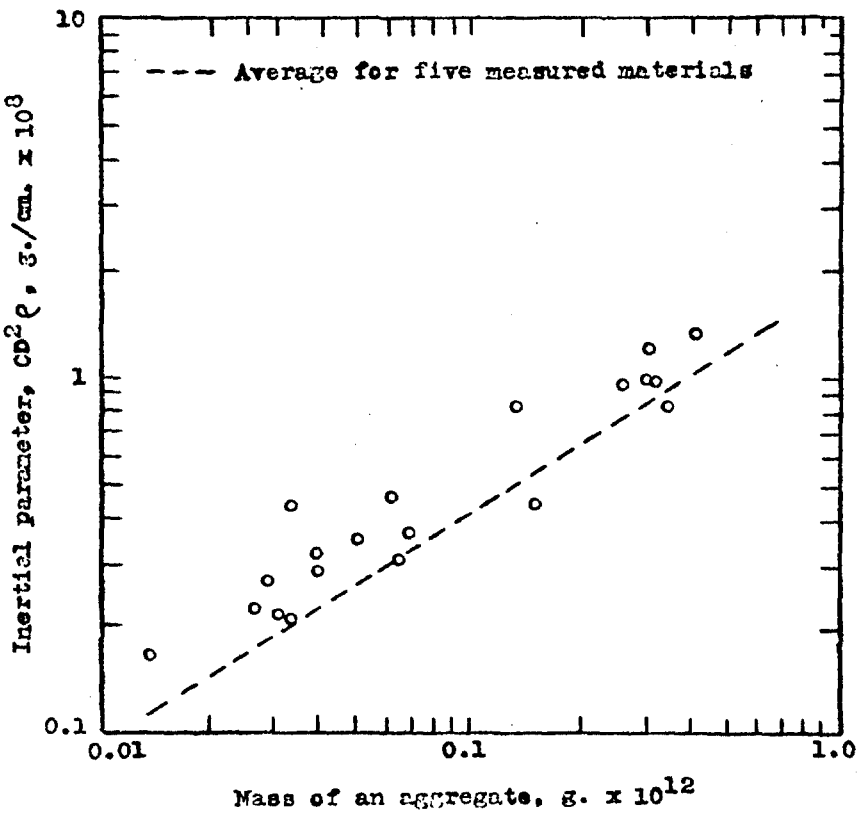

Figure 9. Relationship between mass and inertial parameter for selenium aggregates (1)

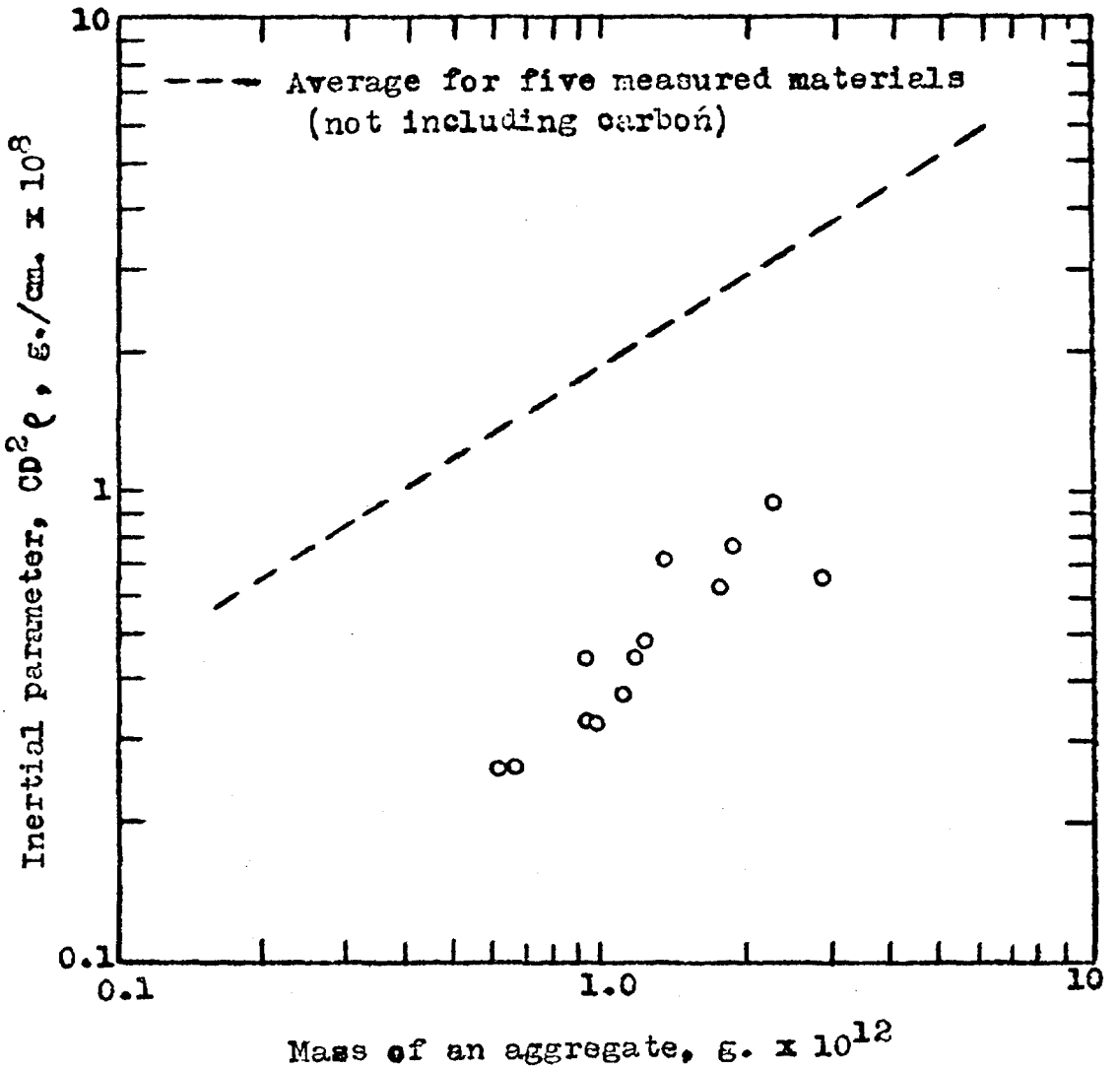

Figure 10. Relationship between mass and inertial parameter for carbon aggregates

ABSORPTION OF NITROGEN OXIDES FROM WASTE GASES

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Introduction

Many industrial processes evolve gases containing nitrogen oxides, and it is often necessary to effect removal or recovery of these oxides. In some cases, the gases must be cleaned before they can be released to the atmosphere, while, in other cases, efficient recovery of the nitrogen oxides is a direct and essential part of the manufacturing process.

The removal of nitrogen oxides from gases becomes particularly difficult at low concentrations because the efficiency of most removal equipment decreases with reduction in oxide concentration. It is necessary, therefore, to understand the controlling mechanisms in the process before attempting to develop improved methods for removing nitrogen oxides from dilute gases.

The purpose of this paper is to present an analysis of the basic principles governing the absorption process and to show the results obtained when various types of equipment are used for removing nitrogen oxides from waste gases.

Controlling Mechanism

Nitrogen oxides are commonly removed from gases by aqueous absorption accompanied by chemical reaction. The important nitrogen oxides in processes involving reactions with aqueous solutions are NO_2, N_2O_4, and NO. Small amounts of N_2O_3 and N_2O_5 are also present in the gases, but these compounds rapidly come to equilibrium with NO and NO_2 and represent only a small fraction of the total oxides at room or higher temperatures (6, 7).

The essential chemical reactions occurring in the removal process are:

$$2\ NO_2\ (\text{or } N_2O_4) + H_2O \rightleftharpoons HNO_3 + HNO_2 \qquad (A)$$

$$2\ HNO_2 \rightleftharpoons H_2O + NO + NO_2\ (\text{or } 1/2\ N_2O_4) \qquad (B)$$

$$2\ NO + O_2 \longrightarrow 2\ NO_2\ (\text{or } N_2O_4) \qquad (C)$$

$$2\ NO_2 = N_2O_4 \qquad (D)$$

Reaction (D) attains equilibrium rapidly and the equilibrium constant for this reaction is known as a function of temperature between 0°C and 90°C (8). The oxidation of NO proceeds relatively slowly although the reaction goes essentially to completion.

Reactions (A) and (B) are reversible and proceed at a finite rate. It is possible, therefore, that the rate of aqueous absorption is controlled by the rate of the chemical reactions. Diffusional resistance or a combination of diffusional resistance and chemical reaction rate could also control the rate of the acqueous absorption. The following integrated rate equations have been obtained for the two limiting cases of chemical reaction rate controlling (5) and gaseous diffusion controlling (4): (See table of nomenclature for notation)
Chemical reaction rate controlling,

$$\frac{1}{(p_{f_{N_2O_4}})^{1/2}} = \frac{1}{(p_{o_{N_2O_4}})^{1/2}} - 2\sqrt{K_p}\ \ln \frac{p_{o_{N_2O_4}}}{p_{f_{N_2O_4}}} + Bt \qquad (1)$$

Gaseous diffusion controlling,

$$(p_{o_{N_2O_4}})^{1/2}\left[\frac{0.715}{\sqrt{K_p}} + (p_{o_{N_2O_4}})^{1/2}\right]^{1.86} = F\,(p_{f_{N_2O_4}})^{1/2}\left[\frac{0.715}{\sqrt{K_p}} + (p_{f_{N_2O_4}})^{1/2}\right]^{1.86} \qquad (2)$$

The following assumptions were made in deriving Eqs. (1) and (2):

1. Chemical reactions occur under irreversible conditions.
2. Constant temperature and constant gas rate prevail.
3. Instantaneous equilibrium exists between NO_2 and N_2O_4.
4. Contact time is sufficiently short so that there is no appreciable oxidation of NO.

The theoretical and experimental results can be interpreted on the basis of plate efficiency. With this approach, the practical significance of the results is immediately apparent. Plate efficiency is defined as the amount of nitrogen oxides removed from the gases divided by the amount of oxides which would have been removed if the plate were theoretically perfect.

By choosing one experimental point as a basis, Eqs. (1) and (2) can be used to predict theoretical curves of plate efficiency versus eNO_2 (i.e., $NO_2 + 2\ N_2O_4$) content of the entering gases for the two possibilities of chemical reaction rate controlling and diffusion controlling. These two theoretical curves are presented in Figure 1.

Experimental tests were conducted to determine the controlling factors in the aqueous absorption of nitrogen oxides. The experimental data were obtained with a bubble-cap plate column under conditions of constant temperature, constant gas rate, irreversible reactions, negligible oxidation of NO while the gas was in contact with the liquid, and essentially instantaneous equilibrium between NO_2 and N_2O_4. A dense mist was observed in the gas phase in all the runs.

The experimental results are presented in Figure 1 for comparison with the theoretical curves. As shown in Figure 1, the experimental plate efficiencies decrease with reduction in gaseous eNO_2 concentration and follow the theoretical curve predicted for the case in which the controlling mechanism is the rate of the chemical reactions. In general, if operating equipment or operating conditions can be obtained which tend to eliminate chemical reaction rates as the controlling factor, the upper limit on the plate efficiency would be represented by the diffusion-controlling curve in Figure 1.

Effects of Operating Variables

Figure 2 shows the effect of temperature on the efficiency of nitrogen oxides removal from gases. As the operating temperature is increased, the removal efficiency decreases. If the rate of the chemical reactions controls the rate of the nitrogen oxides removal, the reduction in efficiency with increase in temperature can be attributed partly to the decrease in the fraction of eNO_2 present as N_2O_4. On the same basis, an increase in operating pressure should give improved removal efficiencies.

The material used as the absorbing medium may affect the removal efficiency. Experimental results are presented in Figure 2 comparing the removal efficiencies for the cases in which water (or dilute nitric acid) and 20 per cent by weight aqueous sodium hydroxide were used as the absorbing media. As indicated in Figure 2, the removal efficiencies with aqueous sodium hydroxide as the absorbing medium are lower than those obtained when water or dilute nitric acid is the absorbing medium. Tests have been made with catalysts in the absorbing medium in an attempt to increase the rate of the controlling chemical reactions; however, no effective catalysts for this purpose have been reported (1).

The type of equipment used for the removal operation determines the magnitude of the contact area between the gas and the absorbing liquid. Experimental tests have shown that the rate of removal of nitrogen oxides from gases with aqueous absorption media is independent of the bulk liquid volume or bulk gas volume and is directly proportional to the interfacial area between the gas and the liquid (2). The controlling chemical reactions, therefore, must take place in the region

of contact between the gas and liquid phases.

Equipment for Removal of Nitrogen Oxides from Waste Gases

The preceding discussion indicates that two factors are of major importance in the development of improved methods for removing nitrogen oxides from waste gases: (1) Since the rates of the chemical reactions may control the rate of nitrogen oxides removal, a reasonably long time of contact between gas and liquid should be maintained, and (2) it is desirable to supply the maximum amount of gas-liquid contact area.

The chemical reactions involved in the removal process produce NO, and the absorption equipment must provide sufficient space for the occurrence of the slow oxidation of NO. However, this paper is concerned primarily with methods for obtaining the maximum removal efficiency for each gas-liquid contacting stage, and it is assumed that sufficient free space can be provided for the NO oxidation.

A variety of types of equipment can be used for the contacting operation. Bubble-cap towers, spray towers, packed towers, fritted bubblers, and Venturi atomizers are used for absorption operations. Removal of nitrogen oxides from gases can also be effected by adsorption on silica gel.

Although Venturi atomizers give a large interfacial area between the dispersed liquid droplets and the gas, this type of absorption unit is not effective for removing nitrogen oxides from gases because of the short contact time (1). Fritted bubblers permit a relatively long contact time and also give a large amount of contact area between the dispersed gas and the liquid. Therefore, despite the disadvantage of the high pressure drop involved in the operation of a fritted bubbler, this type of absorption unit could be useful for removing nitrogen oxides from dilute gases.

Experimental Results with Various types of Removal Equipment

Experimental data were obtained with a fritted bubbler, a packed tower, a spray tower, and a bubble-cap tower at gaseous concentration of eNO_2 ranging from 0.2 to 2.0 per cent by volume. The essential information on the characteristics of the experimental equipment is presented in Table 1.

Water was fed to the units at a constant rate, and the flow rate was measured by a calibrated rotameter and checked by volumetric measurements. Gaseous nitrogen dioxide, obtained from cylinders containing NO_2 and N_2O_4, was diluted with air and admitted at a steady rate to the lower section of the towers. The gas flow rates were measured by calibrated Venturi meters.

The towers were operated under steady conditions until equilibrium was attained as indicated by a constant acid concentration in the liquid product. Temperatures, pressures, and flow rates were read, and samples of the inlet gas, inlet liquid, and product liquid were taken. The liquid samples were analyzed by titrating a known volume with standard NaOH solution. The gas samples were taken in

evacuated bulbs containing hydrogen peroxide. The amount of gas sample was determined by weighing, and the amount of nitrogen oxides present was determined by titrating the nitric acid formed from the reaction between H_2O_2 and NO_2 and N_2O_4. From a knowledge of the flow rates and concentrations, it was possible to calculate the removal efficiency, expressed as the per cent of entering oxides removed.

The variables, such as gas rate, tower height, and liquid rate were chosen of magnitudes which would permit a fair comparison among the removal efficiencies of the various types of equipment. The values chosen represent as closely as possible those which would be used in corresponding industrial units.

The removal efficiency was found to be independent of the liquid rate in the bubble-cap tower and the fritted bubbler as long as the concentration of the liquid did not increase above 10 per cent by weight nitric acid. The spray tower was operated at a liquid rate which would give a finely dispersed mist, while the packed tower was operated at approximately 90 per cent of the liquid flooding velocity. A slot gas velocity of 1.17 ft/sec was used in the bubble-cap tower, while the gas rate used in the fritted bubbler was the rate at which well dispersed bubbles first appeared. Superficial gas velocities of 1.84 ft/sec were used in both the packed and spray towers.

Air was used as the diluent gas for all the test runs. The gas-liquid contact time in the bubble-cap and fritted-bubbler units was not sufficient for any appreciable oxidation of the NO formed in the chemical reactions. Some of the NO formed was oxidized to NO_2 in the packed and spray towers; however, this difference in the operation is necessary in order to make a fair comparison among the various types of equipment.

Comparative results are presented in Figure 3 showing the effect of entering oxide concentration on the removal efficiencies for the different types of equipment. A reduction in oxide concentration causes a decrease in removal efficiency for all the types of equipment. Thus, as the gases become more dilute, the removal problem becomes more difficult.

The results obtained with the single-nozzle spray tower indicate very poor removal efficiencies at gaseous oxide concentrations less than about 1 per cent. At higher concentrations, the spray-tower efficiencies are comparable to those obtained in the other types of equipment. The use of multiple spray nozzles would, of course, cause a definite increase in the removal efficiency.

The removal efficiencies with the packed tower are lower than those found with the bubble-cap tower or fritted bubbler. It should be noted, however, that the decrease in efficiency with reduction in oxide content is fairly gradual, and, at nitrogen oxide concentrations less than about 0.2 per cent, the packed tower would be nearly as efficient as the other types of equipment.

From Figure 3, it can be seen that the fritted bubbler gives much better removal efficiencies than the other types of equipment tested. The pressure drop per stage for the fritted bubbler was approximately 30 times greater than the equivalent pressure drop for the

bubble-cap tower. Unless the gases were already under pressure, it would be expensive to add the equipment necessary to force a gas through a number of fritted-bubbler stages.

Since the removal efficiency of the bubble-cap tower approaches that of the fritted bubbler at low gaseous oxide concentrations, the optimum type of absorption equipment should combine the good features of both operations. A bubble-cap unit designed with a number of small gas outlets in the caps should approximate the beneficial effects of the small bubbles and large gas-liquid contact area found in a fritted bubbler.

The results shown in Figure 3 indicate that the silica gel adsorber gives the best removal efficiency of the units tested at gaseous concentrations less than 0.4 per cent nitrogen oxides. If essentially complete removal of the oxides is necessary, the silica gel adsorber should be used since the removal efficiency does not fall off rapidly at low gaseous concentrations.

NOMENCLATURE

A = gas-liquid interfacial area, sq cm.
B = a constant at any temperature.
$D_{N_2O_4}$ = gaseous diffusivity of N_2O_4, sq cm/sec.
eNO_2 = $NO_2 + 2\ N_2O_4$.
$\mathrm{Ln}\ F$ = $(A/V_g)\ (D_{N_2O_4}/x_F)\ 1.43\ t$.
K_p = equilibrium constant for the reaction $2\ NO_2 = N_2O_4$, atm^{-1}.
$Pf_{N_2O_4}$ = final partial pressure of N_2O_4, atm.
$Po_{N_2O_4}$ = original partial pressure of N_2O_4, atm.
t = contact time, sec.
V_g = volume of bulk of gas, cc.
x_F = effective film thickness, cm.

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TABLE 1

TEST CONDITIONS USED FOR DETERMINING THE EFFICIENCY OF NITROGEN DIOXIDE REMOVAL FROM DILUTE GASES WITH DIFFERENT TYPES OF EQUIPMENT

Total pressure = 1 atmosphere
Operating temperature = 25°C
Absorbent = Water. Gaseous diluent = Air

Type of Equipment	Gas Rate cu ft (S.C.) per min	Liquid Rate cc per min	Pressure Drop cm H_2O	Remarks
Bubble-cap tower (one stage)	1.06 (slot velocity = 1.17 ft/sec)	300	1.8	Tower diameter = 7 1/2 in. Six bubble caps with 4 or 8 5/16-in. slots per cap. Liquid depth = 1 in. Distance between bubble-cap plate and top and bottom plates = 12 in.
Packed tower (1/4-in. glass Raschig rings)	0.53 (superficial vapor velocity = 1.84 ft/sec)	150	2.0 per foot of packed height	Tower diameter = 1 in. Packed height = 46 in. Efficiency expressed as per foot of packed height. No channeling observed.
Spray tower (1 No. T58-1 mm spray nozzle)	0.53 (superficial vapor velocity = 1.84 ft/sec)	470	1.0	Tower diameter = 1 in. Tower height = 52 in. Finely dispersed spray directed countercurrent to rising gas. Negligible amount of liquid carryover in gas.
Fritted-glass bubbler (one stage)	0.53	300	59.0	Tower diameter = 5 1/2 in. 12 medium-frit glass rods. Fritted area = 1.03 sq in per rod. Liquid head over frits = 3 3/4 in.
Silica gel adsorber (No. 5 commercial gel - Ref. 3)	0.53 (superficial vapor velocity = 1.84 ft/sec)			Packed height = 12 in. Fraction saturated = 0.90. Time per cycle = 30 min. Efficiencies calculated from Ref. (3).

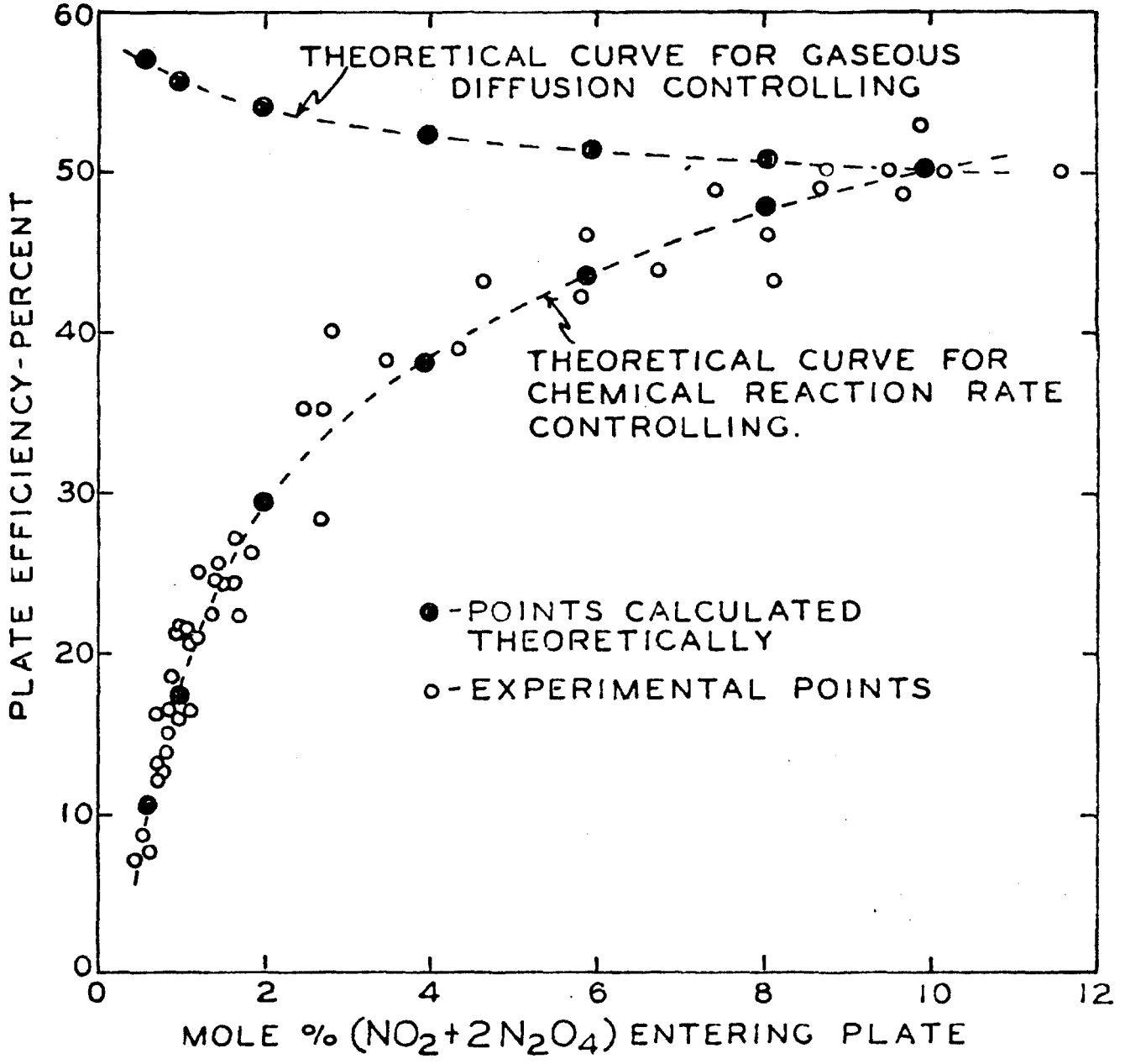

FIG. 1-EFFECT OF eNO_2 CONCENTRATION ON PLATE EFFICIENCY WITH ONE-PLATE BUBBLE-CAP TOWER (PRES.= 1 ATM., TEMP. = 23 °C., GAS SLOT VELOCITY = 1.18 FT./SEC.)

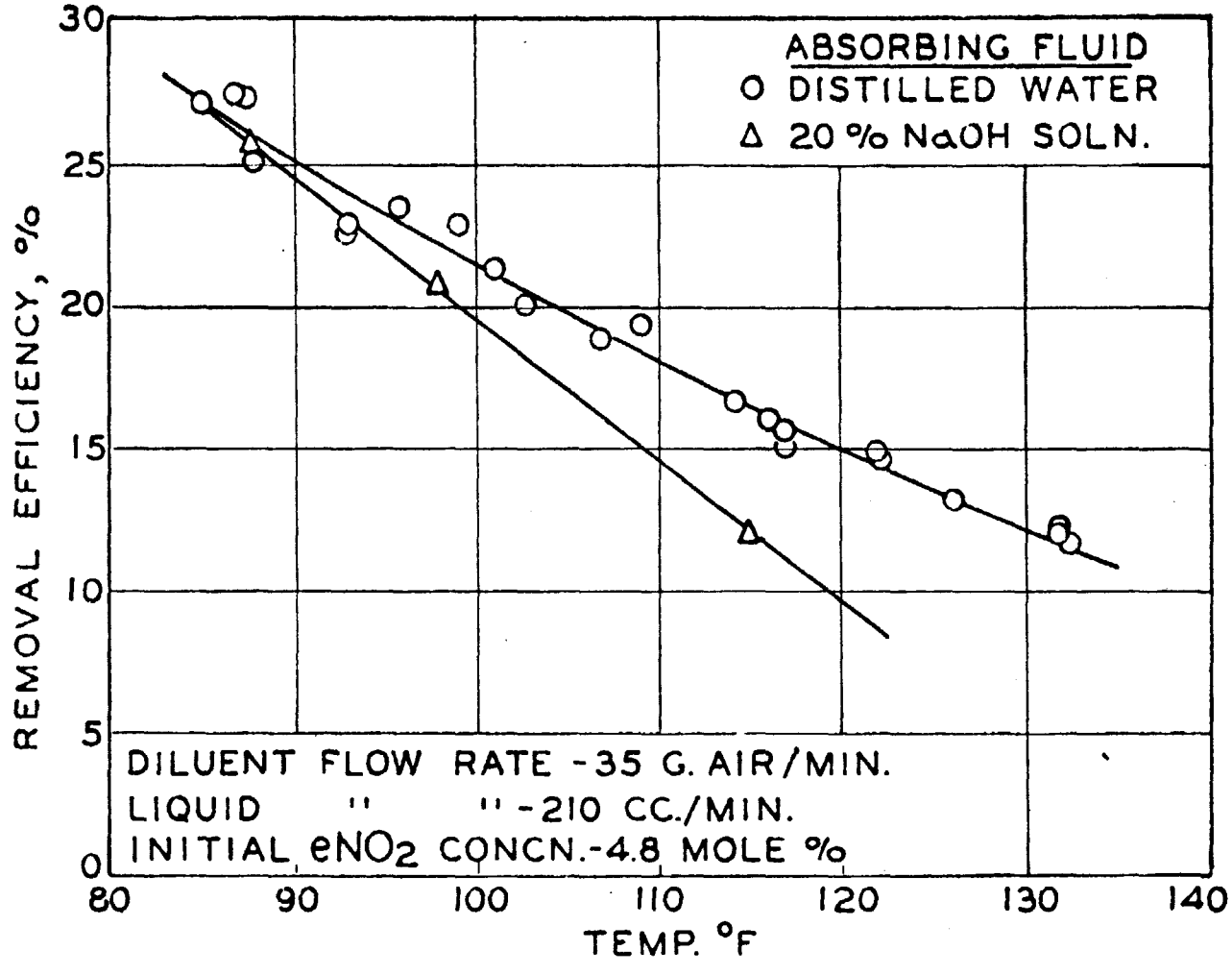

FIG. 2-EFFECT OF TEMPERATURE ON REMOVAL EFFICIENCY WITH WETTED-WALL TOWER (DIA.=2.15 CM., HEIGHT=100 CM., PRES.=1 ATM.)

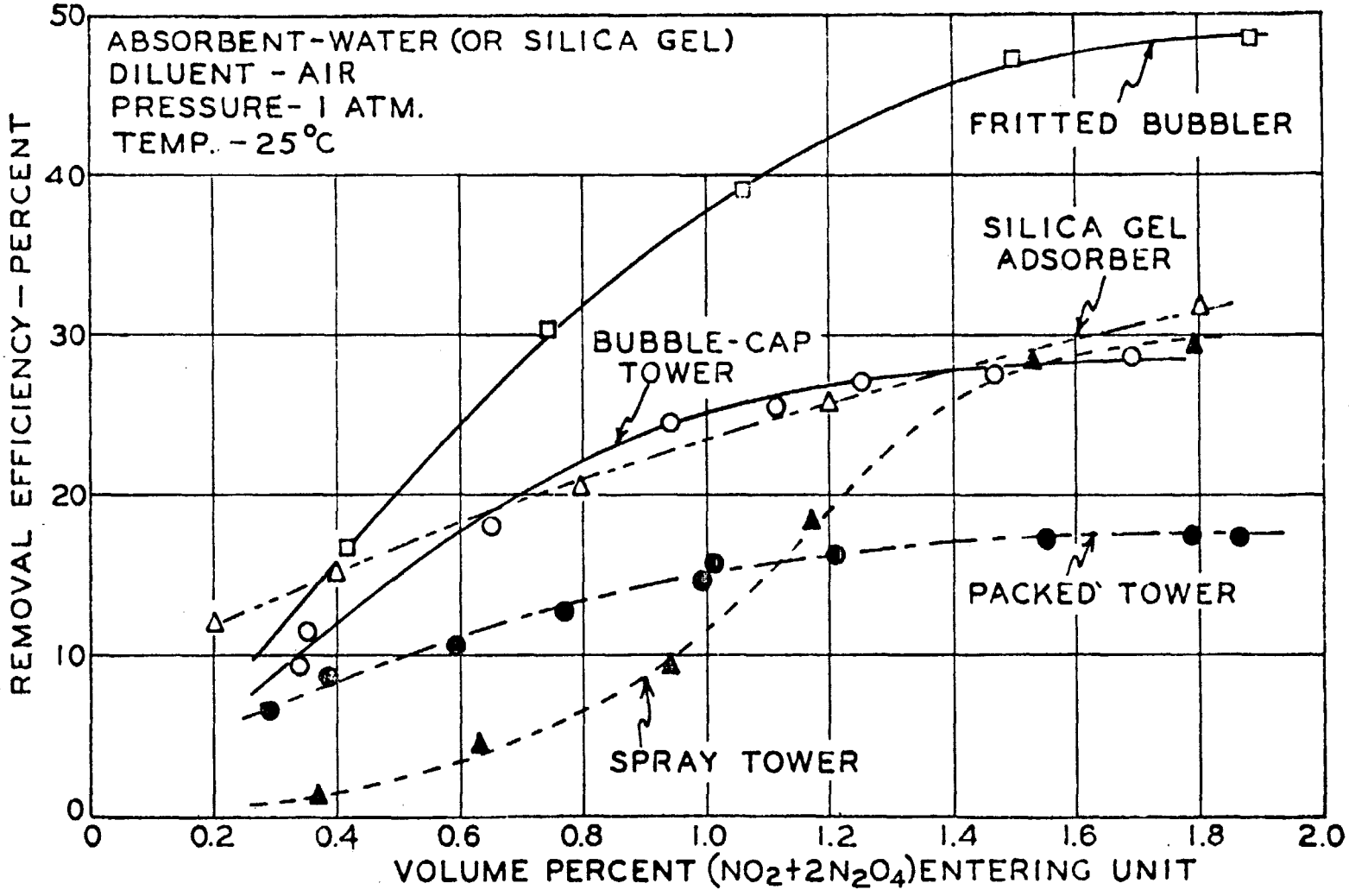

FIG. 3-EFFICIENCY OF NITROGEN DIOXIDE REMOVAL FROM DILUTE GASES WITH DIFFERENT TYPES OF EQUIPMENT

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TID-7513(Pt. 2)

Subject Category: RADIOACTIVE WASTE

UNITED STATES ATOMIC ENERGY COMMISSION

FOURTH ATOMIC ENERGY COMMISSION AIR CLEANING CONFERENCE HELD AT ARGONNE NATIONAL LABORATORY, NOVEMBER 1955

Classification changed to
Unclassified by authority of
TID [illegible] No. 5436
C.R. Barnes & Apr 22, 1957

June 1956
[TIE Issuance Date]

Division of Reactor Development
Washington, D. C.

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DIVISION OF REACTOR DEVELOPMENT
Washington D. C.

TABLE OF CONTENTS

AIR CLEANING PROBLEMS AND ACTIVITIES AT THE GOODYEAR ATOMIC CORPORATION, PORTSMOUTH, OHIO

By Howard Caterson

LOCATION AND DESCRIPTION OF PLANT

As many of you know, the Goodyear Atomic Corporation operates for the Atomic Energy Commission a gaseous diffusion plant located in Pike County, Ohio just 20 miles north of Portsmouth and the Ohio River. The plant was built at the direction of the Atomic Energy Commission for extracting uranium-235 isotope from various isotopic assay mixtures of uranium. The area of Southern Ohio in which the plant is located is thinly populated and essentially rural. In Pike County, where the plant is located, the 1950 census showed Waverly with a population of 1700 inhabitants as the largest town. Prior to construction of the plant, most of the county's population was engaged in agricultural activities. Although not perhaps as isolated as Los Alamos, or some of the test sites in the west, there seems to be ample area with sparse population between the plant site and the principal communities. So that you may better orient yourselves, I have marked on the map (Fig. 1) the principal residential areas - Portsmouth, Lucasville, Beaver, Piketon and Waverly.

The plant itself is located on a 4000-acre site and consists of three large process buildings and an assortment of auxiliaries. The dimensions of a typical building are 2,500 feet long by 500 feet wide.

PRINCIPAL AIRBORNE CONTAMINANTS

Uranium and fluorine, in several combinations, are the principal airborne contaminants which might result from the plant operations. I might mention that the diffusion cascade itself consists of a vast configuration of relatively large diameter pipes, vessels and gas pumps which continuously circulate uranium hexafluoride in gaseous state. Except at the time of equipment or pipe failure, the uranium gas is contained in the cascade system. Process gas can, of course, escape accidentally at the feed point and at the withdrawal points. In the presence of wet air, uranium hexafluoride will hydrolyze to an oxifluoride or reduced to the insoluble tetrafluoride. Under normal atmospheric conditions, these compounds are solid and can form small particles which easily become airborne. The other gaseous contaminants consist of fluorine and hydrogen fluoride. Fluorine and hydrogen fluoride may be associated with or without uranium.

CONTAINMENT OR DISPERSION?

There are two directly opposite philosophies prevelent at our plant on the subject of airborne uranium contaminants. Should the released material be contained and collected at the point of disposal or should the airborne material be exhausted to the atmosphere so that the area concentration is reduced by dilution? Containment usually requires more equipment and is frequently more expensive. Containment, however, will prevent widespread contamination and will enable easier recovery of airborne materials.

URANIUM GAS RELEASES - LARGELY CONSIDERED INTERNAL

It has been noted that the airborne activity following a release of process gas (UF_6) tends to decrease more rapidly at the U-235 depleted end of the cascade than at the U-235 product end. The complete reason for this is not known at this time. The rapid settling of particulate matter after a release does permit entry by decontamination personnel wearing company-issued clothing and shoes. Respiratory equipment is usually used for protection against ingestion brought about by dusts stirred up during the cleaning activity.

Uranium gas released in an enclosed area handling higher assay material from the cascade does require ventilation to reduce the airborne activity. This higher assay material is sufficiently valuable that a filtering system is being installed for collection and recovery of the uranium. Since the alpha activity of this material is very high, the dollar value is considered fortunate from an industrial hygiene point of view. It is proposed that several deep bed fibre glass filter units be used as the filtering agent. It is believed and hoped that the routine changing of the filters will not give the fluorides sufficient time to attack the filter media. In one such area where this problem exists, the ventilation provided by operating air samplers within the enclosed area is sufficient to reduce the airborne activity. The filter papers collecting the airborne contaminants are processed to recover the uranium. This is an interim measure until the permanent ventilation system is installed.

In the room where depleted uranium hexafluoride is withdrawn from the cascade, the airborne activity following a release decreases rapidly. There are two ventilation systems in the area - one, over each withdrawal point, designed to handle small releases, and the second, an emergency system located in the ceiling designed to exhaust any major release to the outside. It is the philosophy of our Health Physics Department that when the contaminant is contained, there is no necessity to spread it over a large area. Therefore, it is their recommendation that the emergency ventilation system be used during a major release only when needed to facilitate the evacuation of personnel from the area.

In our product withdrawal area, vacuum pumps were provided, preceded by mechanical and chemical traps, to exhaust within the rooms. After a brief period of operation in this facility it was discovered that the traps did not remove all of the uranium hexafluoride gas and it was being dispersed in light concentrations throughout the room. The vacuum pumps have since been connected to vent lines exhausting them to the outside. Because of the monetary worth of even the small quantity of vented uranium, filters are being designed to collect material which passes through the pumps.

THE AIR CLEANING PROBLEM

An extensive ventilation system is provided in each process building (8,300,000, 8,750,000, 7,000,000 CFM respectively) to control and maintain ambient air temperatures in order to prevent the process gas (UF_6) from freezing out and to provide air for cooling motors. Air mixing and filter rooms are provided at the air intake openings into the buildings. A typical process building will include some 7,600 20" x 20" x 2" viscous type wire mesh filters (American Air Filter Type HV-2 - Design A - 1200 CFM per filter capacity). The filter banks are washed clean with warm water and recoiled when the static pressure drop reaches 0.25" of water (design point - 0.12" of water). Recoiling has been a fire hazard when improper spraying devices are used. On one occasion, atomizing spray heads were used resulting in large quantities of oil vapor being carried into large portions of the building. Suggestions of uninflammable oils for consideration in this application would be welcomed. Although the above certainly represents an extremely large industrial ventilating installation, there are no unique radiation or nuclear problems directly associated with this application.

EXTERNAL ATMOSPHERE CONTAMINANTS

Fluorine and other light mass gasses such as nitrogen or air, must be removed from the cascade to prevent an excessive build-up of volumes which should better be occupied by uranium gas. The removal of these so-called "lights" is accomplished by allowing the gasses to vent through stacks. There has been, over the months, a build-up of radioactivity around the vents from traces of uranium passing through with the "light" gasses.

Until an adequate scrubber is designed for fluorine being vented, it is proposed to allow the vent gases to pass directly into the atmosphere. The odor threshold for the various fluorine components is considerably below the plant limits (1PPM); as a result, nearly everyone on plant site has a more sensitive detector than the Industrial Hygiene Department. Even though background checks for fluoride contents of mud, water, foilage and air indicate no change over the initial values observed prior to beginning plant operation, both off and on plant site, plans for fluorine scrubbers are being developed.

These application items and problems which I have just discussed are mentioned to give you a cross section of typical problems associated with airborne activity at the Portsmouth plant site. Although some of the materials are not commonly used in other industries, it is not claimed that Portsmouth's problems are unusually difficult or particularly unique. We are confident that the bulk of these problems have and will continue to be solved using standard industrial hygiene and engineering techniques.

FUTURE CONSIDERATIONS

Although the plant site is located in a sparsely populated area, there are privately owned lands and farms on all sides of the plant site. Our Industrial Hygiene and Health Physics Groups regularly check plant effluent streams and take air samples from regular points. In addition to this monthly data, arrangements have been made for annual photographic surveys as a check to determine whether airborne radioactive materials and corrosive gases have had any effect on foilage and crops. The first aerial and ground photographic survey was made before plant operations began in 1954 and the second survey was completed this past summer. As expected, no apparent changes have yet been detected.

Several unanswered problems have been mentioned and I hope that perhaps in some of the discussions here this week I might pick up some clues which will give us some help. Among these unanswered problems were the absolute removal of uranium hexafluoride by banks of mechanical and chemical traps; the best filter media to be used for the collection of uranium fluorides and for the scrubbing and collection of fluorine from vented gases. In addition, a method which would analyze fluorides quickly and accurately is needed. Our Laboratory people report that the present modified Willard & Winters Titration Procedure requires a time consuming distillation and gives much delayed results.

In summary, I would like to say that during the start of operations at the Portsmouth Plant there have been many interesting problems in the area of air contamination and air cleaning. The bulk of these center around uranium and fluorine compounds and the bulk of the solutions have been handled by dispersion and dilution. Trapping has been successful, although improvements are in order. It is not anticipated that difficulties in the near or foreseeable future with the community will result from the present methods of operation at the Portsmouth Area Plant.

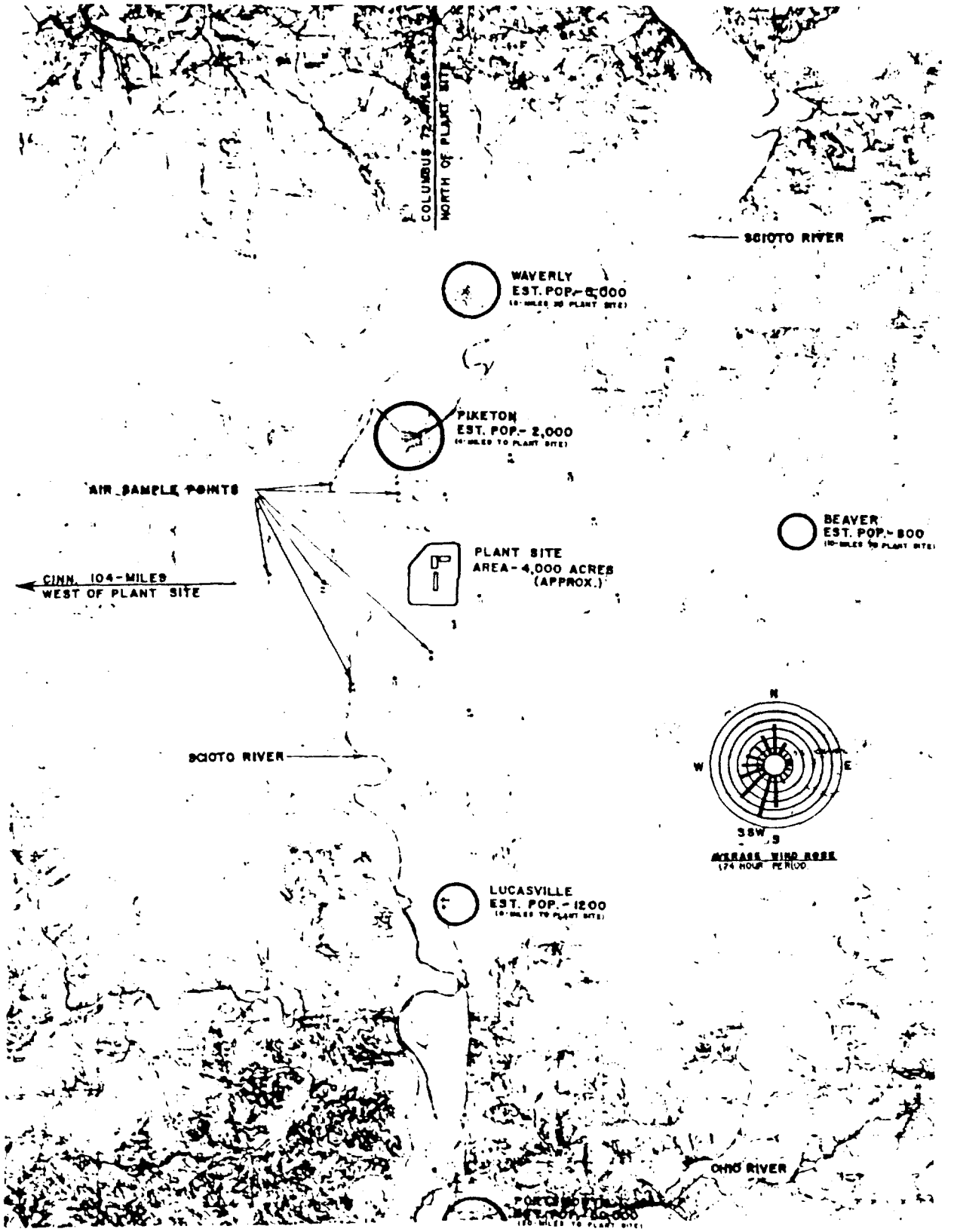


Fig. 1 -- Principal Residential Areas.

"SPECIAL AIR CLEANING AND VENTILATING EQUIPMENT FOR SPECIAL MACHINING OPERATIONS"

Argonne National Laboratory
November 3, 1955
by
M. D. Thaxter, UCRL Berkeley

Machining oralloy shapes for experimental devices or for weapons components poses a number of problems suggesting specialized engineering solutions.

These problems may be listed:

1. Dimensions of the work piece are such as to require a versatile size #2 milling machine.

2. High degrees of precision machining may be required, necessitating fine finish cuts, frequent inspection, good visibility, and expert operators.

3. Toughness of the metal is notorious, necessitating relatively massive, hence expensive, precision tools, amply powered and with abundant lubricant and coolant.

4. Oralloy is not 100% pure U^{235}. Oralloy is of course radioactive. The U^{234} impurity increases its radioactive hazard when inhaled or ingested. Penetrating radiation, both beta and gamma, is such that workmen should limit their close contact to work pieces and to chips to a minimum.

5. Criticality considerations are frequently controlling as to design and operations. The effect of moderators and tampers must be forseen. In fact, the near presence of the operator, due to the hydrogenous constituents of his body, may preclude certain shapes. Subdivision of the work piece, as in chip formation, can change the critcality of the array rapidly. A gross subdivision, as in a fire, followed by collection of the finely divided oxide in water may promptly change a subcritical configuration to above critical.

6. Oralloy idizes easily. This property is enhanced by local temperature increases (as in machining) and is further intimately related to the available surface. At room temperature in air oralloy masses will promptly develop an oxide coating which is self-limiting in depth. Exposure of a new surface is followed by additional oxide formation. This reaction is strongly exothermic. If in machining operations this temperature rise is not controlled rigidly, combustion commences and may proceed very rapidly. Under combustion conditions, uranium metal will remove oxygen from water, carbon dioxide, carbonates, and of course from air. An established uranium fire in air may be practically impossible to put out.

7. Accountability standards established by the AEC for Oralloy requires recovery of all scrap within "reasonable" limits for the operation concerned. This may mean fractions of a gram. At a published $25.00/gram there is also an economic incentive to suffer no appreciable losses in processing. Scrap may not be poisoned by cadmium, boron or other neutron-absorbing contaminants which could hinder reprocessing.

8. As an eighth item, although not a problem peculiar to oralloy machining, the following philosophy enters into the engineering. All radioisotope processing (whether mechanical or chemical) at UCRL is held to the criteria that work rooms shall be contamination free; that special protective suits, respirators, clothing, etc., shall be for emergencies only and that contamination potentials shall be engineered to confine the problem to its locus and not to permit planned or probable dispersal.

Design of the milling machine facility:

The salient features of the mill and its enclosure may best be presented by showing a few slides (Chem 2802 - 45° front view): a #2 mill is modified to include a special table for chucking the work piece. This table is surrounded with a coolant pan to hold a 2" lake for quenching and submerging the bulk of chips. Surrounding all is a five sided enclosure fastened to the table. The front side is lucite with glove ports mounted in a rotary plate and with one access door leading to an

internal crane. The two ends have access doors. (Slide 2800 - front view) (Slide 2801 - back view) The back is a stainless sheet rolling onto vertical shafts under tension. Top, bottom and sides of the sheet are sealed with Teflon wipers. This enclosure can therefore rise and fall, traverse, and proceed front to back with the same scope as the original milling machine. Major controls are external to the enclosure. Coolant is supplied at 4 GPM. An "Ansul" dry chemical system is installed for fire suppression.

The enclosure is deemed to supply a reasonable compromise with the machinists' habits and requirements and those dictated by the "problems" above enumerated. It is the subject of AEC Accident and Fire Prevention information Issue No. 19 October 10, 1955.

Design of the air cleaning facility:

The air cleaning design, as to capacity, is dictated by the area of opened access doors. A 50 FPM velocity was selected for all 3 doors open--a rare possibility. This gave us 300 CFM.

Because of the complexity of operations and sizes of pieces, an early hope to exhaust the cutter area under close capture conditions was abandoned in favor of general enclosure exhaust.

The rigorousness of design to be described is dictated by the worst possible air cleaning eventuality--a massive out-of-control conflgration in the milling enclosure. Such an event would discharge abundant heat and a dense cloud of glowing uranium oxide to the exhaust train. Clouds with these properties have in practice already plugged filters and then burned through or melted down adjacent structures. It was therefore decided to install a "quencher" early in the system. We selected the perforated double-plate inertial separator (sold under the name "Neva-Clog") which, when employed with flooding nozzles delivering distilled water coolant at 10 gpm is estimated to be adequate for quenching and placing into water suspension a very large fraction mass-wise of uranium or uranium oxide so airborne.

The coolant is drained from both upstre and downstream faces of the separator to a cadmium clad trifurcated sump the dimensions of which comply with criticality requirements. A siphon from one element returns the circulating coolant to a neoprene impellor pump and back to the flooding nozzles.

Downstream airwise of the separator is a glass fiber filter pad (PF 105) as an "accountability" collector for that fraction of uranium particulates passing the separator. Downstream of it is a high temperature resistant fibrous pad made of "Fiberfrax" employed as a fire stop.

Downstream of the fire stop filter is an all-glass fiber clean-up filter of 1106 B paper in the familiar CWS pleated pattern.

An exhauster adequate to overcome the various pressure drops encountered discharges to an ordinary sheet metal duct exhausted to outdoors.

Controls include a low level sump alarm, a coolant flow alarm, the usual electrical fusing and panel lights denoting energized motors or the contrary. Manometers indicate pressure drops across the air cleaning elements.

An emergency air flow restriction valve, spring loaded, may be activated by the operator to cut CFM from 300 to 70.

Access ports are provided for viewing, for wash down and recovery as well as for monitoring.

A periodic shut-downs the coolant pump circuit may be tapped via Saunders valves into a porous stainless steel plate acting as support for a filter on which fines can be recovered for accountability weighing.

The assembly just described is a mobile unit (as are most of the UCRL radioisotope processing units, where possible). To accomplish this, many liberties had to be taken with good aerodynamic concepts otherwise the unit would--on a straight line arrangement--have extended to 62 feet long. Actually it is 4'6" x 4'8" x 6'6" high. Slide 441 shows a side elevation featuring the control panel. Slide 442 shows a side elevation featuring the sump and Slide 444 is a top view. It is

anticipated this air cleaning unit will also be employed on other machines such as lathes, drill presses, etc. Although considerable thought and effort has been expended we recognize this is our Mark I model and some changes may be dictated by operating experience. We would like to present some numbers derived from experimental runs, however. In one of these several hundred grams of uranium chips were deliberately ignited into the system (Table I)

It is a pleasure to acknowledge the assistance received from the past three air cleaning seminars and specifically from the Harvard University's School of Public Health Air Cleaning Laboratory. We are also indebted to the N.Y.O.O. Industrial Hygiene Labs under W. Harris for his experience and data on uranium machining. Mr. Jack Murrow, chemist in our group is to be praised for his competent efforts in experimentation and design and for his coordination of the various detailers and technicians.

I particularly wish to express personal satisfaction in working under a Chief, Nels Garden, who invites problem solutions not necessarily rooted in technological antiquity.

TABLE I

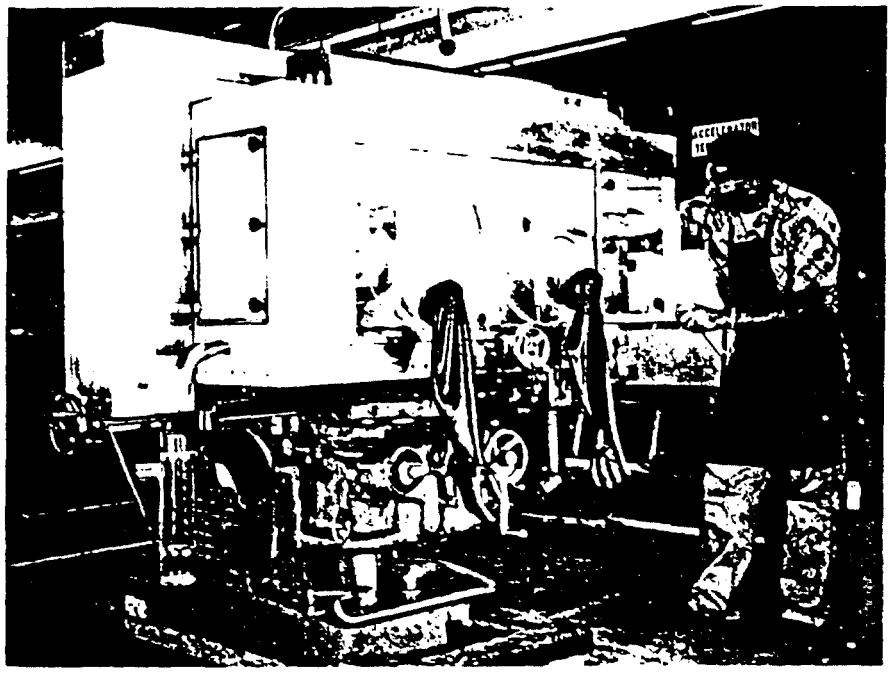
Operating Data

ITEM	Cross Sectional Area ft^2	Velocity Air @340 CFM FPM	Velocity Water	Pressure Drop Inches Water Operating @ 340 CFM	Pressure Drop Inches Water Design @ 300 CFM	Inlet Wet Bulb °F	Inlet Dry Bulb °F	Inlet Rel. Humid. %	Discharge Wet Bulb °F	Discharge Dry Bulb °F	Discharge Rel. Humid. %
Inertial Separator	2.37	145	3.2-5.5 gal/ft^2	5-6	5-6	56	68	48	60	72	50
Recovery Filter	4	85	-	0.9-1.3	2						
Firestop Filter	1	340	-	2.6-3.0	1-1.5						
Clean up Filter	4	85	-	0.7-0.9	0.5						
TOTAL	-	85-2300	7.5-13 gpm	13.6	13.5						

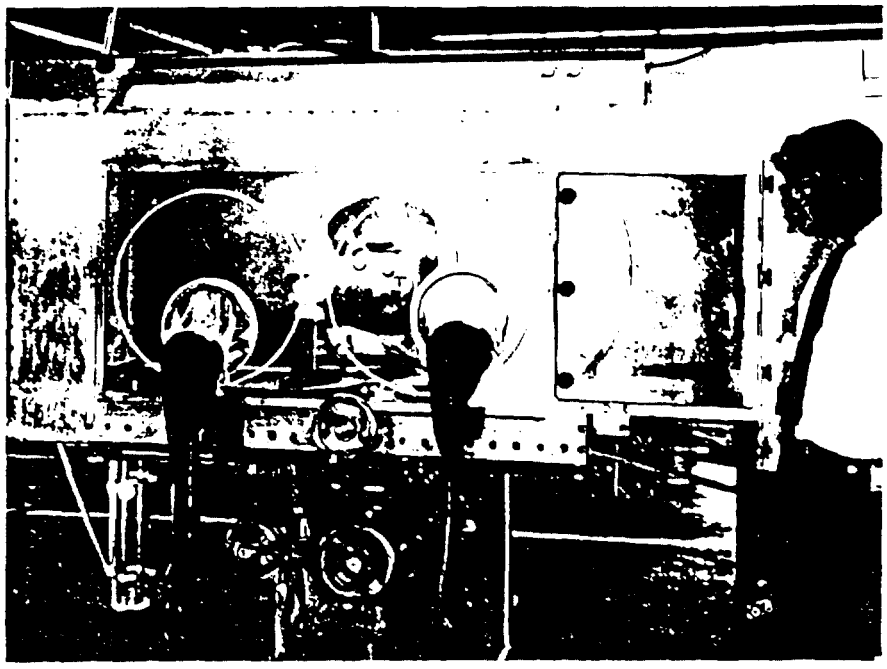
At above typical conditions and at 340 CFM approx. 1/4 gallon of water would be evaporated per hour.

CONSTRUCTION DATA

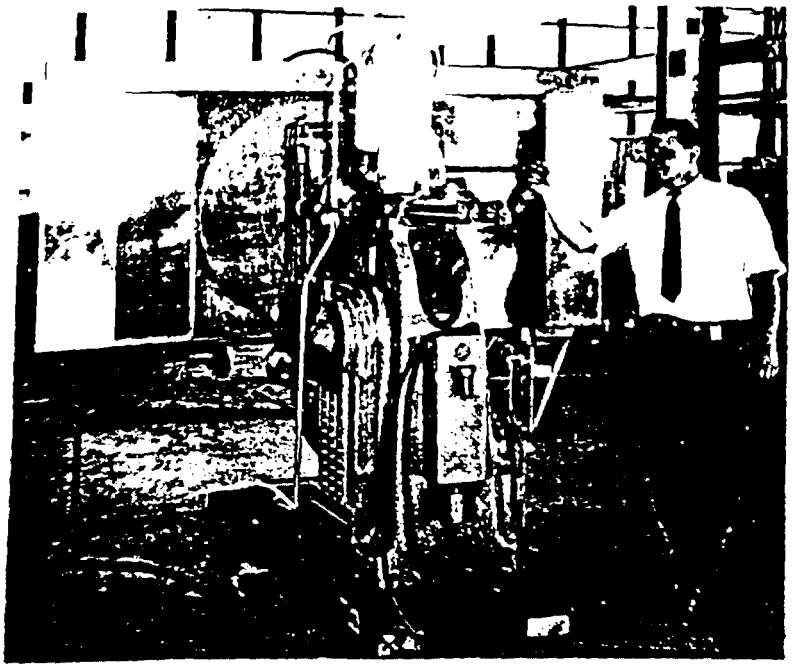
Exhauster	McKee-Eclipse Centrifugal Pressure Blower #1-6515-1½, 3600 RPM - 1½ HP, 440V, 3ø Rated capacity 400 CFM 13.75 inches #20
Pump	Jabsco, 1¼", Model FM, Bronze body, Neoprene impellor, S.S. Shaft, 900 RPM 1 HP Rated capacity 14.1 gpm - 32 psi
Pipe	1¼ copper water tube, type L. Velocity - 3-3.5 fpm
Outside Purchases	$1100.00
Materials	approx. $225.00
Labor	56 man days (designing not included)



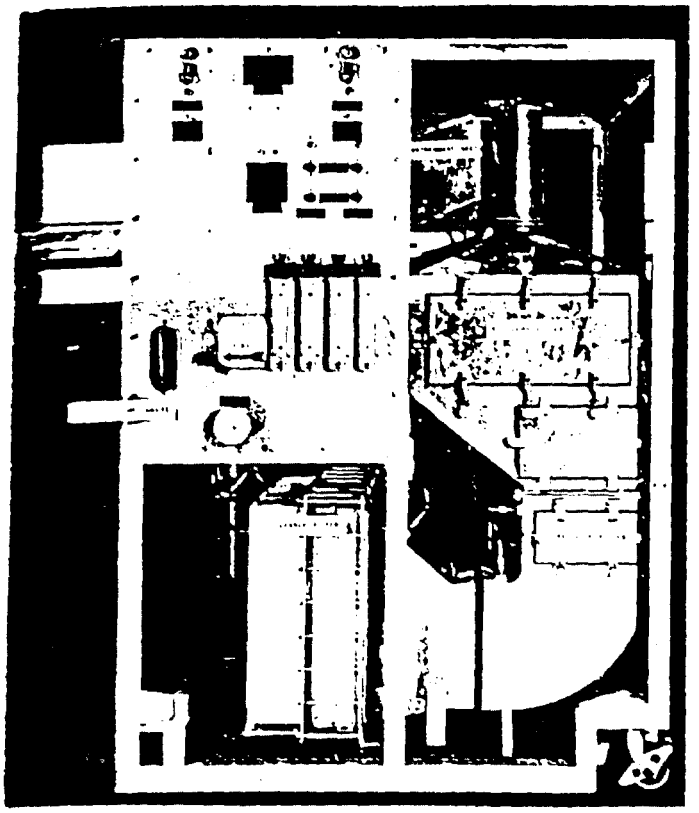
Slide 2802--45° Front View



Slide 2800--Front View



Slide 2801--Back View



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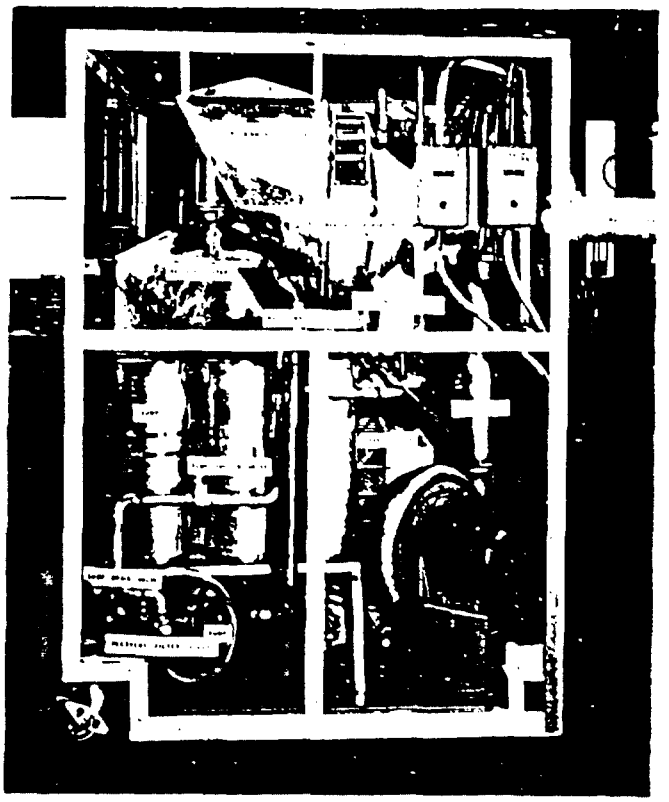

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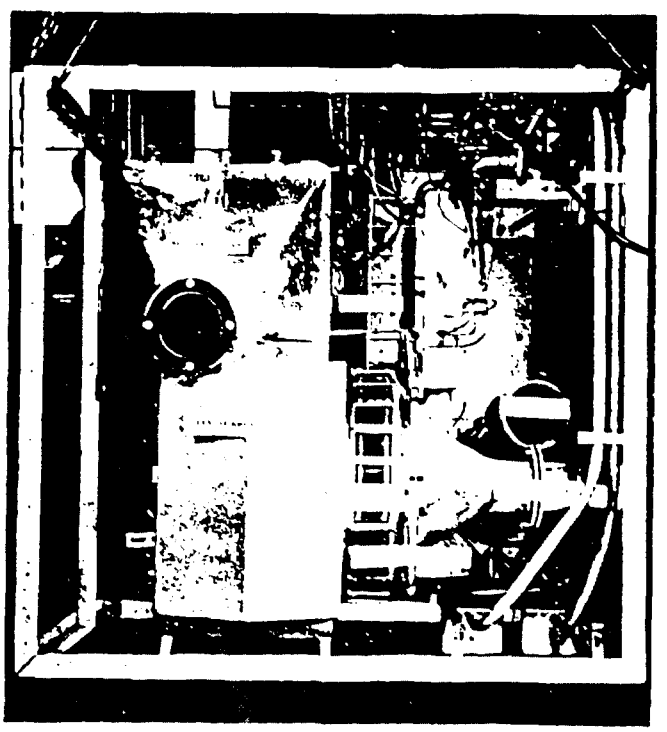

Slide 444

AIR CLEANING AND INERT ATMOSPHERE VENTILATION SYSTEMS FOR FACILITY 350

by

A. B. Shuck

The Argonne National Laboratory Fuel Fabrication Facility will be a plant for development and fabrication of reactor fuel components containing plutonium or uranium-233. It is not, as has been rumored, a refabrication plant for irradiated fuels. The Facility will be housed in a building 245' long by 72' wide. The first floor plan of this building is shown in Figure 1. It is divided ventilation-wise into three areas which, for reference, we have termed the Administration Area, the Technical Area, and the Fabrication Area.

The Administration Area consists of a lobby, offices, counting room and clothing change rooms. This area is considered to have the same likelihood of contamination as any office or street area in the immediate vicinity of a closely controlled radioactive materials laboratory. The area will be air conditioned and ventilated as any uncontaminated area. The Technical Area will contain storage vaults for radioactive materials, a mechanical laboratory used for maintenance or modification of equipment and tooling, x-ray rooms, dark rooms, and a Health Physics Department work and storage room. No direct work upon radioactive materials will be done in this area and contamination

will be the result of a handling accident or of tracking contaminated material from the Fabrication Area.

The Technical Area is isolated from the Fabrication Area, from the Administration Area, and from a Shipping and Receiving dock area by means of air locks with interlocked doors. The Fabrication Area will be used for all work performed directly upon radioactive materials or upon clad fuel elements containing radioactive materials and, while every effort will be made to keep all personnel areas free of contamination, the contamination risk will be greatest in the Fabrication Area. Air will be supplied to each of the areas by means of separate air conditioning systems. A multizoned air conditioning system will be used for the Administration Area and zoned air conditioning systems will be used for the Technical Area and for the Fabrication Area. Replaceable medium type roughing and secondard filters will be used on all air supplied to the Technical Area and to the Fabrication Area. The roughing filters will consist of 32 24" x 24" x 9" filters in V-arrangement. Each roughing filter will be American Air Filter Company 5 ply type F Air Matte fireproof medium. The secondary filters, 32 in number, and 24" x 24" x 9", will be American Air Filter Company 10 ply type Air Matte filter medium. Similar filters will be installed for ventilation of the fan room. The air will be dehumidified by cooling and then reheated. A maximum absolute humidity equal to 50% relative humidity at 80°F has been established.

The transmission of air borne contamination between areas will be controlled by the usual methods of ventilation and pressure control. The

Technical Area will be established as a reference zone against which the pressure of the Fabrication Area and the Administration Area will be controlled. The pressure of the Technical Area will be maintained at approximately 0.05" w.g. below the ambient barometric pressure. This will be established as a dynamic pressure-air flow relationship by throttling the air supply to a flow slightly less than that of the exhaust air. The area has no openings to the outside or to the other areas except through the air locks. The regulation of the air flow to produce the desired pressure will necessarily be a field adjustment since at this time there is no way of accurately determining the leakage rate of the zone. It is felt that this method will establish a more uniform pressure than if referenced to the wind sensitive outside air pressure.

The pressure in the Administration Area will be controlled by modulation of the vortex damper on the exhaust fan against the pressure of the Technical Area by means of a differential pressure regulator set at +0.05" referenced to the Technical Area. The pressure in the Fabrication Area will be controlled at -0.075" w.g. referenced to the pressure of the Technical Area by means of the differential pressure regulator modulating a vortex damper on the room air exhaust system.

The Fabrication Area will contain equipment for alloying, melting, casting, rolling of shapes, plate and foil, wire fabrication, pressing, extruding, heat treating, and surface treating of plutonium alloys. This equipment will be housed in the system of interconnecting, gas tight, hood lines. Each hood line will be connected to a back-bone hooded conveyor by means of a pneumatically operated sealing door. Access to and egress

from the system will be by means of an especially designed hood line with provision for air lock insertion of uncontaminated material and for sealing contaminated material in plastic pouches for extraction from the hood system. Additional equipment will be provided for canning, welding, and bonding of the radioactive metals into the nonradioactive jacketing materials, for machining, welding, brazing, and shearing of the clad fuel elements and for fabrication of finished fuel assemblies. The operations upon the clad fuels will be carried out in individually hooded equipment which will be separated from the contaminated hood system. The layout of the hoods in the Fabrication Area is shown in Figure 2.

Since the equipment housed is larger than that ordinarily hooded, various methods of protecting the operating personnel from exposure to the alpha radioactive materials were considered in the preliminary studies for the Fuel Fabrication Facility. The glove box approach to the problem was decided upon mainly because there is more background of experience with this method at ANL and at other installations from which to draw and because it appeared to offer the maximum of process flexibility while affording satisfactory protection to the working personnel.

The heavy equipment in the Fuel Fabrication Facility requires large sturdy enclosures. Accordingly, a flexible, modular enclosure system was developed using aluminum extrusions for a rigid frame with heavy transparent plastic or aluminum panel inserts in place of the usual light sheet metal construction. A prototype of this enclosure is shown in Figure 3. All of the enclosures were designed with gloves on both sides and enclosed a space

width of 48". The frames were fabricated from the five aluminum extrusions shown in Figure 4. The extrusions incorporated gasket grooves, window recesses, bolting flanges, and ventilation passages in the as-extruded shapes. Details of the hood construction will be available in a forthcoming ANL report.

The ventilation of the Fuel Fabrication Facility consists of the following systems: Two-once through systems for ventilating (1) the alpha radioactive hood lines and (2) the clad hood lines. Two emergency stand-by or purge systems for ventilating (1) the alpha radioactive hood lines and (2) the clad work hood lines. A once through filtered air system to exhaust the room air and ventilating the equipment housed in the enclosures below the primary hood system.

The hoods in which the unclad radioactive materials are worked will be operated at a negative pressure of between 0.6" and 0.8" w.g. whether operated on air or inert gas atmosphere. When the hoods are to be air ventilated, the pressure will be controlled by drawing a maximum of 120 cubic feet of room air through two 12" x 12" x 6" AEC fireproof medium filters at the outer end of each hood line. Outlet and inlet dampers will be manually adjusted to produce the required pressure. The filtered air will be distributed through hollow cavities in the lower longitudinal extrusions and will be introduced to the hood modules through slots with adjustable cover plates to regulate the amount of air to each module. The air will ventilate the hood and will be withdrawn through similar slots in the upper longitudinal extrusions and then will be carried through the extrusions and piped to the outlet filter housing located just above the conveyor hood. Updraft ventilation is used to facili-

tate heat removal. Both the inlet and the outlet filters will be changed into the hood system. After filtration through a 12" x 12" x 6" high efficiency fireproof filter, the air will pass a rubber lined butterfly control valve. This valve will serve the dual function of providing positive shut-off of the air system when the hoods are operated on inert gas and as a balancing damper for air operation. The air will then pass through a short run of pipe to the main exhaust ventilation header which will be maintained to the static pressure of approximately -2.0" w.g. It will then pass through a bank of final AEC high efficiency fireproof filters in the fan loft, through a vortex damper controlled exhauster and will be discharged to a common discharge header connected to a 100' stack outside of the building.

Safe operation and filter changing required complete stand-by equipment and it was determined early in the design studies to extend the stand-by equipment into a true emergency system capable of taking care of accidental or deliberate break in the main hood barrier. This system will consist of a purge blower which will operate continuously at essentially no flow. A prefilter and final filter system installed in the fan loft will be capable of handling up to 3000 cubic feet of gas. The purge ventilation system at the hood will consist of a gas tight, rubber lined, 10" butterfly valve operated by a pilot-positioned damper motor and controlled by means of a pneumatically operated static pressure regulator with one control tip within the hood and a reference tip within the room. The controller will be set to maintain approximately 400' per minute face velocity across an opening into the hoods but, when the hoods are operating at - .6" to - .8" w.g., to close the valve fully and to seal. Four hundred feet per minute velocity will be maintained

through an opening of less than seven square feet. The removal of the window will open an area of approximately 10 square feet and will reduce the velocity to 300 feet per minute. If two windows are removed from any hood line or from two hood lines, the velocity will be reduced to approximately 150 feet per minute which is considered the minimum to prevent the outward diffusion of contaminated particles. Separate purge systems will be provided for the alpha radioactive materials hood systems and for the clad work hood system. Both systems will be similar in function. Final filtration will be through two banks of four 24" x 24" x 12" AEC fireproof medium filters in series. The first filters of each series will be changed by the plastic pouch technique.

The room ventilation will be a once through system. The excess building ventilation not required for ventilation of the primary glove boxes will be carried through paneled spaces below the hoods to cool and ventilate the contamination risk equipment housed within these spaces. A slight negative pressure will be maintained in the spaces by the introduction of air to the enclosures through special glass wool filters. The air leaving the spaces will be prefiltered through similar glass wool filters before exhausting to the general building exhaust system. The final filters of the general building exhaust system will be of the AEC high efficiency type. Thus, it will be seen that all air leaving the primary hood systems will be twice filtered through AEC high efficiency fireproof filters but the general room exhaust air will be prefiltered and then finally filtered through AEC standard high efficiency filters.

The Inert Atmosphere System

Originally it was thought that a straight system of air ventilation of the primary hoods for Facility 350 with local helium or argon supplied to small chip collectors or work enclosures would be sufficient to prevent burning and oxidation of the plutonium alloys. Subsequently, it developed that many of the alloys under consideration were spontaneously pyrophoric and, for this reason, these alloys cannot be fabricated in the other AEC facilities. It became necessary to expand the inert atmosphere system and to investigate various possibilities for producing an economically operated inert ventilation system serving entire hoods and hood lines. (This problem has already been solved on a smaller scale in the Plutonium Physical Metallurgy Laboratory at ANL.)

Several gases were suggested for use as a protective atmosphere, including nitrogen, CO_2, synthetic hydrocarbon atmospheres, hydrogen, argon and helium. Of these, only argon and helium were found to be of use. Argon gas has the advantage of being of the same order of density as air and thus can be handled by fans and blowers designed for air, but purification of argon is somewhat of a problem. Regenerative adsorptive systems do not work well with argon since argon is adsorbed nearly as readily as oxygen and nitrogen. Chemical purification methods may be applied but have the disadvantage of involving the handling and disposal of large quantities of reactive alkali or alkaline earth metals which almost certainly will become radioactively contaminated and which by the nature of the process, form high melting temperature sludges which tend to clog the purification system. The operation of an argon liquifying and rectifying system was suggested to obtain high purity argon and to eliminate other gases but this appeared to be a costly expedient.

Helium gas has certain disadvantages. Its low density makes it difficult to circulate by means of fans or centrifugal blowers. Its high diffusivity makes it somewhat more difficult to contain than the heavier gases. The high ratio of constant pressure to constant volume heat capacity ($k = 1.66$ for helium as compared to $k = 1.4$ for diatomic gases) causes the temperature to increase much more in compression than does that of the other gases. The negative Joule-Thompson coefficient causes the helium to heat slightly upon free expansion through an orifice or expansion valve. The principal advantage of the use of helium is that regenerative adsorption methods of purifying it produce good yields and high cleanup factors. This final factor influenced our decision to use helium.

The present plans call for the use of a recirculating helium atmosphere which can be used interchangeably with the once through air ventilation in the various hood lines connected to the conveyorized alpha radioactive hood system and in the welding and liquid metals hood lines. The helium will be recirculating by means of seven stage turbocompressors with an aftercooler after each compressor. These compressors will be piped and valved so that they can be used independently, in parallel, or in series.

The helium gas will be purified by adsorption of the moisture on activated drying agents (silica gel and activated alumina). The gases such as oxygen and nitrogen will be absorbed on activated carbon at normal refrigeration temperatures, -20°F to -40°F, and at a pressure of approximately 165 psia. The peculiar thermodynamic properties of helium will be used to assist the operation of the system. Hot gas will be piped directly

from the compressor to regenerate the drying towers. By expanding the compressed helium from 165 psia to the normal operating pressure through turbines, the gas may be used as its own refrigerant and passed through a series of countercurrent heat exchangers between the activated carbon adsorption towers to reduce the temperature below that which can be obtained with a freon refrigerant system. Regeneration of the activated carbon will be accomplished by evacuation without change in temperature.

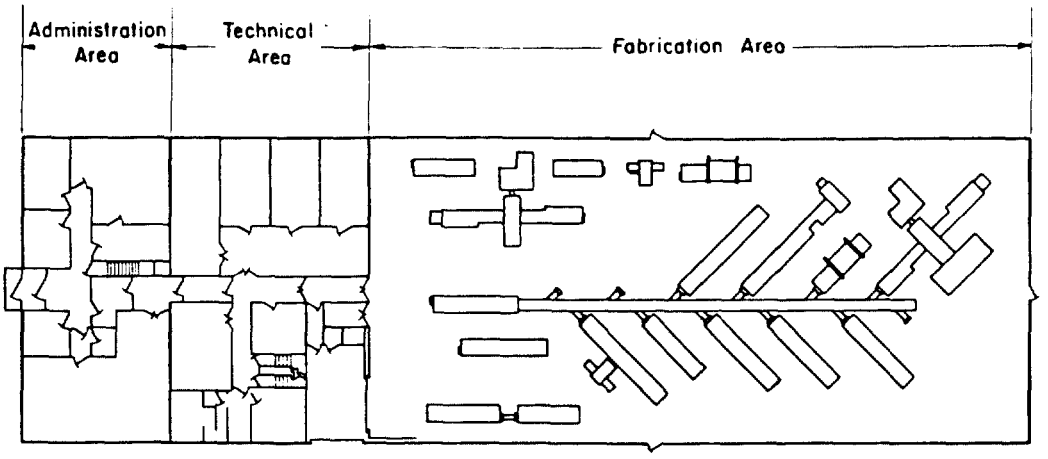

FIGURE 1
BUILDING 350
FIRST FLOOR PLAN

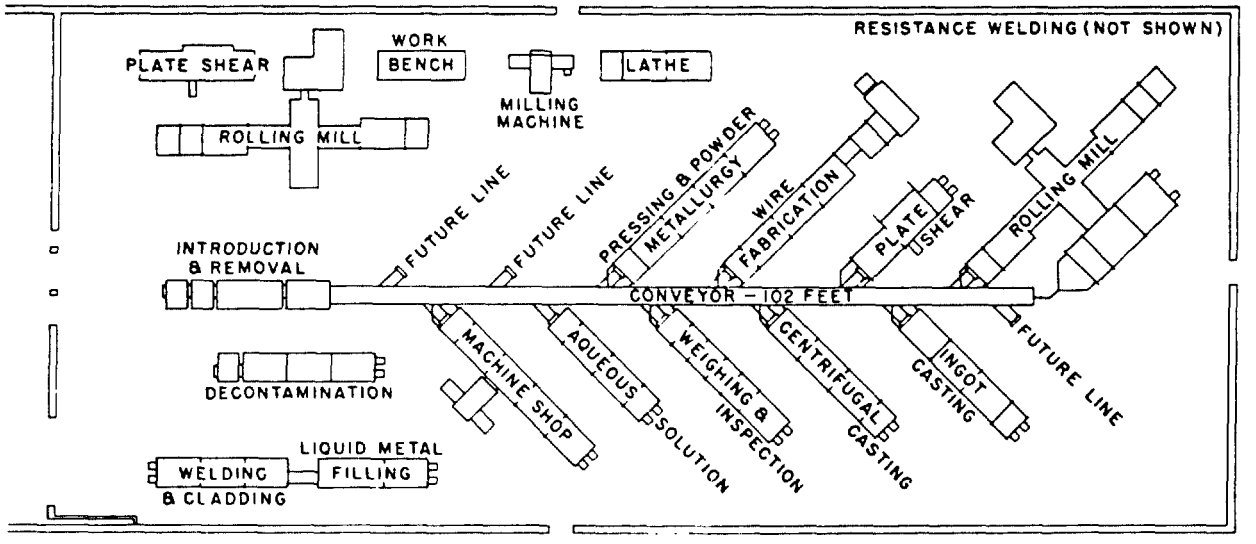

Fig. 2

FUEL FABRICATION FACILITY EQUIPMENT AND HOOD LAYOUT

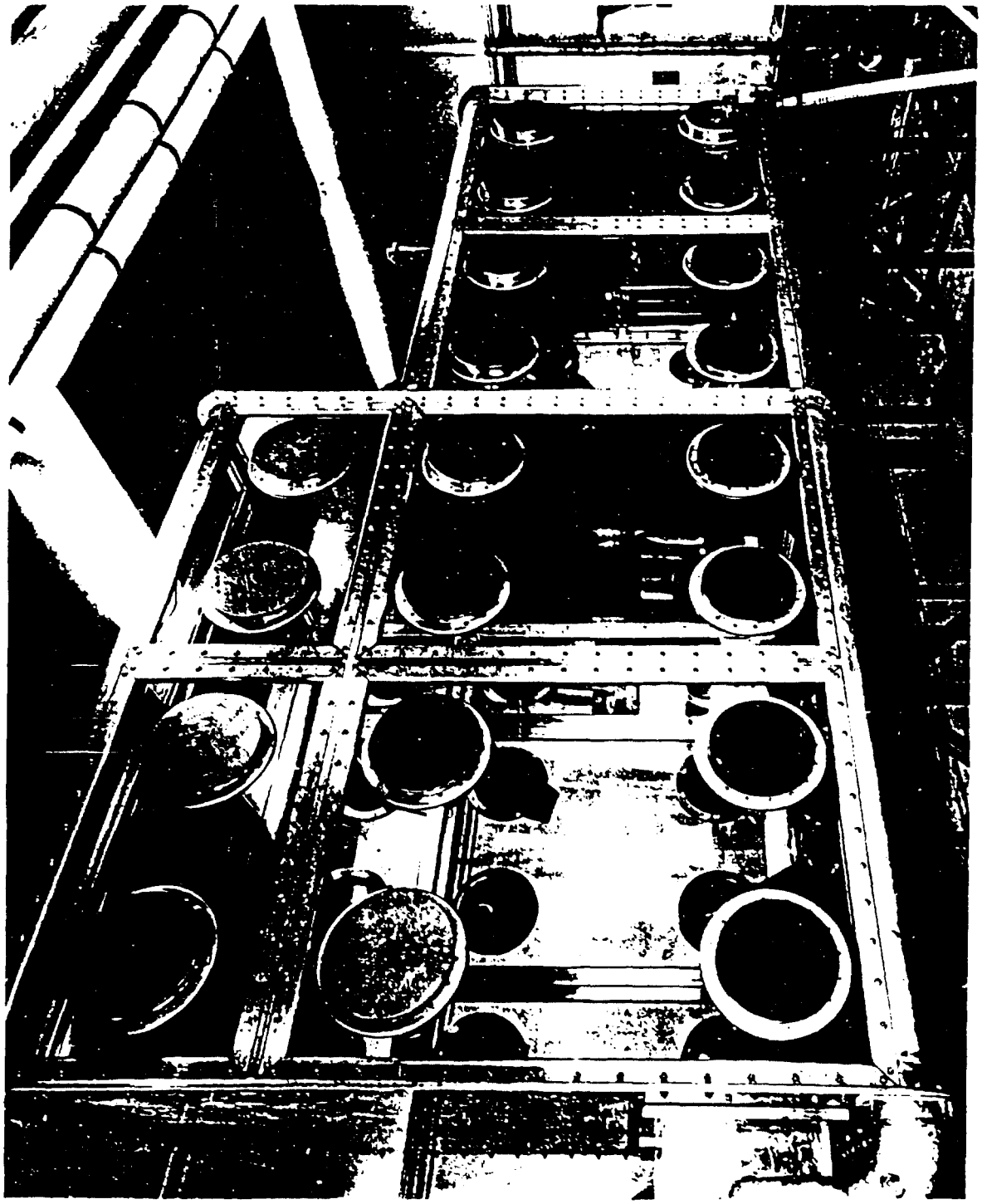

FIG. 3 - PROTOTYPE OF HOOD CONSTRUCTION FACILITY 350

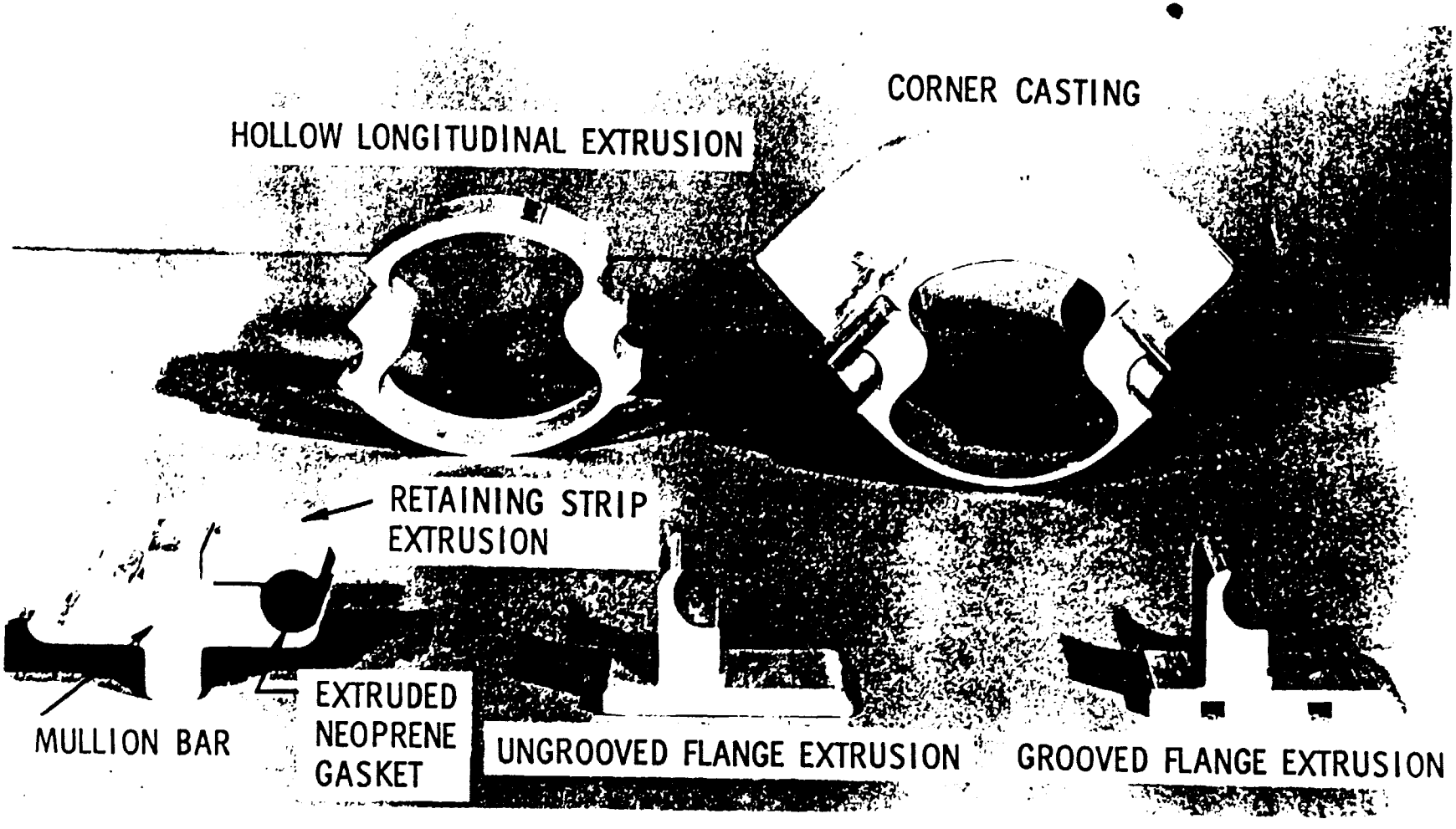

Fig. 4

SECTIONS OF ALUMINUM EXTRUSIONS AND CASTING USED FOR CONSTRUCTION OF THE HOOD FRAMES

DO NOT DESTROY

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TID-7513(Pt. 3)

Subject Category: RADIOACTIVE WASTE

UNITED STATES ATOMIC ENERGY COMMISSION

FOURTH ATOMIC ENERGY COMMISSION AIR CLEANING CONFERENCE HELD AT ARGONNE NATIONAL LABORATORY, NOVEMBER 1955

June 1956
[TIE Issuance Date]

Division of Reactor Development
Washington, D. C.

Technical Information Extension, Oak Ridge, Tennessee

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AEC, Oak Ridge, Tenn.

was released from the burning cellulose material (not necessarily filter media, but with similar burning characteristics) prevented continuation of the project and rendered the all-metal building unusable ever since. Fortunately the project was almost complete so project time and dollar loss was low but the building still stands abandoned as a stark reminder of a serious problem. There are too many vital production, research and development facilities within the AEC program where filter fires could cause similar disasters on a much larger and more serious scale.

II. CONVENTIONAL FIRE PROTECTION STANDARDS FOR VENTILATION SYSTEMS

Before we pursue recent filter fires at AEC installations, I would like to review briefly some of the conventional fire protection standards for ventilation and air conditioning systems. The code adopted for the AEC that incorporates reasonable provisions based on minimum requirements for safety to life and property from fire is the National Fire Protection Association Code No. 90A "Standards for the Installation of Air Conditioning and Ventilation Systems of Other than Residence Type." The standards were revised and approved last May and the 1955 edition was published July 30th. Most of you are quite familiar with this code and use it regularly. This code like all of the other National Fire Codes are henceforth being revised and published annually, and I urge you to keep up-to-date by getting the latest edition around August each year.

These standards apply to the air-duct systems employing mechanical means for the movement of air and used for heating, ventilating, and air conditioning including filtration. Important consideration is given smoke removal systems, particularly in windowless structures where panic hazards are likely. Although personnel loads are usually light the panic problem is applicable to some of our AEC buildings. The construction of duct systems is of prime consideration in the code and one of serious importance to older AEC installations where combustible ducts and plenums are in use, or where non-combustible, easily shattered, materials are laid over combustible frames and supports. Fires are occurring in such duct work at AEC plants.

I would like to quote Paragraph 115 of the NFPA Ventilation standards: "Work involving the use of torches shall not be undertaken on ducts until the system has been shut down, the duct cleared, and all combustible lining and covering material has been removed from the portion of the duct being repaired."

Failure to comply with Paragraph 115 is the prime cause of most fires in ventilation systems at AEC plants and in private industry. A typical disasterous fire in the duct work and ventilation system started by a welder's spark, occurred in Rochester, New York, in a high-value film warehouse of the Eastman Kodak Works. Before extinguishment was accomplished a $3,000,000 fire loss had been incurred and the entire plant was virtually closed down. See the NFPA Quarterly of January 1952 for details. Code 90A emphasizes the need for inspection and clean-out openings.

These are particularly needed on each side of fire damper installations. The requirements for installation of ducts is quite clearly stated. Section 130 "Automatic Fire Doors and Dampers" is a vital guide for the design of a system that will not convey fire through fire walls and fire partitions. This section is frequently ignored or lightly treated in even new design work that is being reviewed. A solid 12-inch fire division wall is only as good as the poorest cutoff in the duct work that pierce it. A cardinal guide, at least from the fire protection view-point, should be to never pierce a fire wall with duct work if it can possibly be avoided.

The sections on fans and controls are of serious consideration, particularly the tying in of controls to fire alarm systems so prompt shutdowns can be made where conditions warrant it. Compliance with the "National Electric Code" and required clearances of heating equipment is understandably included. The section on Smoke Detectors is informative, but these devices as well as sprinkler systems are generally lacking from most AEC installations. The recommended

FIRE CONSIDERATIONS IN FILTER DESIGN

By Don J. Keigher

Fire Protection Engineer
Hanford Operations Office

Since my first walk across the roof of the old "Site B" on the University of Chicago campus, the fire hazards of filters and filter systems have been of personal concern and interest. The sight of an 8- × 8- × 8-foot light frame and tar-paper roof house covering a bank of wood and paper filters, sitting on the roof of an old brewery building, surrounded by higher apartment buildings and residences, was a shock to a fire protection engineer still very new to the fire problems of the atomic age. The primary purpose of that installation was a very efficient air-cleaning performance—which they were getting. The fire hazards of the set-up were known and accepted as a necessary "calculated risk" in getting the job done.

A "calculated risk" is a term used by management, that fire protection engineers must often accept for financial or other quite valid reasons. Our concern is whether the true fire risk, with all its ramifications, is known, and if the risk can be reduced by the application of good fire protection engineering principles. This is a dual problem for the fire protection engineers at atomic energy facilities where elaborate ventilation and air supply systems are needed and where so many combustible filters are in use. We feel that we must emphasize the importance of the fire considerations in filters and filter designs, and we must assist in the search for better methods or media to reduce this fire problem.

In looking back it is amazing how few fires developed in the filter banks, large and small, of the old asbestos-cellulose units, that were and still are in use at most of the major AEC installations. Not a single major fire occurred in filters or resulted from filter fires during Manhattan Engineering District days nor in the early history of AEC. Some minor fires that were potentially serious did occur in those early years to point up the concern of fire and safety personnel. In the fire and safety field it is easy to sell improvements after disasters, but we prefer doing it before, as we are attempting to do in the filter field.

I. COMBUSTIBLE FILTERS POSE PROBLEM

Those early high efficiency filters, originally developed by the Chemical Warfare Service, were deliberately designed to be combustible so they could be readily reduced by burning so as to recover any contamination contained therein. A need for such a filter still exists. I'm sure, it can be lived with if precautionary measures are taken. As fire protection engineers always do, we are forever advocating the elimination of burnable materials, so we're strongly recommending that most of these combustible units be replaced with equally efficient filters that can withstand high temperatures and not contribute to the fire itself. Of grave concern is the possible release of the contained radio-active material from these burning filters; the results from such a release can be devastating. The P-11 fire that occurred at Hanford in 1950 is an example of what can result from the release of contamination from a fire. The contamination that

maintenance procedure is an excellent appendix to the code.

I don't think the standards emphasize enough the need for accessability to ventilation systems. This is the prime problem in most fire fighting situations. When firemen cannot get at the seat of a fire, vast amounts of accumulated heat and smoke is given off, causing excessive fire and smoke damages and in turn force the fire fighters out of congested basements and crowded machinery spaces. When radioactive materials are airborne in such duct work the fire control problem becomes nigh impossible.

Another consideration of conventional standards that is of concern in the "hot" atmosphere, is the filter media used in intake air cleaning equipment. Because of the possible exposure from outside fire sources, particularly leaves, tumble weed, alley rubbish, etc., from our experience we recommend that flame treated or non-combustible filters be used at least in the first bank of intake filters. Burnable and burning materials are easily sucked into many such installations, but they can be readily stopped if treated media is used.

Also to be considered are the many large banks of combustible filters whether these be intake filters or the absolute filters in the exhaust systems. Frequently these banks contain literally millions of B.T.U.'s of heat potential. Based on the average figure of 7500 BTU per pound of paper, a bank of 100 or 120 24- × 24- × 11½-inch CWS-Type 6 filter units, such as we have at Hanford, represents roughly 25,000,000 of BTU of potential heat. The effect of such a heat release at the unprotected steel supports and structural members of an all-metal building would literally collapse most of the building in a matter of minutes.

III. RECENT FILTER FIRES IN AEC

Recent fires in filters and small filter banks at AEC installations have borne out the concern safety and fire personnel have always had for these highly combustible installations. Known fires have been reported here at Argonne, at Idaho Falls, at Hanford, and at Oak Ridge. I suspect there have been others. Two resulted from small particles of hot carbon residue, the costliest was started by a welding spark, one indirectly from a fire caused by spontaneous ignition, and the fifth from spontaneous ignition through nitric acid fume action. All were in the asbestos-cellulose CWS Type 6, or improved AEC 1 type. Although these filters consist of fine asbestos fibers mixed with coarser cellulose fibers to give mechanical strength and act as a support for the asbestos, according to "AEC's Handbook on Air Cleaning," the asbestos offers little fire retardant qualities to the filter.

Argonne Incidents

The first incident I would like to cite occurred here at Argonne on February 19, 1953, in the fan loft of the 310 Building. The radio-active waste incinerator was in use when the operator noticed a pressure drop across the filter in the uptakes. Almost simultaneously smoke was noticed coming from the outside stack. The fire department was called while building personnel investigated the apparent fire. They found the single unit filter in the incinerator uptake burning briskly and proceeded to remove it from the housing. Two 15-pound carbon dioxide fire extinguishers did not completely extinguish the fire. Water pump cans were used by the firemen to completely extinguish the burning filter.

On investigation it was found that the three small electric after heaters located in the duct above the scrubbers glowed red hot when in normal use. It was found in test that small carbon particles in the stack gases could pass through the scrubbers, accumulate in the duct and occasionally pieces would peel off and become heated on the red hot heater elements. These heated particles would occasionally reach the filter face and with the proper size, air velocity, and heat, the filter had ignited.

An almost identical fire of unknown cause had occurred in the same uptake and filter a year previous—February 27, 1952. At that time the incinerator was not in use but the heaters had

been on while some control adjustments were being made. From the '53 incident the cause was verified. A non-combustible filter was recommended after both fires. Loss from each of these fires was only about $150, but the potential was serious.

Serious Oak Ridge Incident

In the incident at the Oak Ridge Y-12 plant a $17,500 fire loss and a serious production interruption resulted. The fire, or series of fires, was in the C and A air conditioning systems of Building 9204-2 and harrassed plant personnel and Oak Ridge firemen from April 19 through 21 of this year. Following the extinguishment of the initial fire, which had been caused by a spark from a welding job dropping into the plenum chamber on to a filter, re-ignition occurred on each of the two following days. About 500 pounds of CO_2 were used to control the first fire while filters were removed from the building. Water could not and was not used at any time during the fire because of the likely reactivity of the entrapped chemical dust. Eight filters damaged in the fire were replaced, the plenum cleared and the unit returned to use after a 5½-hour delay. But the fire was not over.

The magnitude of each of these banks should be understood. Each of the plenum chambers involved in this fire is approximately 70 feet long, 10 feet wide and 18 feet high, and contains 70 standard filter units stacked in banks 7 units high. This is a package of around 20,000,000 BTU's waiting to be released in an essentially frame building.

After 15 hours of normal operation smoke was again noticed coming from the plenum. Warm and very hot areas were found in the joints of the duct-work lining which was built of layers of combustible fiber board sandwiched between sheets of transite. All joints showing evidence of fire were cut out and after a 13-hour production delay the system was restored to use.

Within 12 hours more fire was noticed and inspection revealed that the filters were again on fire. Despite the use of portable CO_2 extinguishers to retard the fire as previously, the intense heat made a hit-and-run method of attack necessary during attempts to remove and isolate the burning filters. Since this work was slow, difficult, and hazardous the decision was made to apply CO_2 in massive attack. Approximately a ton of CO_2 from a large liquid CO_2 truck was applied and knocked out the fire. Many of the burning filters were finally extinguished outside the building with water.

During the series of fires about 5000 pounds of CO_2 were used in all from the portable extinguishers and the Cardox truck. About 115 hours of production time was involved, along with the $17,500 damages, indirect losses and general upset.

P-11 Hanford Fire

The aforementioned P-11 fire at Hanford also involved filters. The hot gases and heat from the paper-boxed materials was being exhausted through the absolute CWS-type hood filters. Naturally the filters caught fire. Considerable difficulty was experienced in the fire in the hood filters. It was necessary under difficult working conditions to break open the filter units to put out the flames and prevent further spread of radioactive material to the atmosphere. This was the first experience of the Hanford fire personnel with the stubborn difficult filter fire extinguishing job.

Idaho Falls C.P.P. Filter Fire

The fifth incident that illustrates another aspect of filter fires occurred at the Phillips Petroleum plant, National Reactor Test Station, Idaho, on the day following the Oak Ridge fire—April 22, 1955. The fire took place in a case of four filters in the blower room of the CPP-602 Building. These filters filtered exhaust air from laboratory hoods on the floor below. Water was necessary to bring the blazing bank under control. Total loss was about $800 for the four

filters, the blackened filter case, blower case, and stack.

Investigation indicated that the fire could only have originated in the filters themselves, since no other source of ignition was available and inspection of the duct work showed that the fire had not travelled from the hoods to the filters. Release of nitric acid fumes from the hoods apparently was sufficient to cause deep nitration of the cellulose filter media kicking off a hot fire.

Detailed information on any one of these fires may be obtained through the Safety and Fire Protection Branch, Washington Office, USAEC.

In the case of this and the other fires mentioned, with the exception of P-11, very little radio-active material was contained in the filters that burned. Adequate precautions including assault masks, with radiation monitoring, etc., were taken by laboratory, brigade and fire department personnel in all of these instances. Fortunately, personnel were always around to detect and report these incidents promptly. In none of these instances were standard automatic detection or sprinkler protection provided. Obviously such fortuitous circumstances cannot always be expected when filter fires occur.

The potential seriousness of these filter fires, and others unreported, cannot be over emphasized. We mentioned earlier that filter fires can result in two serious effects—damage-wise and production-wise. The first and the more serious is the release of highly radio-active materials into vital buildings or areas around them. That radio-active material is a serious hazard to all personnel working in or around that building, particularly the fire fighters. Sometimes the released material is not particularly radio-active but it is highly toxic, as are some of the materials we deal with at Hanford. In any case the facility is untenable temporarily and only after costly decontamination and delay can it be returned to use—or if not econonically feasible, as in the case of Hanford's P-11 Building, abandoned.

The second serious effect from a filter fire is the release of tremendous heat energy in confined spaces. Combustion is rapid because of the nature of the cellulose-asbestos filter media—the wood frame is a lesser fuel contributor—and the velocity of the air moving through the units. Most of the buildings at AEC facilities where the most filtration is necessary are usually large all-metal or light noncombustible structures, with many of the older ones frame or partially frame. In either case, if not quickly controlled, sufficient heat to weaken and collapse the unprotected steel structural members or ignite the frame is available. Often in these very buildings fire fighting forces have limited access and delayed attack because of security requirements and complex construction and layout. Generally fire divisions in these buildings are inadequate. Total fire losses can be expected in such buildings, even when there is very little to burn. No building has yet been built that can sustain a fire and not suffer loss from it. If the combustible material is not originally available, someone will at some time or another drag in enough to make it possible.

We have never had a serious filter fire at Hanford although some of the conditions I've mentioned do prevail there, but a series of test fires in filters convinced all who witnessed them that they can be serious and are nasty to deal with.

IV. FILTER FIRE TESTS

As an outgrowth of the P-11 fire a study, involving many members of the General Electric and AEC staffs at Hanford, was made into the filter field. The committee investigating that fire among other recommendations included—and I quote—"d. A study should be undertaken to provide non-flammable filter elements for application where conditions of high levels of radioactivity or toxicity exist."

An indirect result of this recommendation were the filter fire tests conducted at Hanford in April 1953. Previous to these tests a series of studies were made by General Electric personnel on the means of protecting the thousands of combustible filter units already in use.

Numerous possibilities were considered but the ultimate conclusion was that the proper solution to the problem would be the installation of non-combustible type filter elements.

These studies spurred the filter fire tests of the CWS Type-6 units as a "yardstick" for estimating the probable fire that could result, and size and type extinguishing agent needed to put it out. The purpose of the tests was to check the advisability of continued use of CWS Type 6 filters in the 234-5 Building. (See Fig. 1.)

A scaled-down model ventilation system was constructed in a large quonset hut, consisting of 30 feet of 18-inch round pipe going into a plenum chamber 54- × 54-inch in which four standard size 24- × 24- × 11½-inch CWS filters were installed in a framework of the same type construction as exists in the actual filter rooms. The plenum was then reduced down to an exhaust fan which exhausted to the outside. (See Fig. 2.)

All air flows were established to correspond to actual conditions in the 234-5 Building exhaust systems. The air velocity through the 18-inch round duct to the plenum was regulated at 950 fpm and through the filters at 100 fpm. Thermocouples were installed to blanket the test filters.

A total of ten tests were run using varying ignition sources and situations. In Tests 1, 2, and 3, pieces of Kleenex, paper towels, and a handful of lint were lighted and thrown into the air stream 30 feet from the filters. All these materials were virtually burned out before reaching the plenum chamber or dropped harmlessly to the plenum floor with the drop in air velocity. It should be mentioned that the filters were placed vertically in the plenum and the air movement was horizontal.

In Test 4 a small metal tray was loaded with paper tissues, towels, and excelsior and ignited. A hot fire developed throwing off showers of sparks. Most of the sparks were out before reaching the filters; the few that did, appeared to strike the perforated aluminum face plate and go out.

In Test 5 a large wad of excelsior was thrown into the air stream and results similar to Test 4 observed. A lighted cigarette was thrown into the stream, with negative results.

Test 6 was more drastic for the same amount of excelsior was introduced 15 feet or half the distance from the plenum. Sparks appeared to shower the filter face plate for a few seconds but ignition did not take place.

Test 7 was the most drastic of all (see Fig. 3) and very nearly destroyed the test equipment prematurely. A full pad of excelsior was stuffed in the end of the intake duct 30 feet from the plenum. It was ignited and allowed to pre-burn for about 3 minutes before the blower was started. The excelsior burned fiercely, creating a mass of flame that virtually filled the 18-inch round duct and directly touched the filters. All four filters were seen to flash over and glow, then ignite almost simultaneously and the temperature of the discharge air jumped to 600°C. The filters burned fiercely and created intense heat. Small "puffs" or explosions occurred within the plenum chamber, the wire-glass inspection windows cracked, the fan caught fire, and the fan housing distorted. Before the instrument men hastily removed their potentiometer, temperatures of 1112°F were recorded on the filter faces and the exhaust air stream had risen to 1472°F. Higher temperatures were probably reached before the firemen moved in to extinguish the blaze and save the mock-up. A acrid smoke was given off from the adhesive used to bond the filter media to the frame. All personnel evacuated the building.

The firemen directed 1½-inch fog-nozzle streams discharging about 150 gallons of water per minute against the exhaust side of the filter. This seemed to momentarily accelerate burning and the temperature increased. It took almost ten minutes to extinguish the fire with two fog streams with a wetting agent, and even then only half of the burnable material had burned. The wood frames were relatively unmarked from the fire. (See Figs. 4 and 5.)

After clean-up of the mock-up and replacement of the filters a final series of three tests were run to check the spread of fire from filter to filter in a bank.

In Tests 8 and 9 an oily rag and Kleenex tissue were placed at the base of the filter bank and at the face but they burned out without igniting the filters.

In Test 10 an oily rag was hung on the filter face and ignited. The filter ignited immediately and burned for approximately 8 minutes before the others ignited. The others caught fire on the down-stream side due to the intense radiant heat accumulating on that side of the plenum chamber. The fire department extinguished the fires before they became as hot as in Test 7.

It is concluded from these fire tests, and from actual filter fires, that the need for a non-combustible filter with equivalent or better filtering characteristics, even at a somewhat higher cost, is an urgent necessity.

The following comments and conclusions were arrived at from the tests and the actual fires that have happened since:

1. It seemed more difficult to set the filters afire in the tests than it has been in some of the actual fires.
2. In any case the high-air velocity in most exhaust systems tends to reduce the liklihood of ignition, but enhances the fires once ignition has occurred.
3. A non-combustible pre-filter greatly reduces the liklihood of burning material or even flame to get through it to combustible CWS type filters. Thin sheet fiberglass is used at some installations for this purpose.
4. Where large banks of absolute filters are installed only the non-combustible filters should be used. There is too large a fire loading to depend on a non-combustible picfilter only.
5. The prime fuel in filter fires is the filter media and paper separators, not the wooden frame.
6. It seemed relatively difficult for the fire to spread from filter unit to filter unit in the test fires and then only on the down-stream side, yet in actual fires where more than one filter unit was involved it has always occurred.
7. Fires in filter rooms would be extremely difficult to combat. Normally only one side of the filter bank can be available for attack, yet wetter water as used in the tests could not penetrate through the filter. Application must be made from both sides.
8. Carbon dioxide installations and a single sprinkler head would be helpful to retard flame spread, but will usually be inadequate for extinguishing a full-blown filter fire. Heroic systems would be needed to protect large banks.
9. The problem of fire fighting in areas of radiation exposure tend to hamper the firemen because of protective clothing and limited exposure times. Immediate, effective fire attacks usually cannot be carried out.
10. By actual test it was found that the ignition temperature of the CWS filter media was 419°F. All the component parts of the filter unit including the cardboard dividers and adhesive binding materials ignited at 490°F.

V. RECOMMENDED CRITERIA FOR FIRE SAFE ABSOLUTE FILTERS

The perfect filter from the fire protection aspect has not been developed although tests at Hanford have indicated that one or two of the manufacturers have units that with modification should provide the required characteristics.

It is our opinion that the ideal criteria for a fire-safe filter should be—

a. Maximum operating temperature for one hour—1000°F. Such a media is already on the market and temperatures of over a 1000°F would only arise in an already well started fire. A filter unit that will not contribute to a fire starting in it is the best that can be asked for at this time. This unit can be disposed of elevated temperature and/or by crushing.

b. Maximum flow resistance at 5 fpm—.10%. Fire is not a factor here except that the resistance should not increase even after the filter has been subjected to the 1000°F one-hour test.

c. Loading capacity—Comparable to or better than the CWS-6 or AEC-1 media. One manufacturer claims a $\frac{1}{3}$ greater capacity because a thinner media and more folds per filter as a result.

d. Frame—$\frac{1}{16}$-inch steel with steel rivets with all exposed metal painted with fire retardant paint. Hanford experience with the steel frame has not been good, so we feel the 1-inch wood frame with exterior coated with a fire retardant paint will be superior until better adhesives and better expansion and contraction controls are developed. Experience in fires and fire tests to date indicate the wood frame was not a prime fuel.

e. Dividers and separators—Use only fiber-glass types. Flame treated paper types readily lose their flame resistance even in dry atmospheres. The thin aluminum types rapidly deteriorate in acid and wet chemistry atmospheres and in a few months the aluminum salts will load up the filter media until it is useless. Also the aluminum dividers (m.p. 1218°F) noticeably weakened in the 1000°F one-hour test.

f. Filter media—Either the Regal, Type A fiber glass or the MSA type are acceptable from a fire point.

g. Stability—Maintain stability under saturated atmospheres for a minimum 24-hour test. Although not a direct fire necessity any unit that tends to buckle or sag, or pull apart is more easily affected when fire exposed.

Whether or not the high efficiency filter with all these characteristics can be manufactured at competitive prices is not known. Fire and safety people at AEC installations are anxious to assist the ventilation and filter specialists in bringing about such a filter.

Earlier reference was made to the NFPA Code No. 90A as an excellent guide. Another reference newly published this year in May, also by the National Fire Protection Association, is their NFPA Code No. 801 "Recommended Safe Practice for Laboratories Handling Radioactive Materials." This is a guide for fire protection specialists, designers and operators of these laboratories on practices necessary for fire safety. I would like to quote the fourth paragraph of Section 5.1 entitled "Heating and Ventilating" which states: "The use of combustible filter permits easy disposal as an ash, but introduces a fire hazard into the venting system and requires automatic sprinklers or special fire protection measures. In the absence of sprinklers within the ducts, fires in combustible filters are extremely difficult to extinguish."

This we have tried to say, but as we've previously stated automatic protection must always be considered for protection of combustible filters, but the installations will usually be inadequate. Instead we recommend the widespread use of the non-combustible types.

VI. CONCLUSION

We have not touched on the problem for disposing of spent filters. Since we advocate the types that will not burn except at elevated temperature we seem to be adding a problem to the filter-use program. I am anxious to learn how these non-combustible units are disposed of, particularly where it is necessary to recover entrapped materials.

In conclusion I would like to acknowledge the work done in the fire tests, the filter tests, and numerous other studies by General Electric personnel at Hanford, particularly Mr. Palmer who is your next speaker, and the fire protection personnel of the plant.

We have attempted to present some information gained in the filter field through fires and fire tests. More so, I hope we have stimulated your interest in considering the fire aspect in your future design or operation of ventilation systems and filters—The problem is getting more serious! Further, I personally hope to learn a lot more about filters and ventilation systems while at this meeting.

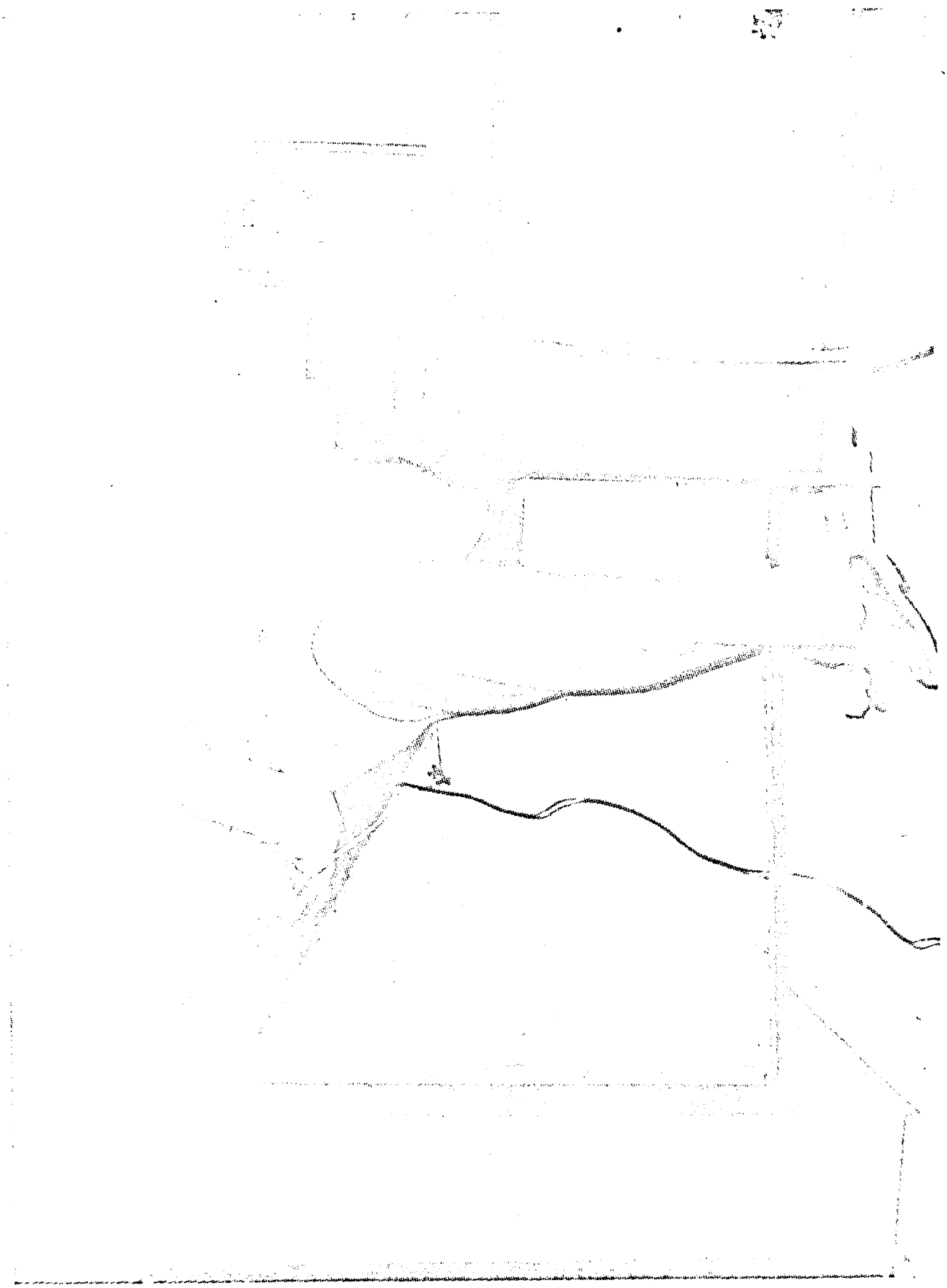

Fig. 1

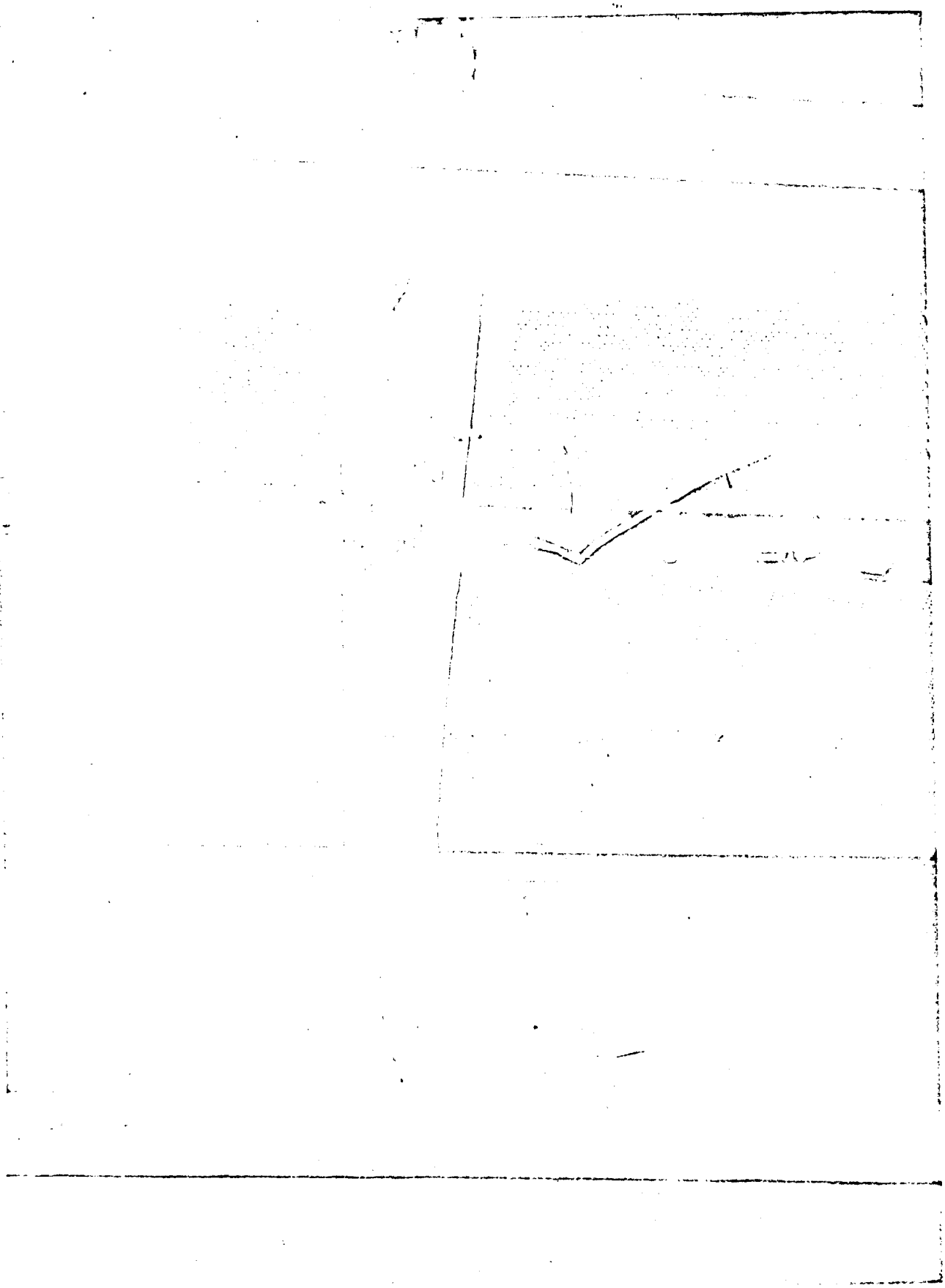

Fig. 2

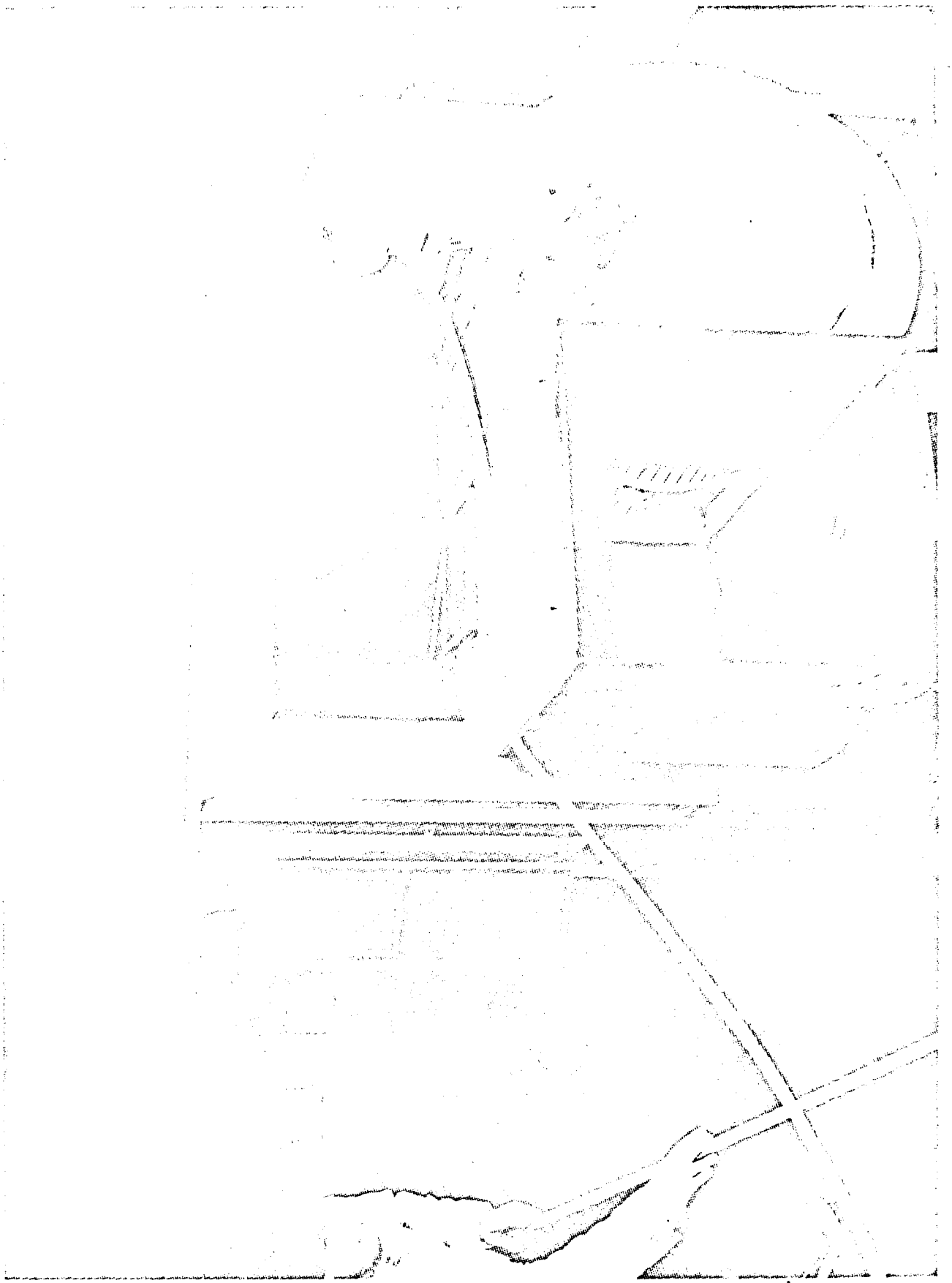

Fig. 3

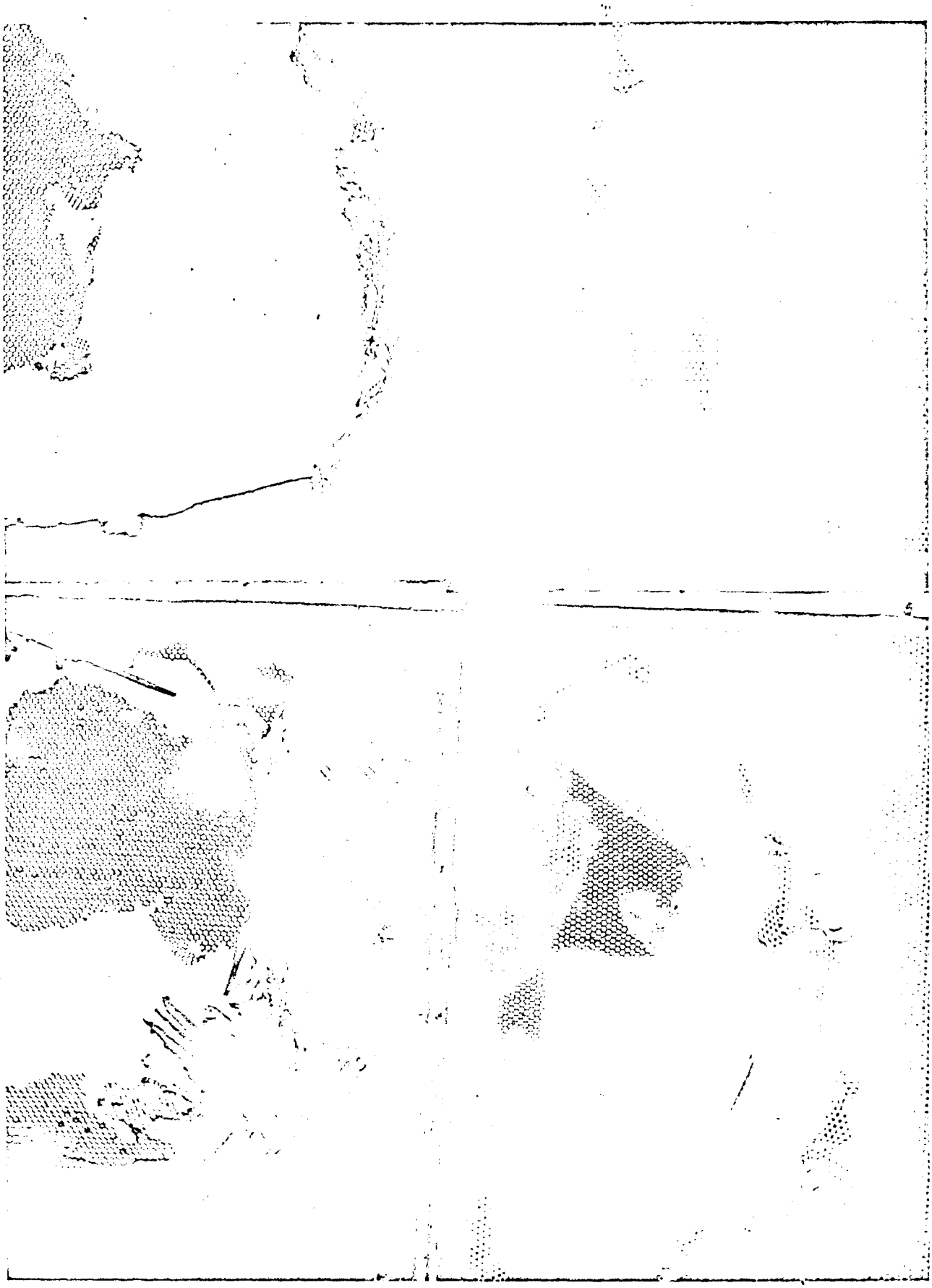

Fig. 4

Fig. 5