INDUSTRIAL HYGIENE SURVEY

OF

OWENS-CORNING FIBERGLAS

Kansas City, Kansas

SURVEY CONDUCTED BY:

Philip J. Bierbaum
John M. Dement
Kenneth M. Wallingford
Ralph D. Zumwalde

REPORT PREPARED BY:

John M. Dement
Kenneth M. Wallingford
Ralph D. Zumwalde

DATE OF REPORT:

May 24, 1973

Environmental Investigations Branch
Division of Field Studies and Clinical Investigations
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH
Cincinnati, Ohio

SURVEY DATES:

January 29-February 2, 1973

PLACE VISITED	:	Owens-Corning Fiberglas Kansas City, Kansas
DATES OF TRIP	:	January 29-February 2, 1973
PERSONS MAKING TRIP (NIOSH-Division of Field Studies and Clinical Investigations)	:	Philip J. Bierbaum John M. Dement Kenneth M. Wallingford Ralph D. Zumwalde
PERSONS CONTACTED	:	*Owens-Corning* Gerald Devitt, Corporate Industrial Hygienist Roger Roth, Plant Manager Edward McConniff, Plant Safety Director Roger Slusher, Production Manager Tom French, Plant Engineer Edward Main, Batch House Supervisor Ray Sanchez, Chief Steward of Plant Unions Charles Anderson, Union President, Local #1 of Insulation Workers of America *NIOSH Regional Office* Ralph Bicknell, NIOSH, Regional Program Director, Region VII Ray Hervin, NIOSH, Regional Industrial Hygienist, Region VII *State Personnel* John Irwin, Industrial Hygienist, Kansas State Health Department
PURPOSE OF TRIP	:	To make an industrial hygiene survey of the subject facility.

INTRODUCTION

The Division of Field Studies and Clinical Investigations of the National Institute for Occupational Safety and Health (NIOSH) has underway an industrywide study of the fibrous glass industry. The initial part of this study has been devoted to environmental studies of "wool insulation" operations as these operations account for more than 75 percent of the fibrous glass produced in the United States.

During the week of January 29-February 2, 1973, an industrial hygiene survey was conducted at the Kansas City, Kansas facility of the Owens-Corning Fiberglas Corporation. The initial plant tour was made by Philip Bierbaum, John Dement, Ken Wallingford and Ralph Zumwalde of the Division of Field Studies and Clinical Investigations, NIOSH, Ray Hervin, NIOSH Regional Industrial Hygienist, Region VII, and John Irwin of the Kansas State Health Department. The actual survey was conducted by John Dement, Ken Wallingford and Ralph Zumwalde.

Products of this plant include standard fibrous glass wool insulation, appliance insulation, blowing wool, roofing material, and ceiling tiles. During the survey air samples were taken in the various process areas to evaluate fibrous glass, free silica, phenol, formaldehyde, ammonia, carbon monoxide, cyclohexane, and toluene exposures. A noise survey also was conducted. The following paragraphs describe the facility, sampling methods which were used, sample results and conclusions and recommendations based on the sample results and observations made during the survey.

DESCRIPTION OF THE PLANT

The Kansas City facility began operation in 1946 and presently employs approximately 1250 persons with about 1100 of these persons being blue collar workers. All production operations in the plant operate on a rotating four shift basis. Corporate headquarters for Owens-Corning are located in Toledo, Ohio.

The principal products of this plant are standard fibrous glass wool insulation, appliance insulation, blowing wool, high density roofing material, roofing shingles, and ceiling tiles. Glass batch and phenol-formaldehyde binder for making the fibrous glass products also are made at the plant.

There are 14 unions represented in this plant. The major union is Local #1 of the Insulation Workers of America. The other unions are much smaller and include most of the trade unions.

MEDICAL PROGRAMS

The company has inplant medical facilities and occupational health consultation is available from corporate headquarters in Toledo, Ohio. Dr. Jon L. Konzen is Medical Director of the Owens-Corning Fiberglas Corporation. Dr. E.C. Sifers, a local general practioner, is a consultant to the plant on a part-time basis and does the pre-employment and periodic examinations. A full time nurse (trained in audiometric testing) is available for employee care.

Inplant medical facilities include a medical department with several examination rooms, an audiometric testing booth and pulmonary function testing equipment (Jones Pulmonaire II). The medical department has no x-ray equipment. All employees are required to undergo a pre-employment physical which includes a standard physical examination, chest x-ray, blood tests, urinalysis and spirometry. Annual chest x-rays are given to each production employee. Batch house workers also are given an annual pulmonary function test.

According to plant management, there have been no known cases of chest disease in this plant attributed to silica or fibrous glass exposure. Mechanical dermatitis secondary to fibrous glass does occur but is not considered a serious problem.

INDUSTRIAL HYGIENE AND SAFETY PROGRAMS

Industrial hygiene matters in this plant are the responsibility of Mr. Gerald Devitt, Corporate Industrial Hygienist for Owens-Corning Fiberglas. An industrial hygiene consultant is used to do routine surveys of the plant and to provide analytical services. Mr. Devitt also serves as Corporate Safety Director.

Safety programs in the plant are administered by Mr. Edward McConniff, Plant Safety Director. Weekly safety meetings are held between management and union representatives. Personal protective devices currently required of employees include hearing protection in fiber forming areas, safety glasses in designated areas, and respiratory protection during periodic abrasive cleaning. Safety shoes are not required; however, all employees are required to wear shoes with leather tops.

The Occupational Safety and Health Administration (OSHA) made a survey of this plant in September of 1971. There were no industrial hygiene citations; however, the plant did receive several minor safety citations.

DESCRIPTION OF THE PROCESSES

Fibrous glass for the insulation products is formed in this plant by two variations of the centrifugal method (known as aerocor and standard insulation). A textile like product called "bonded mat" used for roofing felts also is made by a textile type process. There are seven insulation lines (aerocor 71 and 72 and standard insulation lines 70, J-5, J-6, K-3 and K-4) and three bonded mat lines (RM-1, H and I) located in this facility.

Glass batch material for all forming lines is made in a separate batch house and carried to the glass furnace by "batch cans". The major components for the glass batches are given in Table 1.

Both hand and automatic mixing are used to make the glass batch. The major raw materials (sand, etc.) are held in large overhead hoppers and are automatically weighted and carried to the mixer by a combination of conveyor belts and a bucket elevator. The minor ingredients are weighted and hand dumped into a mixing hopper where a bucket elevator also carries the materials to the mixer. After the raw materials are completely mixed, they are emptied into batch cans (containing approximately 3000 lbs. of batch) and taken to the glass furnaces by an overhead rail system.

In the centrifugal forming processes (aerocor and standard insulation) glass batch is fed into the furnace where boro-silicate glass is formed at temperatures of approximately 2500°F. The molten glass next flows into a smaller refractory container known as a forehearth where the temperature is held at approximately 2200°F. The molten glass flows from the forehearth by gravity into spinners where centrifugal force is used to force the glass through small holes in the periphery of the spinner thus forming primary fibers. Upon leaving the spinners, each glass fiber is met by a high velocity burner flame which further attenuates the fibers. A phenol-formaldehyde binder (containing ammonia) also is sprayed onto the fibers at this time. The fibers, coated with binder, are collected on a conveyer thus forming a continuous blanket. The blanket next passes through a curing oven (400-500°F) causing the phenol-formaldehyde binder to polymerize. If a high density product is desired, the blankets also may be compressed during curing. After curing, the blankets are cut and trimmed and either compression packaged or taken to another area for further fabrication (aerocor fabrication).

Bonded mat material for making roofing felt is manufactured in this plant by an essentially textile operation (RM-1 line). In the process, glass marbles are melted in an electrolytic furnace and glass fibers are formed by molten glass flowing through platinum bushings in the bottom of the furnace. The fibers are coated with a water soluable sizing material (containing bone glue, phenol, formaldehyde and ammonia) and blown onto a conveyer in a random manner. The mat next goes through a curing oven and is rolled onto paper tubes.

Roofing felt is made at this plant using the bonded mat mentioned above. The mat is coated with asphalt and 200 mesh sand and rolled into 50 ft. rolls for shipment. This felt material is used primarily for "built-up" roofs.

Sound deadening ceiling boards also are made at this plant ("Sonoco" operation). In this process, high density boards from the centrifugal process are covered with a plastic facing material by the use of an adhesive. The adhesive uses cyclohexane and toluene as solvents.

INSPECTION OF THE PLANT

Potential Health Hazards: The following are potential health hazards which were noted during the survey:

1. Skin and respiratory exposure to fibrous glass
2. Respiratory exposure to free silica in the glass batch house and roofing felt operations
3. Respiratory exposure to phenol, formaldehyde, and ammonia in resin curing areas
4. Carbon monoxide exposure in fibrous glass production areas
5. Respiratory exposure to cyclohexane and toluene in ceiling tile production area ("Sonoco")
6. High noise exposures in fibrous glass forming areas

Housekeeping: In general, housekeeping in this plant is quite good. The plant appears to have ample space available and overcrowding is not a problem. Floor cleaning is done with both brooms and vacuum sweepers. Occasionally, compressed air is used for cleaning; however, air lines are equipped with pressure reducing regulators.

Sandblasting is used in this plant for periodically cleaning of the resin curing ovens. During sandblasting, workers are required to wear "demand type" dust respirators.

Ventilation: In the glass batch house, all material transfer points and the hand mixing station are provided with local exhaust ventilation. Two "sly" bag collectors rated at 30,000 cfm each are used in connection with this exhaust system. Velocity measurements at the hand mixing hood showed the face velocity to be greater than 150 fpm.

The major points of ventilation in the fibrous glass production areas are the forming hoods. Approximately 110,000 to 150,000 cfm are drawn through each rotary forming hood. Exhaust from these hoods are discharged to the roof without passing through a collector.

All sawing and trimming operations in this plant are provided with local exhaust ventilation. These exhaust points are vented to wet collectors known as "smigs". There are five such collectors located in the plant rated at 30,000 cfm each. The exhaust from these collectors is discharged back into the work areas.

Resin curing oven exhaust containing phenol and formaldehyde are controlled by the use of afterburners and wet scrubbers.

No make-up air is provided in this plant with the exception of that discharged from the inplant collectors, resulting in a noticable negative pressure within the building. According to Mr. Tom French, the Plant Engineer, the building is generally operated at 1/4 in. to 1/2 in. H_2O negativ pressure.

SURVEY PROCEDURES

General

Samples were collected in this plant for evaluating exposure to fibrous glass, free silica, phenol, formaldehyde, ammonia, carbon monoxide, cyclohexane and toluene. A noise survey also was conducted. The following paragraphs describe the methods used to collect and analyze the air samples and make noise measurements.

Dust Measurements

Fibrous Glass Operations (Fiber Count and Total Dust): Both personal and general area samples for airborne fibrous glass were collected in the various fibrous glass operations for evaluation by fiber count and total dust weight.

The samples for fiber count were collected on 37mm diameter Millipore Type AA cellulose ester membrane filters (0.8μ pore size) at a calibrated sampling rate of 2.0 lpm with an open filter face. Fibers less than 10μm in diameter were counted at 430X magnification (4mm acromatic objective with NA=0.65) by the phase contrast method recommended by NIOSH for counting asbestos fibers[1]. Fiber size distributions (length and diameter) were determined for most operations using a "Leitz" rotating stage phase contrast microscope at 400X magnification and a calibrated "Porton" reticle. At least 100 randomly selected fibers were sized for each operation.

The personal samples for total dust were collected on 37mm diameter Mine Safety Appliance (MSA) polyvinyl chloride membrane filters (5μ pore size) at a calibrated sampling rate of 2.0 lpm. Three piece Millipore filter holders were used with only the small plug removed (leaving a 4mm diameter opening). All filters were tared and re-weighed on the 20 milligram "A" scale of a "Cahn Gram Electrobalance". Total dust concentrations are reported in milligrams per cubic meter of air.

Glass Batch House and Roofing Felt Line (Free Silica): Both personal total and personal respirable samples were collected in the glass batch operations and at the roofing felt line for evaluating silica dust exposures. Personal samples for total dust were collected in the same manner previously described for sampling in the fibrous glass production operations. Personal respirable samples for free silica were collected in the glass batch house and at the roofing felt line. These samples were collected on 37 mm diameter MSA polyvinyl chloride filters using a 10mm nylon cyclone[2] presampler at a sampling rate of 1.7 lpm. Respirable sample pumps were fitted with pulsation dampeners as described by LaViolette and Reist.[3] Sample weighing procedures were the same as previously described for total dust samples.

In addition to personal samples, both total and respirable stationary general area samples for free silica were collected in various areas of the glass batch house. These stationary samples were collected in two ways. The first method used the same sampling equipment and methods previously described for personal respirable and personal total dust samples. These sample units were placed in various areas of the glass batch house and allowed to run for the entire work shift. The second method used 37mm MSA polyvinyl chloride filters but sampled at a higher rate. Total mass samples were collected on 37mm MSA polyvinyl chloride filters using a horizontal elutriator presampler meeting the Walton[4] design criteria at a flow rate of 10.0 lpm. Constant flow was maintained in both the higher volume samplers (total and respirable) by use of a critical orifice with a static pressure regain section.

The samples for free silica were analyzed using the colorimetric method of Talvitie.[5]

Organic Compounds

Formaldehyde: Airborne formaldehyde samples were collected in the area of the forming hoods and resin curing ovens by drawing 1.0 lpm of air through a two stage bubble absorber. Each absorber was equipped with a course fritted tube inlet and filled with 20 ml of distilled water. With two absorbers in series, the total collection efficiency for formaldehyde is approximately 95 percent.[6] Laboratory analysis for formaldehyde was performed using the chromotropic acid, colorimetric method recommended by the Intersociety Committee.[6 7]

Phenol: Samples for total airborne phenolic compounds also were collected in the area of the forming hoods and resin curing ovens. These samples were collected by drawing 1.0 lpm of air through a two stage absorber equipped with course fritted tube inlets. Each absorber was filled with 20 ml of 0.1N sodium hydroxide. Laboratory analysis for total phenolic compounds was performed by distillation from an acidified system and coupling with 4-aminoantipyrine in an alkaline medium containing an oxidant.[8]

Cyclohexane and Toluene: Personal samples for cyclohexane and toluene were collected in the ceiling tile film facing operations ("Sonoco"). These samples were collected by passing the vapors through activated charcoal (MSA Organic Vapor Sampling Tubes) at a sample rate of 1.0 lpm. Laboratory analysis was performed using the gas chromatograph method described by Kupel, et al.[9]

Inorganic Compounds

Detector tubes were used to evaluate concentrations of ammonia and carbon monoxide in the various production areas. Carbon monoxide measurements were made using "Drager Carbon Monoxide 5/c" tubes using the ten stroke (5-150 ppm) measuring scale. Ammonia measurements were made using "Drager Ammonia 5/2" tubes with a measuring range of 5 to 70 ppm.

Noise

In addition to air sampling, noise measurements were made in most areas. A General Radio Type 1565-A sound level meter calibrated with a Type 1562-A calibrator was used for all measurements. The meter response was set on the slow position and measurements made on the "A" and "C" weighing networks in order to get an estimate of the frequency distribution of the noise.[10]

RESULTS AND DISCUSSION

Fibrous Glass Samples

Results of the air samples for both total dust weight and fiber count in the areas of fibrous glass operations are shown in Tables 2 and 3. Highest concentrations determined by either sample method were found for packer handlers on line 70 (183 fibers ≤10μ in diameter/liter for sample 1 and 4.8 mg/m^3 for sample MSA-213). The sampling periods for the fibrous glass samples were 4 to 5 hours in length; therefore, the results in Tables 2 and 3 should be fairly good measures of the worker's average 8-hour exposures. The only OSHA standard presently applicable for fibrous glass exposure is that for nuisance dusts of 15 mg/m^3. No sample approached this value.

Airborne fiber size distributions (length and diameter) for each operation are shown in Figures 1, 2, 3, and 4. Table 4 gives a summary of results of the airborne fiber size determinations. The median airborne fiber diameter for the aerocor, standard insulation and aerocor fabrication operations was approximately 1.1μm and the median diameter for the blowing wool operation was 1.3μm. Airborne fiber lengths ranged from a median of 19μm in the standard wool insulation operations to a median of 26μm in the aerocor operations.

Although the respirability of airborne fibers is not clearly understood, this characteristic is thought to be chiefly diameter dependent and fibers greater than 10μm in diameter certainly have little chance of deep pulmonary penetration. Timbrell's[11] work suggests that the two major mechanisms of fiber deposition in the upper airways (settlement under gravity and inertial deposition) are chiefly dependent upon particle free falling speed and fibers with densities less than 3.5 g/cm and less than 3.5μm in diameter may escape deposition by these two mechanisms and penetrate deeply into the lungs. Trimbrell's work further suggests that the limitation on the lengths of fibers which reach the deep pulmonary air spaces is imposed by the nasal hairs and small diameters of the respiratory bronchioles. Timbrell and Skidmore[12] in a more recent inhalation experiment with rats using fibrous glass 0.75-1.5μm in diameter and lengths up to 100μm, found a few fibers up to 50μm in length in the lungs of rats sacrificed during exposure although the bulk of all fibers found were less than 20μm in length.

Another study conducted by Gross et al.[13] concerned itself with fiber size distributions in the lungs of previous fibrous glass workers. Postmortem examinations were made of lung sections of 20 fiber glass workers who had been exposed to fibrous glass dust between 16 and 32 years. In this study approximately 95 percent of all fibers observed were less than approximately 40μm in length. Occasionally fibers 50 to 60μm in length were observed. However, it must be pointed out that these size distributions were made following the lung clearing process; therefore, no statement can be made regarding initial deposition of fibers.

In contrast to the above quoted articles, Murphy[14] reported a case of acute pulmonary involvement following a short fibrous glass exposure. A lower lobectomy was performed and careful pathological studies demonstrated the presence of glass fibers up to 14 μm in diameter and 60μm in length in the terminal bronchioles. In addition, Balber[15] reports finding fibers 100μm to 200μm in length in the alveolar regions of asbestos workers at autopsy.

As can be seen, considerable difference of opinion exists as to the true nature of a respirable fiber. For purposes of this discussion, based on the above cited studies, "potentially" respirable glass fibers shall be defined as those less than 3.5 μm in diameter and less than 50μm in length. From Table 4, it can be seen that the majority of all airborne fibers in this facility, regardless of operation, are below 3.5μm in diameter (ranging from 86 to 91 percent). In addition, 68 to 80 percent of all fibers are less than 50μm in length.

Although a good majority of the airborne fibers observed in this facility could be considered "potentially" respirable, their concentrations are very low (highest concentration of 183 fibers ≤10μm in diameter/liter). There is no evidence, at the present time, that such fiber exposures result in significant acute or chronic pulmonary effects.

Silica Dust Samples

Results of the personal and stationary general area silica dust samples in the glass batch operations are shown in Table 5. From this table, it can be seen that only 7 of the 27 samples had silica dust concentrations in excess of the present OSHA standards. [As calculated by the formulas:allowable total dust= $\frac{30}{\%\ SiO_2 + 2}$ (mg/m^3), allowable respirable dust= $\frac{10}{\%\ SiO_2 + 2}$ (mg/m^3)] Only one personal sample (MSA 229) was in excess of the present OSHA standard (1.28 mg/m^3 versus an allowable concentration of 0.91 mg/m^3).

The stationary samples in the glass batch operations show the highest areas of silica dust concentration to be at the sand hopper in the middle of the hopper room and on the mixer platform. Even in these areas, respirable dust concentrations were only slightly in excess of the OSHA standards.

Results of the personal and stationary samples for free silica in the roofing line rolling operation are shown in Table 6. All three samples in this operation were in excess of the present OSHA standards. Addition of appropriate ventilation equipment at the rolling operation is probably needed.

Phenol, Formaldehyde and Ammonia Samples

Results of the air samples for phenol, formaldehyde and ammonia are shown in Tables 7, 8 and 9, respectively. The highest concentrations of both phenol (0.35 ppm) and ammonia (20 ppm) were found in the fiber forming area of the RM-1 bonded mat line. In addition, an ammonia concentration of 20 ppm was also found at the entrance to the spinner area of the "K" line. No measured concentration of phenol or ammonia approached the present OSHA standards of 5 ppm and 50 ppm, for these pollutants.

The highest concentration of formaldehyde (1.14 ppm) was found at the entrance to the J-5 curing oven. All other formaldehyde concentrations were below 0.5 ppm. The present OSHA standard for formaldehyde exposure is 3 ppm on an 8-hour time weighted average basis.

Carbon Monoxide

Results of the detector tube samples for carbon monoxide are shown in Table 10. The highest concentration obtained was 35 ppm in the aerocor packing area. Concentrations of 25 ppm and 20 ppm were observed at the entrance to the 71 line curing oven and in the packing area of the J-5 line, respectively.

Although all samples obtained were below the present OSHA 8-hour average exposure standard for carbon monoxide of 50 ppm, concentrations in the packing areas should be of concern. The major reason for these carbon monoxide exposures appears to be the lack of make-up air throughout the plant. Make-up air would serve as dilution ventilation and lower carbon monoxide levels.

Cyclohexane and Toluene in "Sonoco" Facing

Results of the carbon tube samples for cyclohexane and toluene in the "Sonoco" facing operations are shown in Table 11. The highest concentrations observed were 53.2 ppm of cyclohexane and 15.8 ppm of toluene. These concentrations are far below the present OSHA 8-hour exposure standards of 300 ppm and 200 ppm for cyclohexane and toluene, respectively.

Noise

Results of all noise measurements are shown in Table 12. As was anticipated, high noise levels were measured in each of the fibrous glass wool forming areas. Workers in these areas currently wear hearing protection when not in the operator booths (noise levels in the booths ranged from 77 to 78 dBA).

Noise levels measured in the RM-1 forming area ranged from 92 to 93 dBA. Workers in this area do not presently wear hearing protection. Intermittent noise levels as high as 101 dBA were observed in the glass batch area when hopper vibrators were in use. However, on an 8-hour basis, the average noise exposure is probably below 90 dBA in the glass batch operations.

For each noise measurement shown in Table 12, comparison of the "C" and "A" scale reading showed the "C" reading to be higher in every case indicating a prevalence of low frequency noise probably below 600 Hz.[10]

CONCLUSIONS AND RECOMMENDATIONS

Based on the sample results given herein and observations made during the survey, the following conclusions are drawn and recommendations made:

1. Fibrous glass exposures observed during this survey were low based on either fiber count or total dust weight. Although

a good portion of the airborne fibers in these operations could possibly be considered "potentially" respirable, there is presently no evidence that such exposures are related to acute or chronic pulmonary involvement.

2. Silica dust concentrations in the glass batch operations are generally below the present OSHA standards. Higher concentrations were observed near the sand hoppers and on the mixer platform. Workers seldom spend significant amounts of time in these areas.

3. All silica dust samples taken at the roll-up operations of the roofing line were in excess of present OSHA standards. Due to the nature of the roll-up operation, providing local exhaust ventilation may present some technical problems. Perhaps some form of canopy hood enclosing the rolling operation as much as possible would be sufficient.

4. Concentrations of phenol, formaldehyde, and ammonia observed in this facility were well below present OSHA standards.

5. Concentrations of carbon monoxide, although below the present OSHA standard could be considered a problem. Consideration should

be given to providing make-up air in this facility in order that carbon monoxide concentrations may be lowered by the effect of dilution ventilation.

6. Concentrations of cyclohexane and toluene observed in the "Sonoco" facing operations were below present OSHA standards.

7. Noise levels in the RM-1 forming area are presently above the present OSHA 8-hour standard and workers in this area are not wearing hearing protection. Hearing protection should be required in this area.

R E F E R E N C E S

1. "Criteria for a Recommended Standard: Occupational Exposure to Asbestos", USDHEW, Public Health Service, National Institute for Occupational Safety and Health, 1972.

2. Lippmann, M. and W.B. Harris, "Size-Selective Samplers for Estimating Respirable Dust Concentrations". Health Physics 8, 155, (1962)

3. LaViolette, P.A. and P.C. Resit, "An Improved Pulsation Dampener for Use with Respirable Sampling Devices". AIHAJ 33:279-282, May, 1972.

4. Walton, Witt., "The Theory of Size-Classification of Airborne Dust Clouds by Elutriation". Brit. Journal Appl. Phys. Suppl., 3529-3540 (1954).

5 Talvitie, N.A., "Determination of Free Silica: Gravimetric and Spectorphotometric Procedures Applicable to Airborne and Settled Dust". AIHAJ 25, 196 (1964).

6. Sleva, Stanley F., "Determination of Formaldehyde: Chromatropic and Method". Public Health Service Publication #999-AP-11, H-1, 1965.

7. Intersociety Committee Publication: "Tentative Method of Analysis for Formaldehyde Content of the Atmosphere", Methods of Air Sampling and Analysis, American Public Health Association, pp. 194-198, 1972

8. Intersociety Committee Publication: "Tentative Method of Analysis for Determination of Phenolic Compounds in the Atmosphere", Methods of Air Sampling and Analysis, American Public Health Association, pp. 220-223, 1972.

9. Kupel, Richard E., et. al.: "A Convenient Optimized Method for the Analysis of Selected Solvent Vapors in the Industrial Atmosphere". AIHAJ 31:225 (1970)

10. Paterson, Arnold P. and Ervin E. Gross, Handbook of Noise Measurement, Sixth Edition, General Radio Company, 1967.

11. Timbrell, V., "The Inhalation of Fibrous Dusts". Annals of the New York Academy of Sciences, Vol. 132, Art. I, pp. 255-273, 1965.

12. Timbrell, V. and J.W. Skidmore, "The Effects of Shape on Particle Penetration and Retention in Animal Lungs". Proc. Third Int. Conf. Inhaled Particles and Vapors, pp. 49-57, Unwin Bros., London (1971).

13. Gross, P., Jiri Tuma, and R.T.P. deTreville, "Lungs of Workers Exposed to Fiber Glass: A Study of Their Pathologic Changes and Their Dust Content". Arch. Env. Health, Vol. 23, pp. 67-71, July, 1971.

14. Murphy, George B., "Fiber Glass Pneumoconiosis", Arch. Env. Health Vol. 3, pp. 102-108, December, 1961.

15. Balber, J.L., Discussion Proc. Third International Conference Inhaled Particles and Vapors. p. 57, Unwin Bros., London, (1971).

APPENDIX

TABLES

FIGURES

TABLE 1

MAJOR RAW MATERIALS LIST

Owens Corning
Kansas City, Kansas

I. GLASS BATCH

	MATERIAL	*RECEIVED*
1.	Sand	Hopper Car
2.	Dolomite	Hopper Car
3.	Barytes	Hopper Car
4.	Trona	Hopper Car
5.	Rasorite	Hopper Car
6.	Limestone	Hopper Car
7.	Cullet	Hopper Car

II. BINDER

	MATERIAL	*RECEIVED*
1.	Water	Piped
2.	Phenol	Tank Car
3.	Formaldehyde	Tank Car
4.	Ammonia	Tank Car
5.	Urea	Tank Car
6.	Sulfate	Bag
7.	Silicone	Bag
8.	Dieyadiamide	Bag
9.	Oil Emulsion	Barrel
10.	Bond Glue	Bag

III. MISCELLANEOUS

	MATERIAL	*RECEIVED*
1.	Ceiling Board Adhesive (cyclohexane & toluene solvents)	Barrel

TABLE 2

RESULTS OF PERSONAL AND GENERAL AREA SAMPLES FOR
TOTAL DUST WEIGHT IN ALL FIBROUS GLASS PRODUCTION OPERATIONS

OWENS CORNING
Kansas City, Kansas

MSA SAMPLE #	*JOB OR SAMPLE LOCATION*	*TOTAL DUST WEIGHT Mg*	*AIR VOLUME M^3*	*TOTAL DUST* CONCENTRATION Mg/M^3*	*SIMULTANEOUS COUNT SAMPLE #*
Lines 71 and 72 Aerocor					
221	Packer-Handler, 71 line	0.56	0.63	0.89	12
222	Packer-Handler, 71 line	0.58	0.63	0.92	13
223	Packer-Handler, 72 line	0.88	0.60	1.47	None
224	Packer-Handler, 72 line	0.66	0.61	1.08	15
226	Forehearth Operator, 72 line	1.02	0.59	1.73	17
266	By Cutter, 71 line	0.43	0.47	0.92	37
289	By Cutter, 71 line	0.42	0.48	0.88	50
265	At Band Saw, 72 line	0.33	0.49	0.68	36
291	At Band Saw, 72 line	0.46	0.46	1.00	52
267	By Edge Slitter, 71 line	0.36	0.47	0.76	38
290	By Edge Slitter, 71 line	0.46	0.46	1.00	51
264	By Chopper, 72 line	0.23	0.50	0.46	35
292	By Chopper, 72 line	0.47	0.47	1.00	53
Aerocor Fabrication					
262	At Chopper, Range Insulation	0.20	0.59	0.33	33
263	At Chopper, Range Insulation	0.29	0.49	0.59	34
283	On Chopper Platform, Low Density	0.47	0.45	1.05	44
285	On Chopper Platform, Low Density	0.36	0.49	0.73	46
286	By Punch Press, Range Insulation	0.43	0.48	0.90	47
260	At Special Cutting Operation	0.32	0.59	0.55	31
261	At Special Curring Operation	0.35	0.59	0.57	32
Standard Insulation Wool (Centrifugal Forming)					
210	Packer-Handler, 70 line	1.46	0.67	2.13	1
212	Packer-Handler, 70 line	2.20	0.67	3.29	None
213	Packer-Handler, 70 line	3.22	0.67	4.80	4
214	Packer-Handler, 70 line	1.95	0.67	2.91	5
215	Packer-Handler, 70 line	2.30	0.66	3.48	6
216	Packer-Handler, 70 line	0.90	0.61	1.50	7

Table 2 (continued)

MSA SAMPLE #	*JOB OR SAMPLE LOCATION*	*TOTAL DUST WEIGHT Mg*	*AIR VOLUME M³*	*TOTAL DUST* CONCENTRATION Mg/M³*	*SIMULTANEOUS COUNT SAMPLE #*
Standard Insulation Wool (Centrifugal Forming) continued					
218	Forming Group Leader	0.82	0.65	1.26	9
220	Forehearth Operator, 70 line	0.51	0.61	0.84	11
217	Machine Operator, 70 line	0.84	0.60	1.39	8
219	Machine Operator, 70 line	0.91	0.66	1.38	10
237	Packer-Handler, J-line	0.55	0.54	1.02	18
238	Packer-Handler, J-line	1.56	0.54	2.90	19
239	Packer-Handler, J-line	0.45	0.53	0.84	20
240	Packer-Handler, J-line	0.25	0.52	0.49	21
241	Machine Operator, J-line	0.21	0.51	0.42	22
242	Forehearth Operator, J-line	1.41	0.50	2.82	23
243	Forehearth Operator, J-line	0.57	0.50	1.14	24
244	Packer-Handler, K-line	0.34	0.47	0.73	None
245	Packer-Handler, K-line	0.26	0.46	0.57	26
246	Packer-Handler, K-line	0.59	0.46	1.28	27
Blowing Wool					
247	Blowing Wool Packer	0.21	0.44	0.48	28
249	Blowing Wool Packer	0.54	0.43	1.27	None
248	Scrap Feeder	0.74	0.44	1.69	29
282	Paper Backing Remover	1.09	0.49	2.23	None
RM-1 Bonded Mat					
269	At Edge Slitter	0.58	0.45	1.29	40
288	At Edge Slitter	0.60	0.48	1.25	49
268	At Packing Roller	0.39	0.45	0.88	39
287	At Packing Roller	0.49	0.48	0.90	48

* No OSHA standard presently exists other than that for nuisance dust of 15 mg/m^3 based on an 8-hour time weighted average exposure.

TABLE 3

RESULTS OF PERSONAL AND GENERAL AREA SAMPLES FOR
FIBER COUNT IN ALL FIBROUS GLASS PRODUCTION OPERATIONS

OWENS CORNING
Kansas City, Kansas

MILLIPORE SAMPLE #	*JOB OR SAMPLE LOCATION*	*AVERAGE FIBERS/FIELD ≤10 DIA.*	*AIR VOLUME LITERS*	*FIBER CONC.* FIBERS ≤10 IN DIAMETER PER LITER*	*SIMULTANEOU MSA WEIGHT SAMPLE #*
Lines 71 and 72, Aerocor					
12	Packer-Handler, 71 line	0.02	626	5	221
13	Packer-Handler, 71 line	0.14	628	34	222
15	Packer-Handler, 72 line	0.06	606	15	224
17	Forehearth Operator	0.16	586	42	226
36	At Band Saw, 72 line	0.04	492	12	265
52	At Band Saw, 72 line	0.12	468	39	291
37	By Cutter, 71 line	0.34	470	110	266
50	By Cutter, 71 line	0.12	480	38	289
38	By Edge Slitter, 71 line	0.16	474	52	267
51	By Edge Slitter, 71 line	0.16	473	52	290
35	By Chopper, 72 line	0.04	500	12	264
53	By Chopper, 72 line	0.12	470	39	292
99	Edge Trimmer, 71 line	0.14	406	58	None
Aerocor Fabrication					
33	At Chopper, Range Insulation	0.18	590	47	262
34	At Chopper, Range Insulation	0.10	486	31	263
44	On Chopper Platform, Low Density	0.16	494	49	283
46	On Chopper Platform, Low Density	0.22	486	69	285
47	By Punch Press, Range Insulation	0.16	480	51	286
31	At Special Cutting Operation	0.32	590	83	260
32	At Special Cutting Operation	0.12	590	31	261
45	At Special Cutting Operation	0.10	494	31	None
Standard Insulation Wool (Centifugal Forming)					
1	Packer-Handler, 70 line	0.82	686	183	210
4	Packer-Handler, 70 line	0.56	674	127	213
5	Packer-Handler, 70 line	0.44	670	100	214
6	Packer-Handler, 70 line	0.68	656	158	215
7	Packer-Handler, 70 line	0.38	606	96	216
9	Forming Group Leader	0.16	648	38	218

Table 3 (continued)

MILLIPORE SAMPLE #	JOB OR SAMPLE LOCATION	AVERAGE FIBERS/FIELD <10 DIA.	AIR VOLUME LITERS	FIBER CONC.* FIBERS ≤10 IN DIAMETER PER LITER	SIMULTANEOUS MSA WEIGHT SAMPLE #
Standard Insulation Wool (Centrifugal Forming) continued					
11	Forehearth Operator, 70 line	0.20	610	50	220
8	Machine Operator, 70 line	0.20	598	51	217
10	Machine Operator, 70 line	0.32	660	74	219
98	At Compactor Press, 70 line	0.43	360	182	None
18	Packer-Handler, J-line	0.34	542	96	237
19	Packer-Handler, J-line	0.22	540	62	238
20	Packer-Handler, J-line	0.08	534	23	239
21	Packer-Handler, J-line	0.18	522	53	240
22	Machine Operator, J-line	0.12	506	36	241
23	Forehearth Operator, J-line	0.12	500	37	242
24	Forehearth Operator, J-line	0.02	500	6	243
26	Packer-Handler, K-line	0.14	462	46	245
27	Packer-Handler, K-line	0.28	460	93	246
Blowing Wool					
28	Blowing Wool Packer	0.16	444	55	247
29	Scrap Feeder	0.22	440	76	248
41	Paper Backing Remover	0.38	394	147	Void
42	At Scrap Feed Station	0.04	382	16	None
RM-1 Bonded Mat					
40	At Edge Slitter	0.06	450	20	269
49	At Edge Slitter	0.02	480	6	288
39	At Packing Roller	0.10	446	34	268
48	At Packing Roller	0.10	480	31	287

* No standard for fibrous glass, based on fiber count has yet been established.

TABLE 4

SUMMARY OF AIRBORNE FIBER SIZE DATA
DETERMINED BY OPTICAL MICROSCOPY

OWENS CORNING
Kansas City, Kansas

FIBER SIZE PARAMETER	AEROCOR	STANDARD INSULATION	AEROCOR FABRICATION	BLOWING WOOL
Diameter				
Median Diameter, μm	1.1	1.1	1.1	1.3
Geometric Standard Deviation, μm	2.0	2.4	2.9	2.4
Percent Fibers ≤3.5μm	93	91	85	86
Length				
Median Length, μm	26	19	23	22
Geometric Standard Deviation, μm	4.9	3.0	4.3	5.1
Percent Fibers ≤50 μm	68	80	71	69

TABLE 5

RESULTS OF PERSONAL AND AREA SAMPLES IN GLASS BATCH OPERATIONS
OWNES CORNING
Kansas City, Kansas

SAMPLE #	*JOB OR SAMPLE LOCATION*	*SAMPLE TYPE*	*COLLECTED DUST WEIGHT Mg*	*AIR VOLUME SAMPLED M^3*	*DUST CONCENTRATION Mg/M^3*	*PERCENT FREE SiO_2 BY WEIGHT*	*ALLOWABLE DUST CONCENTRATION ** Mg/M^3*
230	Hand Batch Operator*	Total	1.54	0.66	2.33	3.9	5.08
227	Hand Batch Operator*	Resp.	0.21	0.56	0.37	4.8	1.47
232	Rail Car Unloader*	Total	1.22	0.62	2.34	9.0	2.73
229	Rail Car Unloader*	Resp.	0.68	0.53	1.28	9.0	0.91
231	At Furnace Level	Total	1.00	0.63	1.58	18.2	1.49
228	At Furnace Level	Resp.	0.26	0.53	0.49	50.0	0.19
233	At Hand Mix Station	Total	5.18	2.21	2.34	4.4	4.69
234	At Hand Mix Station	Resp.	2.56	2.89	0.88	2.7	2.13
235	Midway of Hopper Room	Total	3.64	2.22	1.63	5.8	3.84
236	Midway of Hopper Room	Resp.	1.86	3.16	0.59	7.5	1.05
253	At Hand Mix Station	Total	0.74	0.55	1.34	2.7	6.38
250	At Hand Mix Station	Resp.	0.18	0.47	0.38	27.2	0.34
255	Midway of Hopper Room (Sand Hopper)	Total	0.60	0.55	1.09	35.0	0.81
252	Midway of Hopper Room (Sand Hopper)	Resp.	0.20	0.47	0.43	26.0	0.36
254	On Mixer Platform	Total	0.92	0.55	1.67	25.0	1.11
251	On Mixer Platform	Resp.	0.18	0.47	0.38	---	----
257	In Far End of Hopper Room	Total	2.32	2.03	1.14	7.3	3.23
256	In Far End of Hopper Room	Resp.	1.36	2.65	0.51	5.2	1.39

Table 5 (continued)

SAMPLE #	JOB OR SAMPLE LOCATION	SAMPLE TYPE	COLLECTED DUST WEIGHT Mg	AIR VOLUME SAMPLED M^3	DUST CONCENTRATION Mg/M^3	PERCENT FREE SiO_2 BY WEIGHT	ALLOWABLE DUST CONCENTRATION ** Mg/M^3
259	10' From Can Fill Station	Total	1.19	2.10	0.57	---	---
258	10' From Can Fill Station	Resp.	0.68	3.01	0.23	4.4	1.56
272	At Hand Mix Station	Total	0.99	0.52	1.90	4.7	4.48
273	At Hand Mix Station	Resp.	Void	---	---	---	---
274	On Mixer Platform	Total	0.60	0.51	1.18	8.7	2.80
275	On Mixer Platform	Resp.	0.10	0.44	0.23	6.9	1.25
276	Midway in Hopper Room (Sand Hopper)	Total	0.60	0.51	0.96	13.1	1.99
277	Midway in Hopper Room (Sand Hopper)	Resp.	0.10	0.44	0.34	52.0	0.19
278	10' From Can Fill Station	Total	1.19	1.99	0.60	7.6	3.13
279	10' From Can Fill Station	Resp.	0.66	2.70	0.24	39.4	0.24
280	In Far End of Hopper Room	Total	1.91	1.99	0.97	7.3	3.23
281	In Far End of Hopper Room	Resp.	0.80	2.43	0.33	14.5	0.61

* Indicates personal samples

** Allowable concentrations based on present OSHA standards for free silica exposure calculated by the following formulas:

allowable total dust $mg/m^3 = \frac{30}{\%\ SiO_2 + 2}$, allowable respirable dust $mg/m^3 = \frac{10}{\%\ SiO_2 + 2}$

TABLE 6

RESULTS OF AIR SAMPLES FOR FREE SILICA IN ROOFING LINE ROLLING OPERATION

OWENS CORNING
Kansas City, Kansas

SAMPLE #	*JOB OR SAMPLE LOCATION*	*SAMPLE TYPE*	*COLLECTED DUST WEIGHT MG*	*AIR VOLUME M^3*	*TOTAL DUST CONCENTRATION Mg/m^3*	*PERCENT FREE SiO_2 BY WEIGHT*	*ALLOWABLE**DUST CONCENTRATION Mg/m^3*
293	Roll-up operator*	Resp	Void	0.27	---	---	---
294	Roll-up operator*	Total	0.34	0.32	1.06	31.2	0.90
295	Approximately 5' from roll-up	Resp.	0.20	0.27	0.74	40.0	0.24
296	Approximately 5' from roll-up	Total	0.82	0.32	2.56	12.2	2.11

* Indicates personal samples

** Allowable concentrations based on present OSHA standards for free silica exposure calculated by the following formulas:

$$\text{allowable total dust} = \frac{30}{\%\ SiO_2+2}\ ,\quad \text{allowable respirable dust} = \frac{10}{\%\ SiO_2+2}$$

TABLE 7

RESULTS OF AIR SAMPLES FOR PHENOLIC COMPOUNDS

IN

FIBROUS GLASS PRODUCTION AREAS

OWENS CORNING
Kansas City, Kansas

SAMPLE #	*SAMPLE LOCATION*	*MILLIGRAMS OF PHENOLIC COMPOUNDS IN SAMPLE**	*AIR VOLUME M^3*	*CONCENTRATION ****	
				Mg/M^3	*PPM ***
1	Forehearth, 70 line	0.08	0.300	0.27	0.07
2	Forming, 71 line	0.039	0.295	0.13	0.04
3	Between 71 & 72 Oven	0.017	0.310	0.05	0.01
4	Lower Level, RM-1	0.260	0.315	0.83	0.23
5	Forming Station, RM-1	0.239	0.190	1.26	0.35
6	Forehearth, J-line	0.045	0.195	0.23	0.06
7	Blank	0.0005	---	--	--

* Measured as phenol

** At standard conditions

*** The present OSHA standard for phenol is 5 ppm on an 8-hour time weighted average basis.

TABLE 8

RESULTS OF AIRBORNE FORMALDEHYDE SAMPLES

IN

FIBROUS GLASS PRODUCTION AREAS

Owens Corning
Kansas City, Kansas

SAMPLE #	*AREA SAMPLED*	*Mg FORMALDEHYDE IN SAMPLE*	*AIR VOLUME M^3*	*CONCENTRATION*** *Mg/M^3*	*PPM**
1	Oven Control Panel, J-6	0.15	.290	0.517	0.42
2	Forehearth, J-6	0.12	.285	0.421	0.34
3	Forming Room, RM-1	0.008	.265	0.03	0.02
4	Forehearth, #71 aerocor	0.042	.265	0.158	0.13
5	Entrance to J-5 Curing Oven	0.26	.186	1.398	1.14
6	End of Curing Oven, #71	0.019	.167	0.114	0.09
7	Blank	0.001	----	-----	----

* At standard conditions

** The present OSHA standard for formaldehyde is 3 ppm based on an 8-hour time weighted average basis

TABLE 9

RESULTS OF DETECTOR TUBE SAMPLES FOR AMMONIA

IN

FIBROUS GLASS PRODUCTION AREAS

OWENS CORNING
Kansas City, Kansas

SAMPLE #	*SAMPLE LOCATION*	*APPROXIMATE AMMONIA CONCENTRATION, PPM**
1	Forman's Desk, RM-1 line	15
2	At forming bushings, RM-1 line	15-20
3	At forming bushings, RM-1 line	15
4	At forehearth, 71 line	3
5	At scrap station, RM-1 line	15
6	At entrance to J-6 curing oven	7-8
7	At forehearth booth, J-6 line	2-3
8	At spinners, J-6 line	9-10
9	At ground level in binder room	7
10	At binder mix tank	9
11	In aerocor packing area	1-2
12	At curing oven entrance, 71 line	3-4
13	At forehearth, 71 line	4
14	In line J-5 packing area	2
15	At entrance to J-5 curing oven	5
16	At spinners, J-6 line	10
17	At entrance to spinner area from curing ovens, K-line	20

* The present OSHA standard for ammonia is 50 ppm based on an 8-hour time weighted average basis

TABLE 10

RESULTS OF DETECTOR TUBE SAMPLES FOR CARBON MONOXIDE

IN

FIBROUS GLASS PRODUCTION AREAS

OWENS CORNING
Kansas City, Kansas

SAMPLE #	*SAMPLE LOCATION*	*APPROXIMATE CARBON MONOXIDE CONC. PPM**
1	Between Line 71 & 72 curing ovens	5
2	Oven Entrance, J-6 line	10-15
3	In Aerocor packing area	35
4	At curing oven entrance, 71 line	25
5	At line 71 forehearth	4-5
6	In packing area, J-5 line	20
7	At curing oven entrance, J-5 line	7
8	At entrance to spinner area from curing ovens, K-line	10
9	In medical examination room (no smoking)	10

* The present OSHA standard for carbon monoxide is 50 ppm on an 8-hour time weighted average basis.

TABLE 11

RESULTS OF PERSONAL CHARCOAL TUBE SAMPLES FOR CYCLOHEXANE AND TOLUENE
IN
"SONOCO" FACING OPERATION

OWENS CORNING
Kansas City, Kansas

SAMPLE	*JOB TITLE*	*AIR VOLUME M^3*	*SOLVENT WEIGHT Mg*		*SOLVENT CONCENTRATIONS*			
					*CYCLOHEXANE***		*TOLUENE***	
			CYCLOHEXANE	*TOLUENE*	*Mg/M^3*	*PPM**	*Mg/M^3*	*PPM**
1	Facing machine operator	0.012	1.44	0.45	120.0	29.4	37.5	9.0
2	Hand slitter	0.012	2.61	0.79	217.5	53.2	65.8	15.8
3	Packer	0.013	2.15	0.62	165.3	40.4	47.7	11.4
4	Facing machine operator	0.014	1.56	0.48	111.4	27.3	34.2	8.2
5	Hand slitter	0.013	1.68	0.56	129.2	31.6	43.1	10.3
6	Packer	0.013	1.80	0.56	138.5	33.9	43.1	10.3
7	Facing machine operator	0.006	0.68	0.21	113.3	27.7	35.0	8.4
8	Hand slitter	0.005	0.41	0.14	82.0	20.1	28.0	6.7
9	Packer	0.004	0.59	0.18	147.5	36.1	45.0	10.8

* PPM at Standard conditions
** Present OSHA standards for cyclohexane and toluene are 300 and 200 PPM respectively on an 8-hour time weighted average basis

TABLE 12

RESULTS OF NOISE MEASUREMENTS

OWENS CORNING
Kansas City, Kansas

AREA	*PREDOMINANT NOISE SOURCE*	*SOUND LEVEL READINGS* As*	Cs
RM-1 Forming room	Forming bushings (jets)	93	95
At RM-1 Curing ovens	Forming jets	92	101
At RM-1 Take-off	Curing and forming	79	87
At Line 71 spinners	High air velocity at spinners	105	106
Inside Line 71 operator booth	High air velocity at spinners	78	96
Between 71 & 72 forming hoods	High air velocity at spinners	94	99
Between 71 & 72 curing oven	Forming noise & fans	84	89
At line 72 spinners	High air velocity at spinners	105	105
Inside Line 72 operator booth	High air velocity at spinners	78	96
At Line 72 packing	Forming noise and fans	81	89
At line J-5 spinners	High air velocity at spinners	104	105
Inside J-5 operator booth	High air velocity at spinners	77	88
At j-5 curing oven	Forming noise & fans	84	93
In J-5 packing area	Forming noise & fans	83	89
Next to blowing wool grinder	Grinder	81	93
Blowing wool packing area	Grinder and packing machine	83	93
At glass batch hand Mixing station (vibrator on)	Vibrator & mixer	101	104
At glass batch hand Mixing station (no vibrator)	Mixer	76	85
Glass batch mixer Platform (no vibrator)	Mixer	74	84

* The present OSHA standard for noise exposure is 90 dBA on an 8-hour time-weighted average basis

FIGURE 1

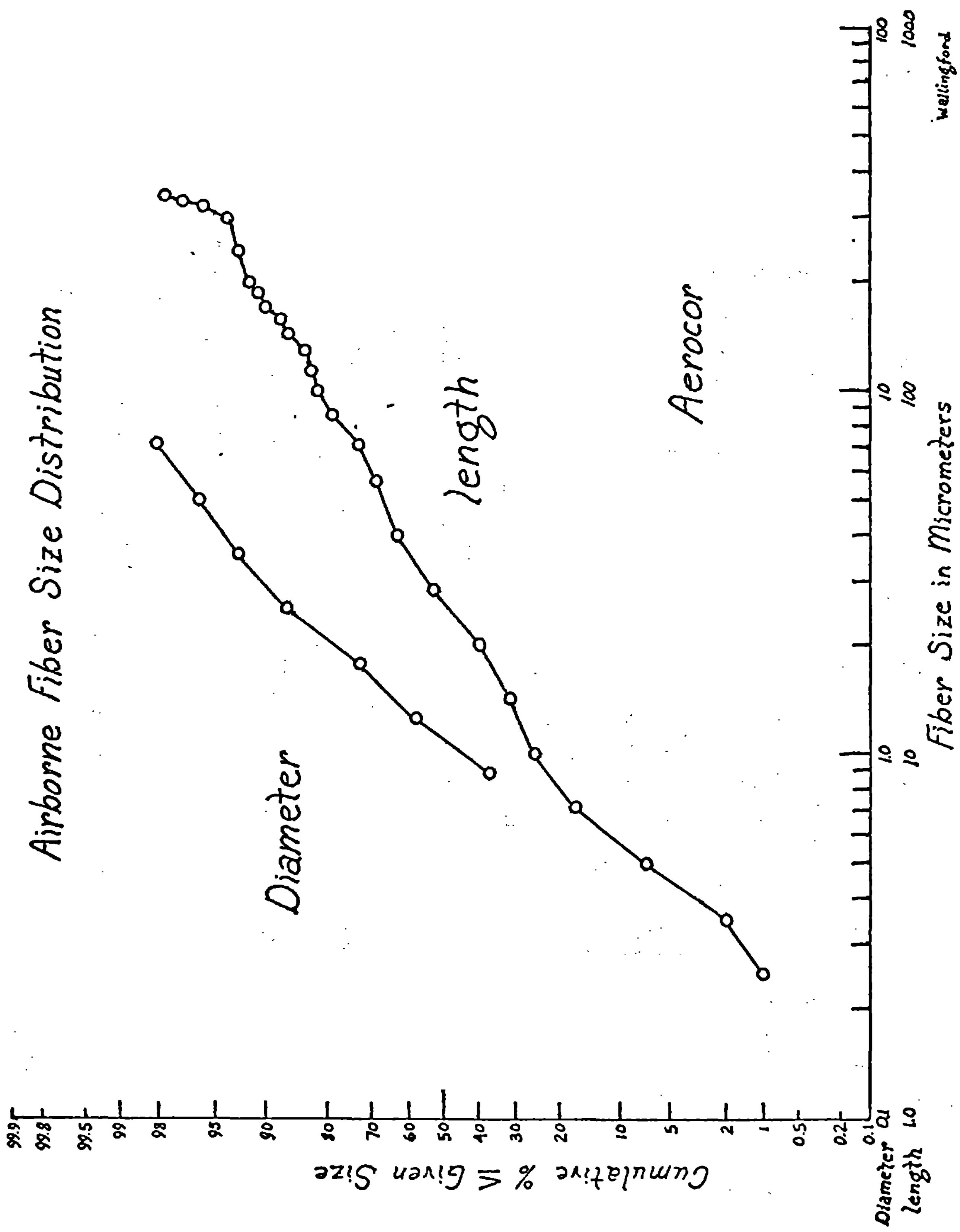
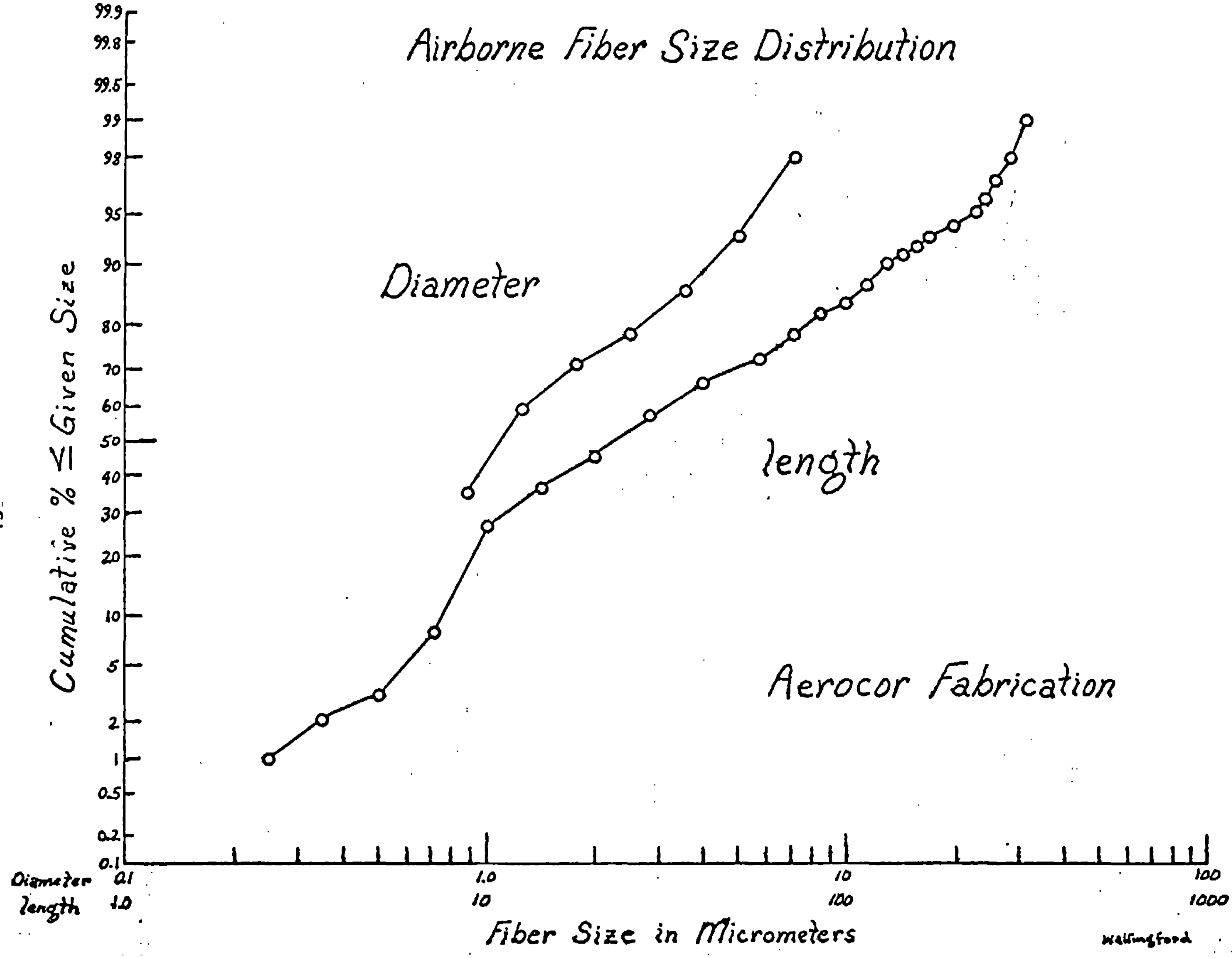

Airborne Fiber Size Distribution
Diameter
length
Aerocor
Cumulative % ≤ Given Size
Fiber Size in Micrometers
Diameter 0.1 1.0 10 100
length 1.0 10 100 1000
99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1
Wellingford

FIGURE 2



Airborne Fiber Size Distribution
Diameter
length
Aerocor Fabrication
Cumulative % ≤ Given Size
99.9
99.8
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
Diameter
length
0.1
1.0
1.0
10
10
100
100
1000
Fiber Size in Micrometers
Wallingford

FIGURE 3

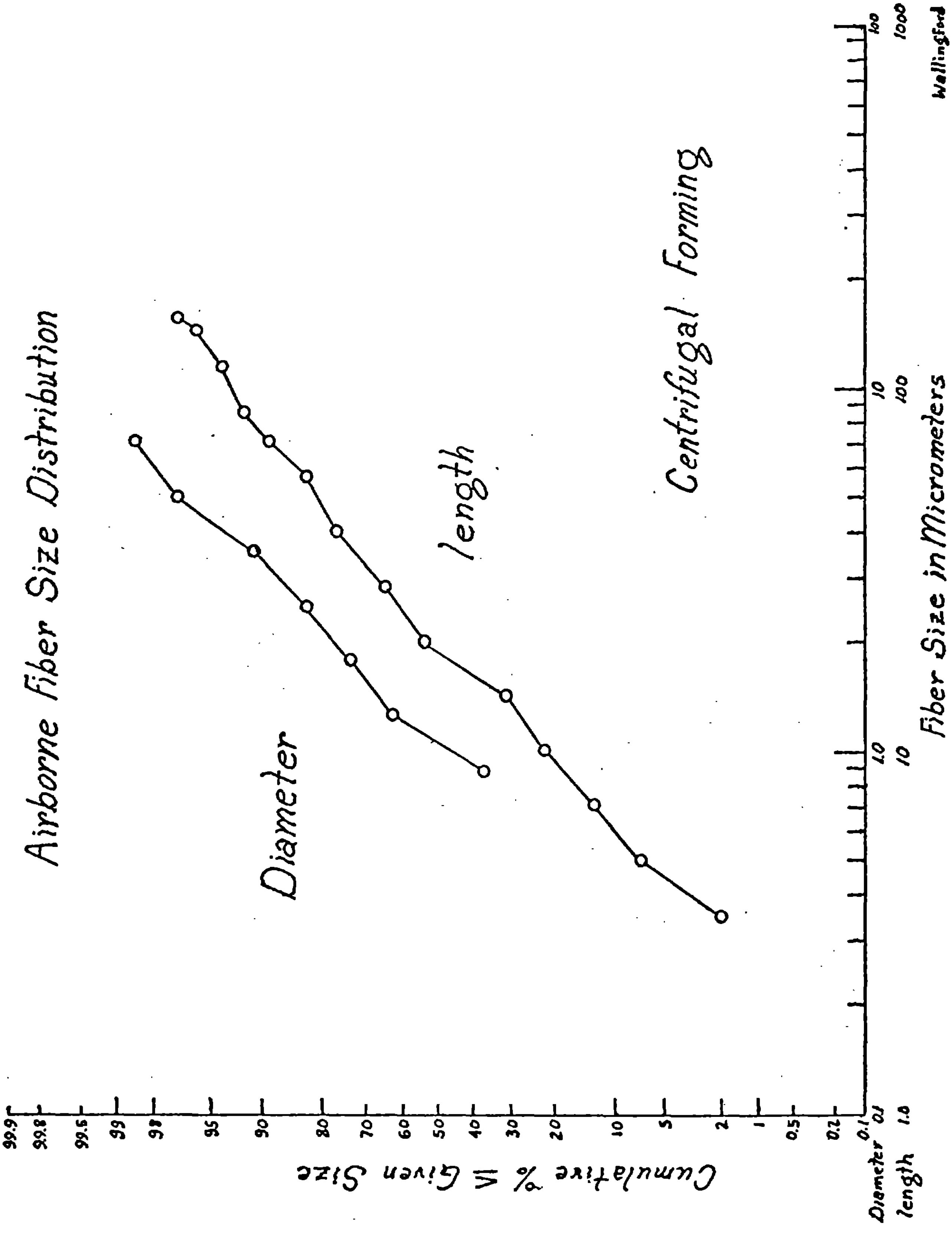
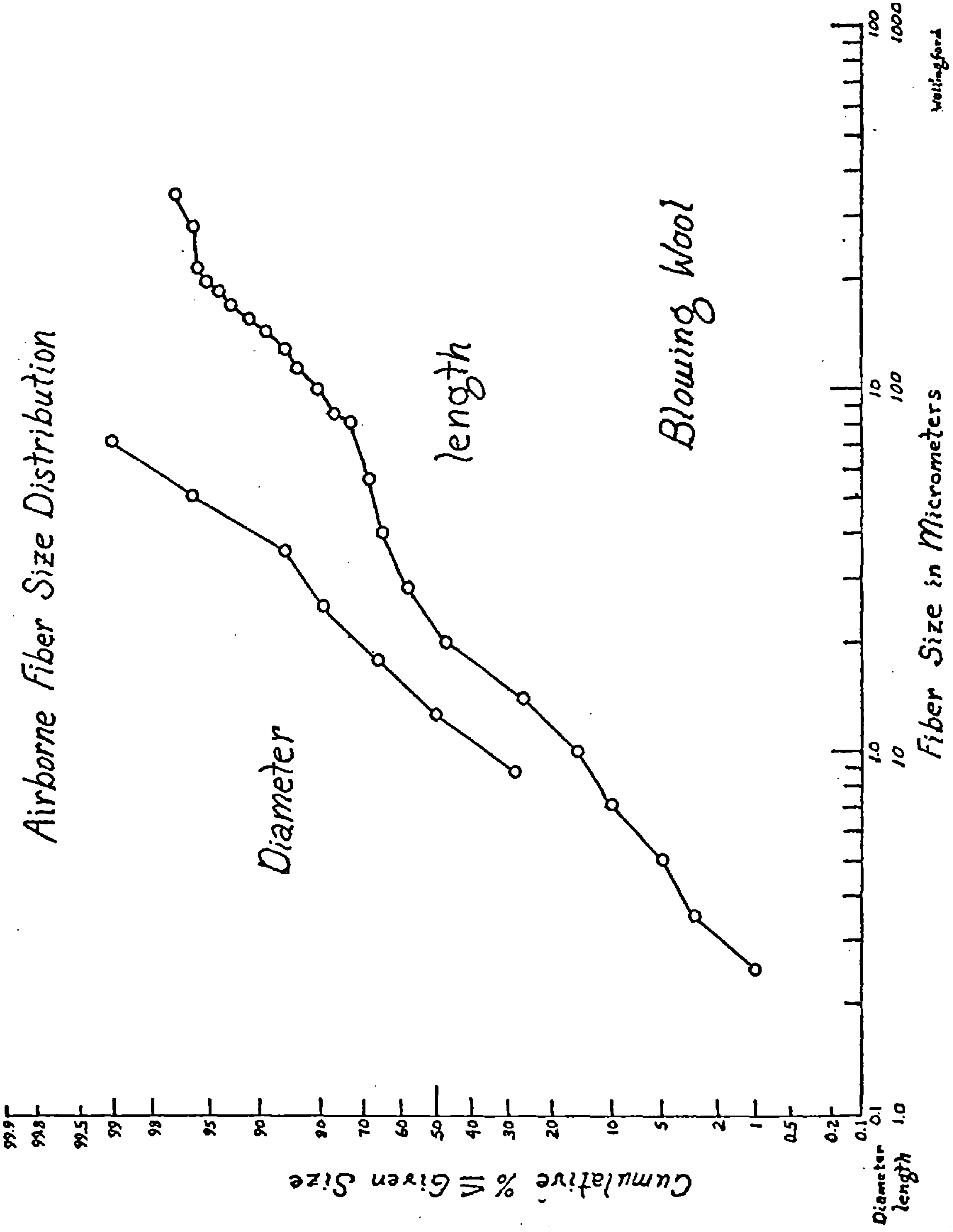

Airborne Fiber Size Distribution
Centrifugal Forming
Diameter
length
Cumulative % ≤ Given Size
99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1
Diameter 0.1 1.0 10 100
length 1.0 10 100 1000
Fiber Size in Micrometers
Wallingford

FIGURE 4



Airborne Fiber Size Distribution
Diameter
length
Blowing Wool
Cumulative % ≤ Given Size
Fiber Size in Micrometers
Diameter
length
Wellingford