

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF LABOR AND INDUSTRY
RALPH M. BASHORE, *Secretary*

Special Bulletin

No. 42

ASBESTOSIS

Part II. The Nature and Amount of Dust
Encountered in Asbestos Fabricat-
ing Plants.

Part III. The Effects of Exposure to Dust
Encountered in Asbestos Fabricat-
ing Plants on the Health of a Group
of Workers.



BUREAU OF INDUSTRIAL STANDARDS
JOHN CAMPBELL, *Director*

Harrisburg, Pennsylvania
September 20, 1935

01 501 0660

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF LABOR AND INDUSTRY

Asbestosis

- I. The Nature and Amount of Dust Encountered in Asbestos Fabricating Plants.
- II. The Effects of Exposure to Dust Encountered in Asbestos Fabricating Plants on the Health of a Group of Workers.

by

WILLIAM B. FULTON, M. D., *Chief of Industrial Hygiene*
MELAN DOOLEY, *Chemist*
JULIA L. MATTHEWS, Ph. D., *Chemist*
ROBERT L. HOUTZ, *Chemist*

INDUSTRIAL HYGIENE SECTION
BUREAU OF INDUSTRIAL STANDARDS

91 501 0661

ASBESTOSIS—Part II. The Nature and Amount of Dust Encountered in Asbestos Fabricating Plants.

INTRODUCTION

In 1934 the Department of Labor and Industry of the Commonwealth of Pennsylvania received a request for information relative to the health of workers employed in asbestos fabricating plants in Pennsylvania. The Department had no data available, and a review of the literature at that time revealed a scarcity of information on the general subject of asbestos pneumokoniosis. Because of this lack of information, the industries in the State were consulted, and their cooperation was obtained to conduct a survey, which would include an evaluation of the hazard from the standpoint of the degree of dustiness and the physical condition of the workers. An agreement was made with the employers and employees that neither would be given specific information as to the physical findings of any particular workman, and that the original identity of all employees in this study would be destroyed, case numbers only being recorded. All records obtained were to become the property of the Department of Labor and Industry.

Asbestosis was first recognized clinically by Dr. H. M. Murray (16) at the Charing Cross Hospital, London, in 1900. Cooke (16) in 1924 reported a case of pulmonary asbestosis. Pancoast and Pendergrass (83) in 1926 examined a group of seventeen asbestos workers. Since then, other investigators have reported individual cases of asbestosis, but it was not until 1930 that Merewether and Price (74) published the results of a study on a group of asbestos workers, together with some evaluation of the degree of exposure. Lanza, McConnell, and Fehnel (66) have recently published a preliminary report of a comprehensive survey on this subject.

The industry in this State consists mainly of several fabricating plants engaged in the making of asbestos cloth, brake lining, insulating tape, asbestos rope and wick, and other miscellaneous products. According to the 1931 Pennsylvania Industrial Directory (61) there are approximately two thousand persons engaged in the manufacture of asbestos products in Pennsylvania.

The nature of asbestos dust is such that many of the standard procedures used for other dusts could not be used. Changes in the accepted standard method were required in the collection, counting, and particle size determination of the dust. In Part I of this report (41) the method of collection and counting of dust encountered in this study was described and summarized.*

* Samples of dust taken in plants for fabricating asbestos products were collected by a modified form of the standard method, using a 95 per cent U. S. P. ethyl alcohol as a medium. In this medium the particles were well distributed and readily counted. When distilled water was utilized as the collecting medium, agglomeration occurred immediately, and made counting impossible. Dispersion of the dust in alcohol is good. A settling time of at least thirty minutes was required before counting. The particle count in any given field remained constant after this period. A modified holster is described. It is constructed of leather straps, in such a way that the dust in the impinger flask is visible at all times.

Preliminary to the collection of atmospheric dust samples in each of the four plants included in the survey, general information was obtained concerning all phases of plant hygiene, with special reference to the general plan of the factory, number and types of operations, ventilation of workrooms, illumination, etc.

The concentration of dust in a plant was determined for each operation or department. A complete study of each operation was made, noting in detail the nature of the work, approximate time required for each operation, and changes in the process, so that samples collected would be representative of the actual exposure to dust.

PROPERTIES OF ASBESTOS

The term "Asbestos" in its commercial sense is loosely applied to a group of minerals with a number of sub-divisions having, in common, fibrous structure, and possessing more or less resistance to the action of fire and acid. The three mineral groups are:

1. Anthophyllite— $(Mg, Fe) SiO_3$.
2. Amphibole or Hornblende—Silicates of Fe, Ca, Mg
3. Serpentine— $3MgO \cdot 2SiO_2 \cdot 2H_2O$.

The three types of asbestos ordinarily used in manufacturing are chrysotile, crocidolite, and amosite. Crocidolite (blue asbestos) and amosite, a yellow or brown variety of crocidolite, both belong to the amphibole or hornblende group. The principal source of the latter two varieties is, at present, Rhodesia, South Africa. Chrysotile, a mineral of the serpentine group, comprises the bulk (about 95%) of the asbestos of commerce. Only relatively small amounts of crocidolite and amosite are used in comparison to the quantity of chrysotile.

The principal source of chrysotile is the Thetford region of Canada, about forty-five miles south of Quebec. The United States does not rank high as a producer of asbestos, the domestic output being less than three per cent of the amount used in its asbestos manufacturing industries (10). No asbestos is mined in Pennsylvania, although small amounts have been found in serpentine quarries from time to time. No attempt has ever been made to separate the asbestos from the serpentine in these quarries. Arizona and Vermont supply the bulk of asbestos mined in this country.

TABLE I—TYPICAL ANALYSES OF CHRYSOTILE

Sample No.	Total SiO ₂	MgO	FeO Fe ₂ O ₃	Al ₂ O ₃	Comb. H ₂ O
1	59.05%	40.07%	2.41%	3.67%	14.46%
2	59.36	42.13	3.31	—	14.50
3	40.42	41.63	2.60	0.82	14.37
4	59.22	40.27	2.78	3.64	14.37
5	40.67	41.50	2.81	0.90	13.55
6	41.80	42.50	0.69	0.89	14.08
7	39.20	42.97	2.36	—	13.87
8	40.42	40.62	2.92	1.92	13.46

In the Canadian deposits the chrysotile is found in veins from one-eighth inch to six inches in length, occurring as bands in the serpentine rock. The mineral is generally a dark to blackish-green lustrous color, although when the fibers are separated into fine filaments, they are white. The fibers are very fine, silky, soft, greasy and slippery to the touch. They cannot be separated into a single fiber like cotton or wool.

Chemically, chrysotile is a hydrated silicate of magnesium with small amounts of oxides of iron and aluminum. There are many published analyses of chrysotile from the Thetford region, and they appear to vary but little. Table I gives eight typical analyses of chrysotile (95). The silica shown in the analyses in Table I does not exist as free silica. It is chemically combined with the bases in a complex molecule. Samples of dust collected in the workers' breathing zone with the electric precipitator (30) were analyzed petrographically and were found to contain no free silica.*

The chrysotile of commerce is classified in two general grades, depending on the length of the fibers. Crude fiber consists of the hand-separated and -selected material essentially in its native or unfiberized form. Mill fiber includes all grades that are obtained by mechanical crushing of the rock and subsequent mechanical separation of the fiber. Crude No. 1 consists of fiber whose length is $\frac{3}{4}$ inch and longer; Crude No. 2 ranges in length from $\frac{3}{8}$ inch up to $\frac{3}{4}$ inch. Mill fiber includes all fibers less than $\frac{3}{8}$ inch in length.

The spinning quality of asbestos fiber depends primarily on its length. Consequently, the best grades of asbestos textiles are made from the crude fiber. The shorter fibers are used in cheaper grades of textiles and in the manufacture of asbestos shingles, paper, plaster, and cement.

DESCRIPTION OF PROCESS

Preparation—Crude fiber as received from the mines has undergone no treatment other than hand-hammering to remove the rock from the fiber, after which it is sorted and screened. It is received at the plant in burlap bags, each containing one hundred pounds. The fibers must first be separated and loosened to remove rock particles. This operation is done in what is known to the industry as a "preparing room." A number of bags, sufficient for one batch, are opened and dumped on the floor of the preparing room. The fiber is fed into rim-wheel crushers and crushed for about fifteen minutes. These crushers have two heavy rollers attached to a radial axle, and revolve on a smooth surface on which the asbestos is placed. After the fibers have been crushed and loosened sufficiently, they are fed into the hopper of an opener or fiberizer, usually of the Saco-Lowell type. This operation serves to further open the fibers. From the opener, the asbestos is discharged onto a rectangular shaker screen where small pieces of stone, foreign material, and some of the dust are removed. The asbestos is lifted from the screen by air suction and conveyed to storage bins. It is then ready for mixing with cotton.

* Petrographic analyses of samples were conducted by Dr. A. E. Galloway, of the Industrial Hygiene Laboratory, Pennsylvania Department of Labor and Industry.

is wheeled in hand trucks from the storage bins, and fed by hand into the feed hopper of the breaker card. It is passed over the revolving cylinders of the breaker card, emerging in the form of a loose blanket or web. The direction of flow is then changed through ninety degrees. It next passes over a camel-back into the finisher card. The fiber is stripped from the last cylinder of the finisher onto a moving leather apron where a set of reciprocating scrapers or rubbers condenses it into loose rovings or "slivers" of unspun yarn. These rovings are wound on long Jack spools to be taken to the spinning department.

The rovings at the extreme ends of the cards cannot be used for spinning purposes because of their lack of uniform thickness. These are gathered up as card waste, and, together with waste from subsequent operations, returned to the preparing room where the waste is shredded and added to later batches.

Some cards are designed so that a fine cotton thread may be incorporated into the rovings as they are doffed from the card. This practice yields a stronger roving.

In the manufacture of asbestos rope and wick, only one card is used. The rope and wick rovings, which are not subsequently spun, are thicker than yarn rovings. Hence, one carding operation is sufficient. Generally a fiber of shorter staple than that used in textile manufacture is used for making rope and wick.

Spinning—The unspun rovings, as they are doffed from the cards, necessarily have no twist and therefore little tensile strength. It is necessary to twist or spin these rovings to impart the desired strength. This spinning may be done either on ring spinning frames or on a machine called a mule. In the plants included in this study all the spinning was done by the latter method. Several of the plants had spinning frames, but they were not in operation.

The mules had from two hundred and sixty to possibly five hundred and fifty spindles mounted in a straight line on a carriage which is made to move forward and backward. The Jack spools from the cards are mounted on the mule and the ends of the rovings fastened to the spindles. As the spindles recede from the Jack spools (a maximum distance of about fifty-four inches) the rovings are unwound. The spindles turn slowly as they recede, to give a slight twist to the rovings. When the spindles have reached the point of greatest recession they are turned very rapidly, and the yarn spun. When sufficient twisting has been done, the spindle carriage moves back again in the direction of the Jack spools, causing the spun yarn (about fifty-four inches) to be wound on the spindles. The operation is then repeated until the spindles are fully wound with single-ply yarn.

The duties of the mule spinner are to remove the spindles from the mule when they are filled, and to tie the broken ends of the unspun rovings as the spindles recede. This last operation requires constant vigilance, because the rovings are continually breaking.

Subsequent Operations—The spindles from the mules are next transferred to a spooling or winding machine to rewind the single-ply yarn on other types of spools. This is simply a mechanical transfer of the yarn.

These spools are next taken to a twisting machine where two or three of the single-ply threads are twisted into one thread. For the manufacture of brake lining or packing the yarn may be reinforced with a fine metallic wire. This addition is performed during the twisting operation. The twisted yarn is finally wound on paper spools about six inches long.

The twisted yarn may be sold as such to other manufacturers, or it may be woven into cloth, tape, or brake lining, or braided in the same plant.

Weaving—Weaving is done on looms in a similar manner to the method employed in weaving wool, cotton or silk. In the weaving of asbestos tape intended for electrical insulation, single-ply yarn with a very low cotton content is used. Most tape looms are constructed so that as many as twelve pieces may be woven at the same time. It is the usual practice in weaving asbestos tape to wet the bobbins or "cops" with water before weaving. The warp is kept dry.

Cloth is woven in much the same way as insulating tape. Two- or three-ply yarn is used. Sometimes the yarn is reinforced with metallic wires, generally brass or copper. Either or both the warp and fill are dry or moistened with water, depending on the use for which the cloth is intended.

Brake lining is woven on looms in the same manner as tape. As many as eight pieces may be woven on one loom at the same time. It may be woven dry or wet, or with the warp impregnated with a "dope" solution. This solution is generally a suspension of gilsonite in gasoline to which other ingredients may be added.

Final operations in the manufacture of woven textiles consist of calendering, inspecting and winding of the products. These operations are all mechanical ones, and require no description.

Gasket Making—One of the important uses of asbestos cloth is in the manufacture of ring gaskets. In this process, the asbestos cloth is spread on the floor and impregnated with a solution of rubber in gasoline, to which has been added barytes and other pigments. The rubber-treated asbestos cloth is cut into strips of predetermined size, and the gaskets formed by hand. They are then coated with soapstone, calendered and packed for shipment. An inexpensive gasket and packing is made by twisting thick rovings into asbestos wick and rope. Still other types of packings are made by braiding asbestos yarn on specially designed machines.

OTHER PROCESSES

Other products containing asbestos are made in some of the plants included in this survey. These products include asbestos paper, insulation for steam pipes, asbestos cements, shingles, lumber, molded brake lining, and cold molded asbestos articles, generally electrical fittings and household appliances. The fiber used for these purposes is of short staple. The percentages of asbestos used in these articles is indicated in Table II.

PARTICLE SIZE DETERMINATION

Cooke and Hill (22), in autopsies of asbestos workers, have found particles in the lungs measuring up to three hundred and sixty microns in length. Accordingly, in the determination of the average particle size of asbestos dust, all fibers, irrespective of length, were measured.

Methods of Particle Size Determination—Within recent years three general methods have been used for measuring the size of particles. One method, a direct one, involves the use of the filar micrometer inserted in a microscope tube, measurements being made by moving the micrometer adjustment and reading the vernier to determine the diameter of the particles.

The second method, an indirect one, was introduced by Green (55) to determine the size of paint and rubber pigments. It has since been applied to the measurement of the average size of industrial dusts. In this method, an indirect one, photomicrographs of the sample are made on lantern slides, which are then projected by a stereopticon on a screen at a known magnification. The images are measured and the average size calculated from these readings.

With the third method, the dust is collected on a microscope slide, and the images projected on a ground-glass screen with a micro-projection apparatus, and measurements made. This latter method is the one used in the present study, and will be described more fully in a later paragraph.

Nature of Asbestos Dust—The dust encountered in asbestos fabricating plants is non-uniform in nature. It is seen to consist of three types: particles more or less spherical in shape; elongated fibers; and cotton fibers. Figure 1 is a photomicrograph of dust pro-

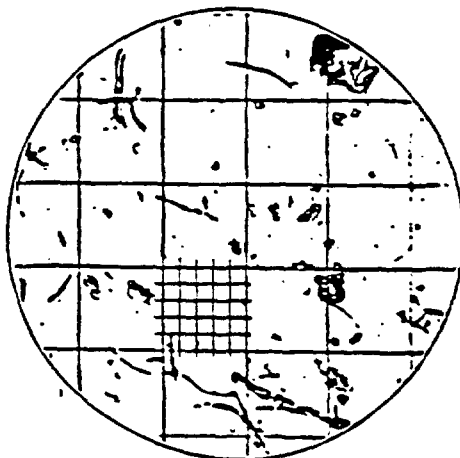


FIGURE 1. PHOTOMICROGRAPH OF DUST FROM AN ASBESTOS FABRICATING PLANT. MAGNIFICATION 600 DIAMETERS

duced when processing mill fiber. The three types can be readily noted.

Because of the non-uniformity of this type of dust, average particle size was determined in two dimensions, one at right angles to the other. Measurements were made of the longest diameters, which were termed longitudinal diameters, and a second set of measurements were made at right angles to the first, which were termed transverse diameters.

Method of Collection—Samples for the determination of particle size were collected by the use of the electric precipitator (30). This method yielded samples that were satisfactory for direct micro-projection and measurement. No intermediate steps for preparing the sample were necessary.

The precipitator employed was designed on the principle of the Cottrell precipitator. The air was drawn through the precipitating tube by a small rotary fan driven by a motor, the rate of flow being measured by a flowmeter. The rate of sampling was one cubic foot (28.3 liters) per minute. The precipitating tube was made of Pyrex glass with an inside diameter of 2.4 cm. A number 1 microscope cover slip, 22 by 70 mm. in size was placed in the precipitating tube directly beneath the central electrode. The dust in the air was deposited electrically on this cover slip. When a representative sample had been precipitated, the cover glass was removed and mounted dry on a microscope slide. A total of sixteen samples was collected at various operations, all being taken in the breathing zone of the workers.

Measurement—A micro-projection apparatus with the microscope arranged in a horizontal position was used. Apochromatic objectives, 8 mm. and 2 mm., and a 10x compensating eyepiece were employed. This system practically eliminated color fringes, gave a flat field, furnished maximum light intensity, and permitted the measurement of the long fibers.

The images were projected on a ground-glass screen at a predetermined distance from the microscope. This screen was ruled in centimeter squares to facilitate measuring. A transparent rule was used, and the size of the projected images recorded in millimeters. Accurate focusing on each individual particle before measuring was accomplished by a remote control attached to the fine adjustment of the microscope by a mechanical sleeve.

Predetermined magnifications of 2000 and 10,000 were used, depending on the objective. Measurements were made according to the method suggested by H. L. Green (56). Using the 8 mm. objective (magnification 2000) the longest diameters of two hundred particles were measured, all lengths less than ten millimeters (five microns) being neglected. The number of fields examined was also recorded. An equal number of particles was measured using the 2 mm. objective (magnification 10,000), and all particles fifty millimeters (five microns) and over were disregarded. Again the number of fields examined was recorded. These measurements were used to calculate the average longitudinal diameter of the sample. The method of calculation is shown in Table III. For the calculation of the average transverse diameter the same procedure was

followed, with measurements being made at right angles to the longest diameters.

TABLE III—EXAMPLE OF METHOD USED IN THE CALCULATION OF AVERAGE LONGITUDINAL DIAMETER

Magnification—2000 133 Fields					Magnification—10,000 112 Fields				
mm.	u	f	f ₁	f ₁ x u	mm.	u	f	f ₁	f ₁ x u
10	3.0	21	0.00613	3.48073	3	0.3	27	1.11	1.11
12	4.0	7	.00206	1.39200	4	0.4	27	1.48	1.48
13	4.5	3	.00045	0.64642	5	0.5	38	1.90	1.90
14	7.0	4	.00139	0.92820	6	0.6	7	0.42	0.42
15	7.5	12	.00378	2.75150	7	0.7	2	0.14	0.14
16	8.0	1	.00015	0.26320	8	0.8	10	3.00	3.00
17	8.5	1	.00015	0.23178	9	0.9	1	0.90	0.90
18	9.0	8	.00250	2.38680	10	1.0	23	2.30	2.30
20	10.0	9	.00251	2.98350	12	1.2	4	4.80	4.80
21	10.5	1	.00015	0.34807	13	1.3	1	1.30	1.30
22	11.0	3	.00045	1.08398	15	1.5	11	1.65	1.65
23	11.5	2	.00020	0.78215	20	2.0	12	24.00	24.00
24	12.0	1	.00015	0.28780	21	2.1	2	4.60	4.60
25	12.5	10	.00340	6.87000	25	2.5	2	5.00	5.00
27	13.5	1	.00015	0.44753	30	3.0	7	21.00	21.00
28	14.0	1	.00015	0.48410	33	3.3	4	14.00	14.00
29	14.5	1	.00015	0.46487	40	4.0	1	4.00	4.00
30	15.0	8	.00250	2.87600	45	4.5	1	4.50	4.50
32	16.0	1	.00015	0.57040					
33	17.5	9	.00251	5.22112					
34	18.0	1	.00015	0.58670					
37	18.5	1	.00015	0.61322					
38	19.0	2	.00030	1.23470					
39	19.5	2	.00030	1.20093					
40	20.0	13	.00300	8.61800					
42	21.0	1	.00015	0.69415					
43	21.5	1	.00015	0.71272					
45	22.5	3	.00045	2.23782					
47	23.5	1	.00015	0.77908					
50	25.0	4	.00120	3.31500					
53	27.5	5	.00157	4.53812					
60	30.0	8	.00250	9.15600					
63	31.5	1	.00015	1.04423					
65	32.5	3	.00045	2.38680					
67	33.5	1	.00015	1.11082					
70	35.0	4	.00120	6.90150					
73	36.5	1	.00015	1.20097					
75	37.5	2	.00030	2.45625					
80	40.0	2	.00030	2.85200					
83	42.5	2	.00030	2.81773					
85	47.5	1	.00015	1.57462					
100	50.0	1	.00015	1.65750					
110	55.0	4	.00120	7.22070					
120	60.0	1	.00015	1.98000					
130	65.0	4	.00120	5.61900					
140	70.0	2	.00030	4.84100					
160	80.0	2	.00030	7.95600					
170	85.0	1	.00015	2.81773					
175	87.5	1	.00015	2.90088					
180	90.0	1	.00015	2.97860					
200	100.0	1	.00015	3.15500					
210	105.0	1	.00015	2.46025					
220	113.0	1	.00015	3.81223					
240	120.0	3	.00045	11.87400					
263	122.5	1	.00015	4.39237					
300	145.0	1	.00015	5.46873					
370	163.0	1	.00015	6.12223					
Total		200	0.63070	174.11003					

mm. = Length of image in millimeters.

u = Length of particle in microns.

f = Frequency

$f_1 = \frac{112 \times f}{133 \times (3)^2}$

Average Diameter = $\frac{\sum (f \times u) + \sum (f_1 \times u)}{\sum f + \sum f_1}$

= 1.33 microns.

Results—Particle size determinations were made on samples of the dust collected at various stages in the process of manufacture but no appreciable variation was found. However, there was a marked difference in the average particle diameter of the dust from the two general grades of asbestos fiber. The calculated longi-

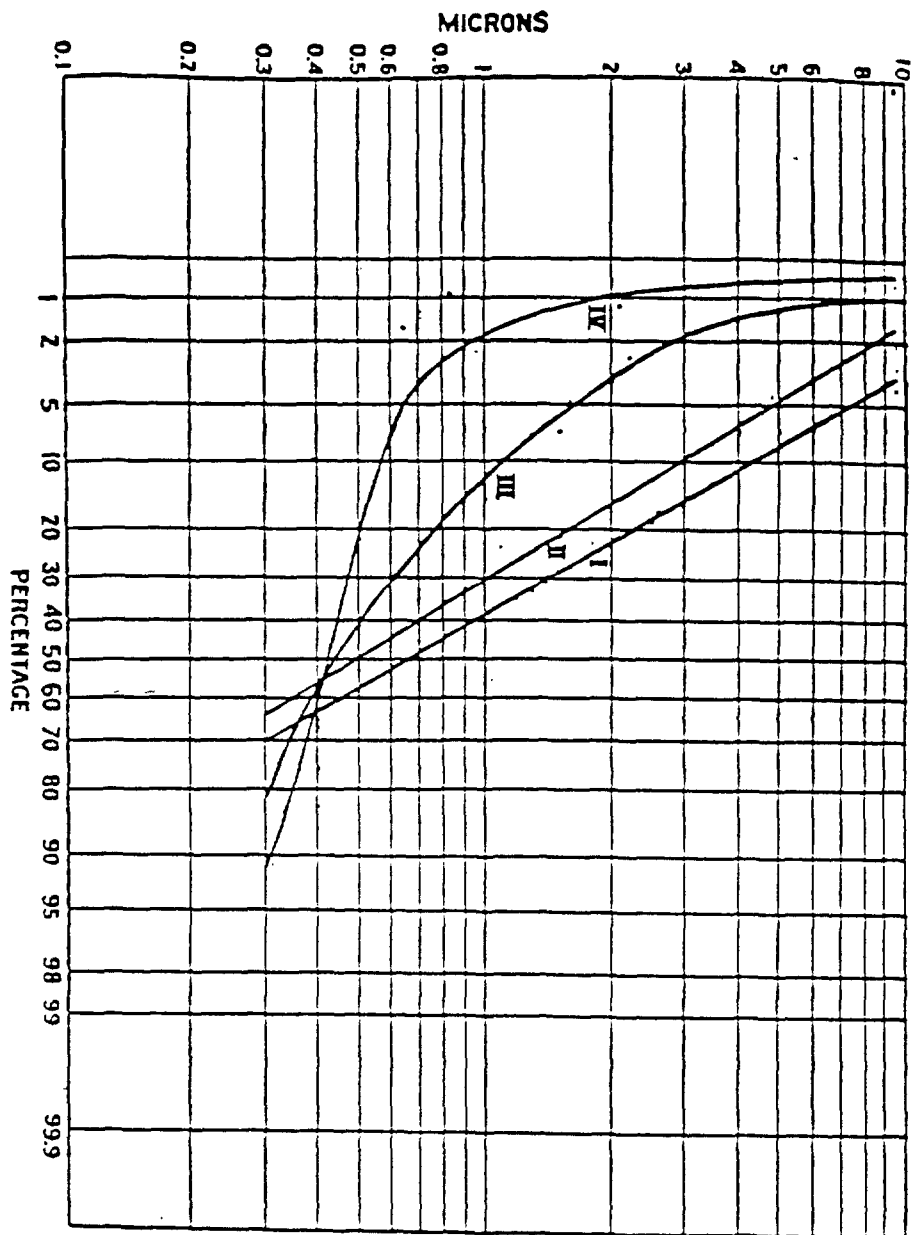


FIGURE 2. SIZE FREQUENCY CURVES FOR DUST FROM ASBESTOS FABRICATING PLANTS SHOWING PERCENTAGE LESS THAN STATED SIZE. I—LONGITUDINAL DIAMETER, CRUDE FIBER; II—LONGITUDINAL DIAMETER, MILL FIBER; III—TRANSVERSE DIAMETER, CRUDE FIBER; AND IV—TRANSVERSE DIAMETER, MILL FIBER

tudinal diameter of the dust from crude fiber was found to be 2.12 microns, while that of mill fiber was 1.35 microns. Transverse diameters were 0.69 microns and 0.45 microns for crude and mill fiber respectively. The longest fiber observed measured four hundred and two microns.

The percentage frequencies of the various-sized particles were determined for longitudinal and transverse dimensions. Figure 2 shows these values plotted on Hazen's logarithmic probability paper.

The difference in the two types of dust is further shown by examination of Table IV. Three per cent of the crude fiber dust was ten microns or more in length, while only 1.7% of the mill fiber dust occurred within these limits. Twenty per cent of the mill fiber dust was 0.5 microns or less in length, while only 16% of the crude fiber dust fell within this range.

TABLE IV. SIZE FREQUENCY DISTRIBUTION OF ASBESTOS DUST

Size Group in Microns	Crude Fiber		Mill Fiber	
	Longitudinal	Transverse	Longitudinal	Transverse
Under 0.49	37.9%	50.1%	46.9%	78.3%
0.5-0.99	27.4	25.0	24.8	20.3
1.0-1.49	5.2	7.8	7.5	—
1.5-1.99	6.2	3.4	4.0	—
2.0-2.49	4.5	1.5	4.6	0.5
2.5-2.99	2.9	—	2.6	—
3.0-3.49	3.2	—	1.7	—
3.5-3.99	2.7	—	1.0	—
4.0-4.49	3.3	—	2.0	—
4.5-4.99	2.6	—	2.0	—
5.0 and over	4.0	1.2	3.0	0.7

DUST CONCENTRATIONS IN THE PLANTS

All samples were collected by the modified form of the Greenburg-Smith impinger (38) using ninety-five per cent U. S. P. ethyl alcohol as the collecting medium. Dust counts were made according to the method described in Part I of this report (41). All particles were counted regardless of size. Particles less than ten microns in greatest diameter averaged approximately ninety-seven per cent of the total. The dust counts for the different operations are shown in Table V.

TABLE A. SUMMARY OF DUST CONCENTRATIONS IN ARBESTON FABRICATING PLANTS

Department	Occupation	Plant A		Plant B		Plant C		Plant D	
		Number of Samples	Millions of particles cu. ft. of air	Number of Samples	Millions of particles cu. ft. of air	Number of Samples	Millions of particles cu. ft. of air	Number of Samples	Millions of particles cu. ft. of air
Preparation	Feeding Saco-Loswell Opener-Crude Fiber	1	....	2	20.2-37.3	1	....	1	....
	Feeding Mixing Picker-Crude Fiber	1	....	1	2.2	1	....	1	....
	Feeding Saco-Loswell Opener-Mill Fiber	1	....	1	110.4-121.3	1	....	1	....
	Feeding Mixing Picker-Mill Fiber	1	....	1	10.7	1	....	1	....
Carding	Feeding Saco-Loswell Opener-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Mixing Picker-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Saco-Loswell Opener-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Mixing Picker-Mill Fiber	1	....	1	....	1	....	1	....
Weaving	Feeding Saco-Loswell Opener-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Mixing Picker-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Saco-Loswell Opener-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Mixing Picker-Mill Fiber	1	....	1	....	1	....	1	....
Winding (Spooling)	Feeding Saco-Loswell Opener-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Mixing Picker-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Saco-Loswell Opener-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Mixing Picker-Mill Fiber	1	....	1	....	1	....	1	....
Rope and Wick	Feeding Saco-Loswell Opener-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Mixing Picker-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Saco-Loswell Opener-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Mixing Picker-Mill Fiber	1	....	1	....	1	....	1	....
Bridling	Feeding Saco-Loswell Opener-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Mixing Picker-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Saco-Loswell Opener-Mill Fiber	1	....	1	....	1	....	1	....
	Feeding Mixing Picker-Mill Fiber	1	....	1	....	1	....	1	....

The relative degree of dustiness in the various departments of the four asbestos fabricating plants surveyed is indicated in Table VI. This summary of the average concentrations from the different plants has been prepared from the data contained in Table V.

TABLE VI. RELATIVE DUST CONCENTRATIONS IN DEPARTMENTS OF ASBESTOS PLANTS

Department	Number of Samples	Concentration—Millions of Particles per Cubic Foot of Air		
		Minimum	Maximum	Average
Preparation and Carding	36	0.6	123.2	44.36
Weaving and Mule Spinning	41	1.0	74.2	16.67
Twisting, Winding, Rope and Wick, Braiding, Gasket, etc.	22	0.3	20.6	4.64

It will be seen that the highest dust concentration occurs in the preparing room, where the asbestos receives its preliminary treatment. The lowest concentration is associated with the making of ring gaskets. The figures given in Table VI, while showing the relative dustiness, do not explain fully the conditions in each department. The concentration of the dust in the successive phases of the process varies, depending on the type of fiber used and the method of manufacture. In order to explain these variations, it is necessary to discuss separately, conditions encountered in the several operations. The figures given in the following paragraphs represent the concentration of dust in millions of particles per cubic foot of air.

Preparation—The dust in the preparing rooms is practically all due to pure asbestos, no cotton having yet been added. The degree of dustiness depends primarily on the type of fiber used. Thus, it was found in plant B that when mill fiber was fed into the Saco-Lowell opener, the average count was 119.4, as compared to a concentration of 33.2 when the longer-staple crude fiber was treated in exactly the same way.

In plant D one of the operations involved the screening of short-length mill fiber without first passing it through a Saco-Lowell opener. The employee engaged in feeding the material onto the screen was found to be exposed to a concentration of 65.7. A second workman, whose duty was to fill burlap bags with the screened fiber after it had been removed from the shaker by suction, was exposed to a concentration of 96.1.

In the mixing room, where the cotton and asbestos are blended, the degree of dustiness was again found to depend primarily on the type of fiber used. For example, the concentration of dust was 10.6 when a mixture of cotton and mill fiber was being fed into the mixing picker. The concentration dropped to 3.1 when the mixture

was made from crude No. 1 fiber. In plant D, when the lowest grade mix was fed into the picker, the concentration was 84.7.

Carding—The marked difference in the total dust count in the carding operation as the result of using different grades of asbestos will again be seen. When the crude fiber mixture is being carded for the manufacture of electrical insulating tape, a concentration of 1.1 was noted. The mixture for cheaper grades of yarn, such as that used for weaving brake lining, is generally made from mill fiber. The concentrations of the dust when mill fiber was being carded were 23.4, 24.3, 29.8, and 80.0. The samples were collected in card rooms of various plants.

Occasionally the loose web of asbestos and cotton, as it emerges from the breaker card and passes over the camel-back, becomes broken. It is then the duty of the operator to go to the rear of the card and repair the broken web, the task requiring approximately one-half hour per day. It was found in one plant that the employee was exposed to a concentration of 57.5 during this time, while during the remainder of the day he was exposed to a concentration of 24.3.

At intervals it is necessary to shut down the card and clean or "strip" the rolls. This is done by scraping them with a hand-card, which is a brush covered with strips of card cloth. The cylinders are slowly turned by hand at the same time. The dust concentration during this operation was 5.5. Sometimes the rolls are cleaned while they are being turned at the customary carding speed. The employees stated that this was a very dusty operation, but it was impossible to obtain samples during this procedure.

Weaving—The concentration of dust in weaving is dependent on many factors, but principally upon the following: (1) quality of the warp and fill being used; (2) whether weaving is done dry or wet; (3) conditions of ventilation; and (4) nature of the finished product.

The influence of the first factor is shown in the weaving of insulating tape and brake lining in plant C. A concentration of 6.9 was associated with the weaving of tape (made from crude fiber). In the weaving of brake lining made from mill fiber, the count was 27.1. In both of these operations the warp was dry and the fill wet.

As pointed out in the description of the weaving process (page 8), weaving may be done either with the yarn dry or moistened with water. The presence of moisture materially decreases the concentration of the dust. For example, in the wet weaving of brake lining the concentration is 6.1, but when it is woven dry the count increases to 27.0.

The effect of ventilation is shown in the weaving of cloth in plant D. In this plant, ordinary electric fans were located just back of the weavers, so that dust generated in the process would be blown away from the worker's breathing zone. When the fans were operating the concentration of dust in dry weaving of cloth forty inches wide was 9.9. When the fans were turned off, the figure rose to 33.3.

The fourth factor, nature of the finished product, also influences the degree of dustiness. Thus, the average concentration en-

countered in weaving insulating tape was 10.5; that of cloth, 21.3; and of brake lining, 23.0

The looms in time accumulate a great deal of lint. This is removed periodically (generally once a week) by beating the loom with a flexible rubber paddle. Each weaver cleans his own loom, the time required being approximately one-half hour per week. During this operation the dust concentration was 74.1.

Spinning—The concentration of dust in the mule spinning room depends on the type of asbestos fiber used in the making of the yarn. A count of 2.1 existed during the spinning of yarn made from crude fiber for the weaving of insulating tape. A yarn made from a high grade of mill fiber produced a concentration of 5.5. The dust associated with the spinning of commercial grade yarn, the cheapest grade made, was found to be 13.2. These figures are for the mule spinning in plant B. In plant A the average concentration to which the mule spinners were exposed was 23.0. In this plant all operations from preparing to weaving were carried on in the same room. Consequently, it is impossible to state that this concentration is due to mule spinning alone.

Other Operations—The minor mechanical operations necessary in the production of asbestos textiles have relatively small concentrations of dust associated with them. In the winding operation in plant A this was found to be 8.0. Again, this number cannot all be ascribed to winding because of the fact that all operations were performed in the same room. In plant B, in the twisting room, a figure of 2.4 was found associated with twisting two-ply yarn. This figure increased to 4.0 when yarn was twisted three-ply.

Warping is a mechanical transfer of the twisted yarn to large spools or warp beams for the looms. It gives rise to very little dust, the concentration being 1.0.

DUST CONCENTRATIONS IN OTHER PROCESSES

In addition to the fabrication of asbestos textiles, one of the plants manufactured other products in which the amount of asbestos was considerably less than the amount used in textiles. These products included 85% magnesia insulation, molded brake lining, asbestos cements, shingles, lumber, and tile. One plant made asbestos paper which contains ninety-five per cent of short-staple mill fiber. Determinations of the dust concentrations were made at some of these operations. The results are shown in Table VII.

OTHER POTENTIAL HAZARDS

This survey was concerned only with the hazard caused by asbestos dust, but other materials that must be considered as potential hazards were found. These materials are gasoline and benzol in the gasket and molded brake lining departments, talc dust in the gasket room, and lead compounds in the rubber mixing department. In the finishing asbestos lumber and tile, additional potential hazards are lacquer solvents and sand from the grinding and polishing operations.

TABLE VII. DUST CONCENTRATIONS OF MISCELLANEOUS OPERATIONS IN AN ASBESTOS PLANT

Department	Operation	Number of Samples	Concentration in Millions of particles per cubic foot of Air
Paper Mill	Crushing asbestos (mill fiber)	2	53.3-154.2
	Bagging asbestos (mill fiber)	1	130.4
	Sawing "air cell" pipe covering	1	18.4
Shingle plant	Sawing asbestos lumber	1	130.2
	Sanding asbestos lumber and tile	2	19.8-22.3
	Grooving bathroom tile	2	23.1-32.2
	Dusting tile (paint spray booth)	1	34.7
Magnesia (15% asbestos)	Filling barrels with magnesia	1	324.6
	Shoveling magnesia on pile	1	2408.6
	Dumping barrels into mixer	1	222.2
	Cleaning pipe molds	2	163.7-199.3
	Feeding insulation into trimmer	1	1.9
	Removing insulation from trimmer	2	5.4-15.1
	Crushing and bagging scrap	2	253.0-263.0
Clutch Facing	"Skinning" facings	1	3.9
	Grinding asbestos paper clutch facings	2	434.4-512.7
	Drilling paper clutch facings	1	15.2

**ASBESTOSIS—PART III.—The Effects of Exposure to Dust
Encountered in Asbestos Fabricating Plants on the Health
of a Group of Workers.**

Complete physical examinations were made of sixty-four persons (48 men, 16 women) employed at the time in the plants listed in Part II of this report. Of this number seven men without previous exposure were used as controls. Selection of the workers was restricted to those employed in textile manufacture. Those workers longest employed were chosen because the necessity of including a sufficient number from this group is evident. Attention was also paid to the group with exposures of shorter duration and to the particular operation at which the worker was employed. Table VIII shows their age distribution.

TABLE VIII. DISTRIBUTION BY AGE OF ALL PERSONS EXAMINED

Group	Number of Persons Examined	Number in Age Group				
		Under 20	20-29	30-39	40-49	50 and over
Controls	7	1	2	—	1	3
Asbestosis	14	—	7	6	—	1
Negative	43	15	12	11	4	2
Totals	64	16	21	17	4	6

Asbestosis was found in fourteen persons (12 men, 2 women), or 25 per cent of the exposed group. Forty persons were diagnosed as negative and the remaining three doubtful. Of the latter group, one individual had previous exposure to silica dust which may have been the primary or contributing cause and, as a result, has been eliminated from any further consideration. The cases having asbestosis were divided into those having slight and moderate pulmonary fibrosis, no advanced cases having been found. The estimation of the degree of involvement depended on the amount and extent of fibrosis seen roentgenologically and in the clinical findings.

The present, past, and family medical, and previous occupational histories were secured from each worker. Direct questions, which might influence the individual's replies in regard to his subjective symptoms, were avoided in obtaining chief complaints. The predominating subjective symptoms in the positive group were cough and dyspnea. Other major subjective symptoms were dry throat and frequent colds. One individual in this group had no subjective symptoms.

Objectively, the major symptoms were again cough and dyspnea. Thirteen persons of those diagnosed positive for asbestosis complained of cough, and eight of dyspnea. Other frequently elicited objective symptoms were frequent colds, palpitation, weakness, precordial pain, and pharyngeal dryness. No objective symptoms could be obtained from one individual in the positive group.

Occurrence of acute respiratory infections was particularly observed in the past medical history. Frequent coryza or other upper air-passage infections which did not result in a loss of time of three or more working days, were listed as objective symptoms. Pneumonia during the course of employment occurred in three of the positive and seven of the negative group. The past medical histories were otherwise negative except for an attack of pleurisy in one individual of the exposed group diagnosed as negative.

Family histories and, in particular, tuberculous contacts were noted. Two workers with asbestosis had roentgenological evidence of healed tuberculosis and negative family histories. Two others who showed evidence of healed tuberculosis, and who did not have asbestosis, also had negative family histories.

Physical examinations were made with the workers stripped to the waist. Mean variations in the present and greatest weight were less in the asbestosis group than in the group diagnosed as negative and in the controls. Five-minute oral temperatures showed a maximum elevation of 0.5°C. Four persons having asbestosis had an elevation of temperature and eleven in the negative group showed it. Elevation of body temperature in the control group was absent. The mucous membranes of the nose and throat of the entire group were essentially negative. The conjunctivae did not appear to be irritated. Tenderness over the antra and frontal sinuses was not found. Deflected nasal septa were common, and diseased tonsils were noted in a few cases. The external auditory canals did not show evidence of plugging or irritation.

Clinical examination of the thorax included inspection, palpation, percussion, and auscultation of the heart and lungs. A tendency to increased anterior-posterior diameters of the chest in the positive exposed group was noted. In the positive group the respiratory murmur and vocal resonance were impaired in five cases. Crepitant, subcrepitant, sibilant, and sonorous rales occurred in nine of the asbestosis cases, the two latter types being predominant.

The recognition of cyanosis presented a difficult problem. When it occurred the skin had an unhealthy leaden hue, with variations in the degree of intensity in the three individuals in the positive group showing this physical sign.

Roentgenological examinations, made of all workers, included fluoroscopic examination, stereoscopic anterior-posterior and oblique skiagrams of the chest. In addition to noting gross chest pathology, the movement of the diaphragm was measured in centimeters during the fluoroscopic examination. Right and left oblique exposures of the chest aided in the interpretation of the films and particularly in the detection of thickened pleura. The hila, trunk, and lung markings of the fibrotic lungs were increased in prominence. In some films the lung fields showed a slight tendency toward beading and nodulation. A small area in the distal third of the lung in one

film suggested atelectasis. Increased aeration, such as one sees in emphysema, occurred in a few cases. Thickened pleura and adhesions were noted in a few cases. The average movement of the domes of the diaphragm of the positive group was less than that of the negative exposed or control groups. Three of the positive and two of the negative group were found with roentgenological evidence of healed tuberculosis. Further evidence of pulmonary disease in four of the positive group was clubbing of the fingers.

The occurrence of asbestos bodies and the presence of *B. tuberculosis* were determined in a single specimen of sputum obtained from each person. Each employee was instructed in the proper method of obtaining the sputum specimen, and was requested to collect a morning sample. An equal volume of antiformin was added to each sample. After complete digestion of the mucus, the mixture was centrifuged for three minutes at approximately 2000 r. p. m. and the supernatant liquid decanted. Distilled water was added to the solid centrifuged portion, and the mixture recentrifuged for three minutes. A drop of the deposit was transferred to a microscope slide and examined for the presence of asbestos bodies under both 8 mm. and 4 mm. objectives.

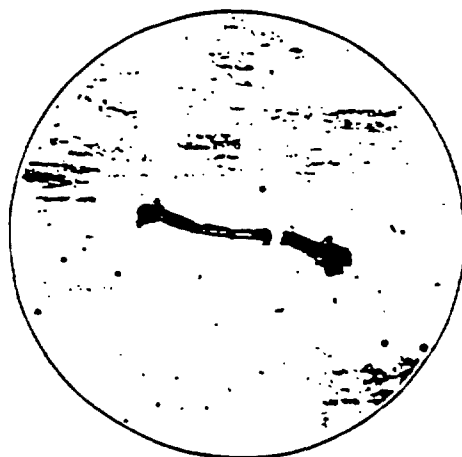


FIGURE 3. PHOTOMICROGRAPH OF
ASBESTOS BODY. MAGNIFICATION 600
DIAMETERS

The greater percentage of sputum specimens were of a whitish color, but a few were muco-purulent. The asbestos bodies were a pale yellowish brown color and varied in size, shape, and number. The largest asbestos body found measured 117 microns in length. The bodies occurred singly, clumped, and as fragments. When present singly or in clumps, they presented a bead-like appearance or a dumb-bell shape, with bulbous ends tapering into a narrow strand at a position midway between the ends. Figure 3 is a photomicrograph of a single asbestos body. In one specimen an average of two or three asbestos bodies or fragments of bodies were seen in

each low-power field, while in others, only one or two bodies were found in the entire specimen. Table IX gives the occurrence of asbestos bodies in a single specimen from each person. Merewether (74) reports that the presence of asbestos bodies cannot be taken at present as indicating anything more than previous exposure to asbestos dust. This is in accord with our findings for it will be noted that they were found in a specimen obtained from one of the controls who at the time was suffering from an acute bronchitis, productive of a muco-purulent sputum. This worker had been employed as a packer foreman in the magnesia department for fifty years. His only exposure to asbestos dust was a rare visit to other parts of the plant.

TABLE IX. OCCURRENCE OF ASBESTOS BODIES IN SPUTUM

Group	Number			Percentage					
	Asbestososis	Negative	Control	Based on Total Number of Persons			Based on Specimens Examined		
				Asbestososis	Negative	Control	Asbestososis	Negative	Control
Asbestos Bodies present	7	10	1	50.0	22.5	14.3	58.3	47.6	21.0
Asbestos Bodies absent	5	11	1	22.7	26.2	12.5	41.6	52.3	79.0
No Specimens	2	21	1	14.3	50.0	42.8	.....	.....	.....
Totals	14	42	3						

A single sputum specimen obtained from each individual was stained and examined for the presence of *B. tuberculosis*. Both direct smears and centrifuged antiforminized specimens were found to be negative.

Clinical examination of the heart showed the apical impulse to be displaced in a few cases. Apical systolic murmurs were heard in five of the positive and two of the negative groups. The blood pressure was determined with a standard mercury sphygmomanometer. Hypertension, although present in a few cases in each group, occurred only in the older workers. Roentgenological evidence of enlargement of the heart was not found. However, the cardiac silhouette in two individuals having asbestosis was found to be top normal in size.

Electrocardiograms of fifty-six of the workers were made following a thirty-minute rest period during which the subject was in a reclining position, while eight were taken with the subject in a sitting position following a short rest period. The most consistently positive electro-cardiographic finding in the entire group was low voltage. It was found to be present in seven of the positive and

eighteen of the negative groups, compared with four of the controls. Right predominance was not present in the tracings of the control group, but did occur in two tracings of individuals with asbestosis and three of the negative group. Left predominance was most frequently found in the tracings of individuals in the advanced age groups. Katz and Slater (62) found eighty-six per cent of individuals with a second positive wave of the Q-R-S complex to have changes in the heart muscle. Our findings show that six of the exposed group had a second positive wave of the Q-R-S complex; two of these had asbestosis, and four were negative, as compared with an absence of this finding in the control group. The P-R interval was increased in the tracings of two exposed persons found to be negative.

A functional test of the individual's response to effort was performed by having him place one foot on a chair and then raise his body twenty-five times in thirty seconds. The pulse rate was determined immediately before and after exercise, and again at the end of a two-minute rest period. The respiratory rate was determined immediately before and two minutes after the exercise test. Table X gives the results of the functional test. Greater variations were seen in the rate of respiration following exercise in the exposed group as compared with the controls than were seen in the pulse rate. Individuals with a pulse rate of 10 above the normal resting rate, two minutes after exercise, were considered abnormal.

TABLE X. FUNCTIONAL TEST OF RESPONSE TO EFFORT

Group	Pulse ¹		Respiration ²	
	Number	Percentage	Number	Percentage
CONTROLS				
Male	--	--	2	20.0
Female	--	--	--	--
NEGATIVE				
Male	3	15.5	15	64.1
Female	2	14.3	4	28.5
ASBESTOSIS				
Male	1	8.3	6	66.6
Female	--	--	1	50.0

¹ Pulse rate 10 above normal resting rate two minutes after exercise.

² Respiratory rate 2 above normal resting rate two minutes after exercise.

Asbestos warts are thought to be produced by a fiber of asbestos which has become lodged in the skin, largely through the irritation and overgrowth of the horny and malpighian strata (27). These growths are usually found on the hands but may also develop on the feet. Forty per cent of the exposed group had one or more of these papillomas on their hands.

Routine blood counts and urinalyses were made on each individual examined. Haemoglobin was determined by the Haden and Hausser colorimetric method and expressed as grams of haemoglobin per 100 cc. of blood. Smears for differential counts were stained with Wright's stain and 200 cells studied microscopically using a 2 mm. oil immersion objective. Practically no change was observed in the blood picture of the three groups. Comparable average variations did not occur in either the erythrocyte or leucocyte count. In two individuals with moderately advanced pulmonary fibrosis, the total leucocyte counts were 10,800 and 11,400 with corresponding increases in the percentages of polymorphonuclear leucocytes. Changes in the percentages of other types of white cells were not observed.

Urine specimens were collected from each worker at the time of physical examination. Specific gravity, albumin content, and the presence of sugar were determined and a microscopic examination made of a centrifuged portion. Urinalyses were essentially negative except for a trace of albumin in four of the positive and thirteen of the negative exposed groups, as compared with two of the controls.

A brief summary of the clinical findings of three asbestos mill workers and the accompanying illustrations (Figures 4 to 7 inc.) are presented to show the two stages of asbestosis encountered in this study.

Case number A-8730—White male; aged 30 years.

Chief complaints—Cough.

Objective symptoms—Occasional frontal headache (2) Epistaxis rare (3) Dry unproductive cough (4) Coughing attacks precipitated by strenuous exercise.

Past Medical History—Usual childhood diseases. Traumatic orchitis, 1934.

Occupational History—Began working at 16 years of age. Millman, 2 years. Mule spinner, worsted mill, 2 years. Ice man, 1 year. Mule spinner, asbestos fabricating plant, 9 years.

Physical Examination—Apparently healthy adult male. Height 62 inches. Weight 122 pounds (greatest weight 122 pounds). Skin clear. No cyanosis. Asbestos warts on both hands. Pulse rate before, immediately after, and two minutes after exercise, 84, 100, 72. Respiration rate immediately before and two minutes after exercise, 20, 22. Chest, normal shape; percussion normal; breath and voice sounds normal; sibilant and sonorous rales both bases. Heart, apical impulse, 5th interspace mid-clavicular line; no murmurs. Blood pressure 134/90.

Fluoroscopy—Diaphragmatic movement, right dome, 2.5 cm.; left dome, 1.5 cm.

X-Ray—Thoracic cage is negative. The trachea is in the midline. The cardiac silhouette is within normal limits of size. The arch of the aorta is not widened. The domes of the diaphragm are somewhat irregular on the left side but fairly irregular on the right. The pleura appears to be slightly thickened on the left side, and is more clearly shown in the oblique view. In the right apex there is possibly an old healed tuberculous process giving the appearance of an apical cap. The hila are increased in prominence. The trunk markings and linear markings are increased in prominence.

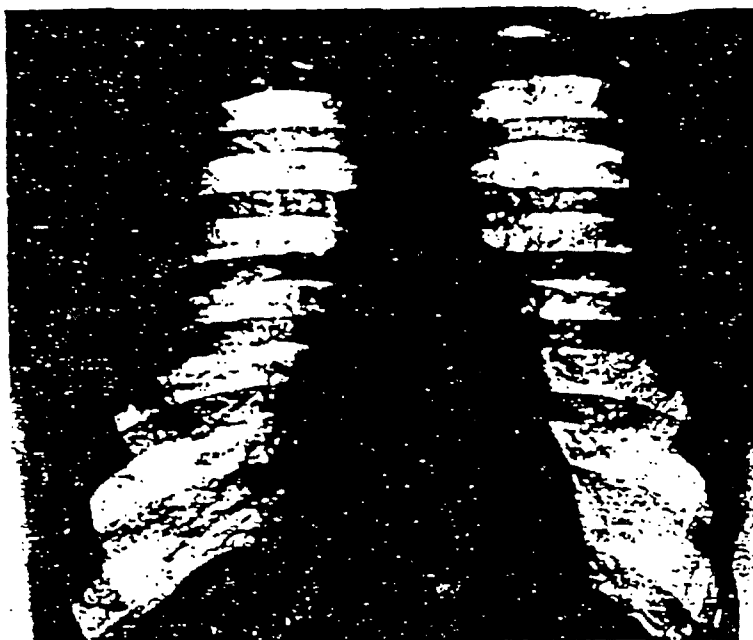


FIGURE 4. CASE NUMBER A8730.

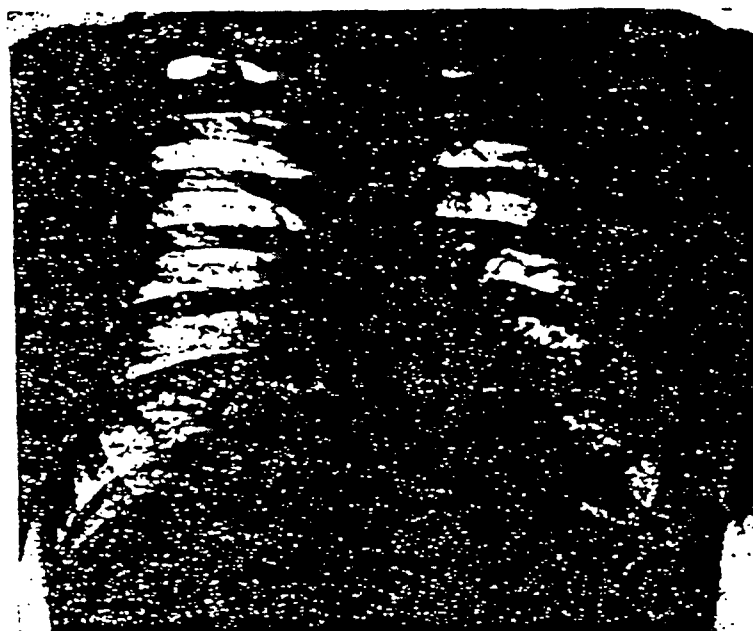


FIGURE 5. CASE NUMBER 447.

01 501 0684

Electrocardiogram—Cardiac rate 72. P-R interval 0.16 second. Voltage 4 mm.

Diagnosis—Asbestosis, slight.

Case Number 447—White male; aged 47 years.

Chief Complaints—(1) Cough; (2) Shortness of breath.

Past Medical History—Usual childhood diseases. Gonorrhea, 1922.

Occupational History—Farmer until 29 years of age. Laborer steel works, 2 years. Laborer grain mill, 1 year. Preparation room asbestos mill, 15 years.

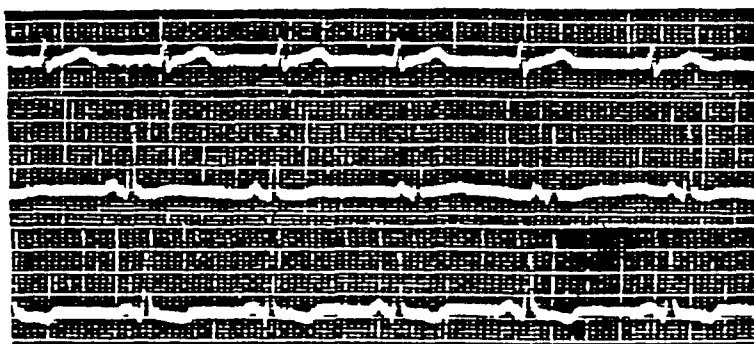


FIGURE 6. ELECTROCARDIOGRAPHIC TRACING OF CASE NUMBER A8730

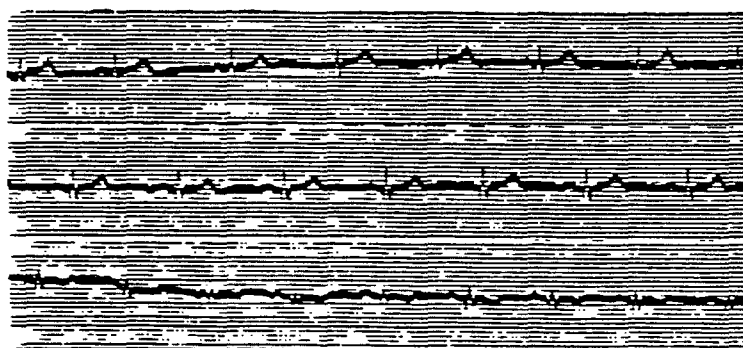


FIGURE 7. ELECTROCARDIOGRAPHIC TRACING OF CASE NUMBER 447

Physical Examination—General appearance fair. Skin clear. Height 59 inches. Weight 120 pounds (greatest weight 125 pounds). No clubbing of fingers. No asbestos warts. Nail beds not cyanotic. Chest, normal shape; percussion normal; respiratory murmur within normal limits; vocal resonance unaltered; sibilant and sonorous rales. Heart, no apparent enlargement; no murmurs. Pulse rate before, immediately after, and two minutes after

functional exercise test, 76, 118, 76. Respiration rate before and two minutes after functional exercise test, 14, 18. Blood pressure 134/90.

Fluoroscopy—Diaphragmatic excursion; right dome, 1.7 cm.; left dome, 2.5 cm.

X-Ray—The thoracic cage is negative. The trachea is in the mid-line. The cardiac silhouette is within normal limits. The domes of the diaphragm are regular. The hila and trunk markings are increased in prominence. The lung markings are also increased in prominence.

Electrocardiogram—Cardiac rate 60. P-R interval 0.16 second. Voltage 3.5 mm. Low voltage of all Q-R-S complexes.

Diagnosis—Asbestosis, moderate.

TABLE XI. INCIDENCE AND DEGREE OF ASBESTOSIS WITH RELATION TO OCCUPATION, DUST CONCENTRATION, AND YEARS OF EXPOSURE

Occupation	Average Concentration Millions of particles per cubic foot	Years of Exposure	Total Number Examined	Asbestosis				
				Negative	Slight	Moderate	Advanced	Doubtful
Preparers and Carriers	44.58	0-5	3	2	--	--	--	1
		6-10	3	--	--	3	--	--
		11-15	5	1	1	2	--	--
		16-20	2	1	1	--	--	--
		over 20	1	1	--	--	--	--
		Total	14	5	2	6	--	1
Weavers and Spinners	16.87	0-5	3	3	--	--	--	--
		6-10	4	3	1	--	--	--
		11-15	4	3	--	1	--	--
		16-20	3	2	2	--	--	--
		over 20	2	2	--	--	--	--
		Total	16	14	3	1	--	--
Winders, Twisters, Warpers, etc.	1.64	0-5	4	4	--	--	--	--
		6-10	7	6	1	--	--	--
		11-15	8	6	1	--	--	1
		16-20	7	1	--	--	--	--
		over 20	1	4	--	--	--	--
		Total	21	21	2	--	--	1
Totals			56	40	7	7	--	2

The principal factors now thought to determine incidence and degree of the pneumoconioses are nature and concentration of the dust, length of exposure, and individual susceptibility. The in-

cidence of asbestosis with relation to occupation, concentration of the dust, and length of exposure in the fifty-six persons examined in this study is indicated in Table XI. Obviously the examination of such a relatively small group prevents the formation of definite conclusions as to the influence of these factors. Nor is it possible from our findings to establish the maximum safe concentration of asbestos dust in the air. However, the results of this investigation show the necessity of a reduction of the dust concentrations in those operations, shown in Part II of this study, where there is continuous exposure to high concentrations.

SUMMARY

- (1). The concentration of dust in asbestos fabricating plants depends primarily on the grade of asbestos; mill fiber gives rise to a higher concentration than crude fiber. Operations arranged in decreasing concentration of dust are preparing, carding, weaving, spinning, twisting, winding, and warping.
- (2). The average particle size of asbestos dust is stated in two diameters, longitudinal and transverse.
- (3). Petrographic analyses of dust encountered in asbestos fabricating plants collected in the workers' breathing zone shows it to contain no free silica.
- (4). Fourteen, or 25% of fifty-six workers employed in the textile departments of asbestos fabricating plants in Pennsylvania had both clinical and roentgenological evidence of asbestosis.

ACKNOWLEDGMENTS

The Department of Labor and Industry of the Commonwealth of Pennsylvania wishes to thank the management and employees of the plants studied for their cooperation and interest which made the success of this study possible; Dr. H. K. Pancoast and Dr. E. P. Pendergrass of the University of Pennsylvania, whose interpretations of the films have been used; Dr. G. W. Grier of the University of Pittsburgh, for his interpretation, assistance, and advice in the roentgenological study; Dr. J. Evans Scheehle, Secretary of the Pennsylvania Department of Welfare, in extending to the Department of Labor and Industry the facilities of his department; Dr. C. A. Laubach, roentgenologist and cardiologist of the Norristown State Hospital, for doing a large majority of the X-ray work, and his technicians for the routine laboratory examinations; Dr. J. D. Heard and Dr. A. B. Fuller of the University of Pittsburgh, and Dr. C. C. Wolferth of the University of Pennsylvania, for their assistance and interpretation of the cardiograms.

BIBLIOGRAPHY

1. Amiante. Hyg. du trav., 1:191-192, 1930.
2. Anderson, H. V., and Clark, G. L.: Application of X-rays in the Classification of Fibrous Silicate Minerals Commonly Termed Asbestos. Ind. and Eng. Chem., 21:924-933, 1929.

3. Auribault: Notes sur l'hygiène et la sécurité des ouvriers dans les filatures et tissages d'amianté. Bull. de l'Insp. du trav., p. 120-132, 1906.
4. Baader, E. W.: Asbestose mit Warzenbildung. München med. Wehnschr., 79:83, 1932.
5. Beger, P. I.: Ueber die Asbestosis Körperchen. Virch. Arch., 290:280-353, 1933.
- 6. Beger, P. I.: More on Asbestosis Bodies. Virch. Arch., 293: 530-539, 1934. Abstr., J. Ind. Hyg., 17:32, 1935.
- 7. Beger, P. I.: Injurious Factors in Asbestosis and Silicosis. Med. Klin., Sept. 14, 1934, p. 1258-1261; 1922-1927. Abstr., J. Ind. Hyg., 17:32, 1935.
8. Beintker, E.: Asbestosis. Arch. f. Gewerbepath. u. Gewerbehyg., 2:345-358, 1931.
- 9. Beintker, E.: Asbestosis Bodies. Virch. Arch., 293: 527-529, 1934. Abstr., J. Ind. Hyg., 17:33, 1935.
10. Bowles, Oliver: Asbestos—Domestic and Foreign Deposits. U. S. Bur. Mines Inf. Circ. No. 6790, June, 1934.
- 11. Bridge, J. C.: Asbestosis. In: Ann. Rep. of the Chief Insp. of Fact. for the Year 1928, p. 95. H. M. Stat. Off., London, 1929.
- 12. Bromley, J. F., Wood, W. B., Ellman, P.: Pneumoconiosis—A Discussion. Part I—Silicosis; Part II—Pulmonary Asbestosis. Part III—Pulmonary Asbestosis. Brit. J. Radiol., p. 262-295, 1934. Abstr., J. Ind. Hyg., 16:1023, 1934.
13. Buttner-Wobst, W. and Trillitzsch, C.: Die Bergflachslunge (asbestosis) und was der deutsche Arzt von ihr wissen muss. Tuberkulose, 11:11-14, 1931.
14. Cirkel, Fritz: Chrysotile Asbestos. Its Occurrence, Exploitation, Milling and Uses. Mines Branch Bull. 69. Canada Dep't of Mines, 1910.
- 15. Clynes: Asbestosis and Silicosis. Brit. Med. J., 1:379, 1931.
- 16. Cooke, W. E.: Fibrosis of the Lungs due to Inhalation of Asbestos Dust. Brit. Med. J., 2:147, 1924.
- 17. Cooke, W. E.: Asbestosis. Brit. Med. J., 2:1024-1025, 1927.
- 18. Cooke, W. E.: Pulmonary Asbestosis. Brit. Med. J., 2:585, 1928.
- 19. Cooke, W. E.: Asbestos Dust and Curious Bodies Found in Pulmonary Asbestosis. Brit. Med. J., 2:578-580, 1929. Abstr., J. Am. Med. Assn., 95:1431, 1930. Abstr., J. Ind. Hyg., 12:34, 1930.
- 20. Cooke, W. E.: Asbestos Dust and Asbestosis Bodies from Lungs of Asbestos Workers. J. State Med., 39:544-548, 1931.

21. Cooke, W. E.: Silico-Anthracosis Presenting Curious Bodies Similar to Those in Asbestosis. *Brit. Med. J.*, 1:656-657, 1932.
- 22. Cooke, W. E., and Hill, C. F.: Pneumokoniosis due to Asbestos Dust. *J. Roy. Micr. Soc.*, 47:232, 1927.
- 23. Cooke, W. E., and Hill, C. F.: Pneumokoniosis Caused by Asbestos Dust. *Brit. Med. J.*, 1:890, 1927.
- 24. Cooke, W. E., MacDonald, S., Oliver T.: Strange Bodies Found in Asbestos Workers. *Lancet*, 2:136-137, 1926.
- 25. Cooke, W. E., and Hill, C. F.: Further Observations on Pulmonary Asbestosis, with Special Reference to Asbestos Dust and Curious Bodies found in the Lungs. *J. Roy. Micr. Soc.*, 50:15-19, 1930.
26. Davis, G. G., Salmonsens, E. M., Earlywine, J. L.: *The Pneumonokonioses (Silicosis). Bibliography and Laws.* Ind. Medicine Inc., Chicago, 1934.
- 27. Dewirtz, A. P.: Warts from Mineral Substances. *Roussky Vestnick Derm.* 1:243-247, March, 1930. Abstr., *J. Ind. Hyg.*, 13:125, 1931.
- 28. Dhers, V.: Amiante et asbestose pulmonaire. *La med. du trav.*, 2:147-172; 187-209, 1930. Abstr., *J. Ind. Hyg.*, 13:49, 1931.
- 29. Donnelly, J.: Pulmonary Asbestosis. *Am. J. Pub. Health.* 23:1275-1281, 1930.
30. Drinker, P.: Alternating Current Precipitators for Sanitary Air Analysis. *J. Ind. Hyg.*, 14:364-370, 1932.
31. Drinker, P.: The Size Frequency and Identification of Certain Phagocytosed Dusts. *J. Ind. Hyg.*, 7:305-316, 1925.
- 32. Effect of Asbestos Dust on Workers' Health in Asbestos Mines and Factories. *Labour Gaz.*, 12:761-762, 1911-1912. Ottawa.
- 33. Ellman, P.: Report on Cases of Pulmonary Asbestosis. *Proc. Roy. Soc. Med.*, 24:526, 541, 699, 1930-1931.
34. Ellman, P.: *Chest Diseases in General Practice.* London. H. K. Lewis, 1932, p. 116.
- 35. Ellman, P.: Pulmonary Asbestosis. *Lancet*, Feb. 4, 1933, p. 252-253. Abstr., *J. Ind. Hyg.*, 15:43, 1933.
- 36. Ellman, P.: Pulmonary Asbestosis: Clinical, Radiological and Pathological Features and Associated Risk of Tuberculosis Infection. *J. Ind. Hyg.*, 15:165-183, 1933.
37. Fahr, T.: Asbest-pneumokoniose. *Aertzl. Verein.* March 3, 1914. Hamburg.
38. Fahr, T.: Asbestosis. *Klin. Wehnschr.*, 11:1114, 1932.
- 39. Feil, A.: Asbestosis in Asbestos Workers: Professional Asbestosis. *Pressé Med.*, 39:1931, 1872-1874.

40. Feuerstack: Ueber das Verhalten des Epithels der Lungenalveolen bei der fibrinösen Pneumonia. Gottingen, Preisschrift, 1882.
41. Fulton, W. B., Houtz, R. L., Dooley, A., Matthews, J. L.: Asbestosis. Part I—The Collection and Counting of Asbestos Dust. Spec. Bull. 37, Pa. Dept. Labor and Industry, 1934.
- 42. Gardner, L. U., and Cummings, D. E.: Studies on Experimental Pneumokoniosis: VI. Inhalation of Asbestos Dust; Its Effect upon Primary Tuberculosis Infection. J. Ind. Hyg., 13:65-81, 97-114, 1931.
43. Gerbis, H., and Ucko: Ueber Asbestosis der Lungen. Ver. f. inn. Med. z. Berlin, Sitz. v. Dec. 7, 1931.
44. Gerbis, H., and Ucko: Asbestosis of the Lung. Deutsche med. Wehnschr., 58:285, 1932.
- 45. German Work on Pulmonary Asbestosis. Lancet, 3:92-93, 1932.
- 46. Gloyne, S. R.: Presence of Asbestosis Fiber in Lesions of Asbestos Workers. Tubercle, 10:404-407, 1929.
- 47. Gloyne, S. R.: Reaction of Tissues to Asbestos Fiber, with Reference to Pulmonary Asbestosis. Tubercle, 11:151-153, 1930.
- 48. Gloyne, S. R.: Method of Staining Asbestosis Bodies Found in Sputum of Asbestos Workers. J. Ind. Hyg., 13:85-86, 1931.
- 49. Gloyne, S. R.: Formation of Asbestosis Bodies. Tubercle, 12:399-401, 1931.
- 50. Gloyne, S. R.: Presence of Asbestosis Bodies in Faeces of Case of Pulmonary Asbestosis. Tubercle, 12:158-161, 1931.
- 51. Gloyne, S. R.: Asbestosis Body. Lancet, 1:1351-1355, 1932.
- 52. Gloyne, S. R.: Infra-red Photomicrographs of Asbestosis Lung. Tubercle, 14:208-209, 1933.
- 53. Gloyne, S. R.: Morbid Anatomy and Histology of Asbestosis. Tubercle, 14:455-461, 493-497, 550-558, 1933. Abstr., J. Ind. Hyg., 15:127-128, 1933.
- 54. Gordon, B., Jr.: Asbestosis. Pennsylvania Med. J., 35:637-639, 1932.
55. Green, Henry: A Photographic Method for the Determination of Particle Size of Paint and Rubber Pigments. J. Franklin Inst., 192:637-666, 1921.
56. Green, H. L.: Some Accurate Methods of Determining the Number and Size Frequency of Particles in Dusts. J. Ind. Hyg., 16:29-39, 1934.
- 57. Haddow, A. C.: Clinical Aspects of Pulmonary Asbestosis. Brit. Med. J., 2:580-581, 1929.

58. Hatch, T., Warren, H., Drinker, P.: Modified Form of the Greenburg-Smith Impinger for Field Use, with a Study of its Operating Characteristics. *J. Ind. Hyg.*, 14:301-311, 1932.
59. Hatch, T. and Pool, C. L.: Quantitation of Impinger Dust Samples by Dark Field Microscopy. *J. Ind. Hyg.*, 16:177-191, 1934.
60. Holtzmann, F.: Die Einwirkung des Asbeststaubes. *Zentralbl. f. Gewerbehyg.*, 8:225-226, 1931.
61. Industrial Directory—1931. Edition. Pa. Dep't of Internal Affairs, Harrisburg.
62. Katz and Slater: The Second Positive Wave of the Q-R-S Complex. *Arch. Int. Med.*, 55: No. 1, Jan. 1935.
63. Kettle, E. H.: Interstitial Reactions Caused by Various Dusts and their Influence on Tuberculous Infections. *J. Path. and Bact.*, 35:395-405, 1932.
64. Knopf, A.: The Quantitative Determination of Quartz ("Free Silica") in Dusts. *U. S. Pub. Health Reports*, 48:183-190, 1933.
65. Kruger, E., Rostoski, O., Saupe, E.: Asbestosis. *Arch. f. Gewerbepath. u. Gewerbehyg.*, 2:558-590, 1931. *Abstr.*, *J. Ind. Hyg.*, 14:144, 1932.
66. Lanza, A. J., McConnell, W. J., Fehnel, S. W.: Effects of the Inhalation of Asbestos Dust on the Lungs of Asbestos Workers. A Preliminary Study. *U. S. Pub. Health Reports*, 50:1-12, 1935.
67. London Letter: Pneumoconiosis Caused by Asbestos Dust. *J. Am. Med. Assn.*, 89:304, 1927.
68. Lovisetto, D.: Asbestosi. In: *Studi sulla pneumaconiosi in Italia*, 1930, p. 115-132. Istit. Poligr. dello Stato, Rome.
69. Lynch, K. M. and Smith, W. A.: Asbestosis Bodies in Sputum and Lung. *J. Am. Med. Assn.*, 95:659-661, 1930.
70. Lynch, K. M. and Smith, W. A.: Pulmonary Asbestosis, 11. Including a Report of a Pure Case. *Am. Rev. Tuberc.*, 23:643-660, 1931. *Abstr.*, *J. Ind. Hyg.*, 13:241, 1931.
71. MacDonald, S.: Histology of Pulmonary Asbestosis. *Brit. Med. J.*, 2:1025-1026, 1927.
72. Merewether, E. R. A.: Occurrence of Pulmonary Fibrosis and Other Pulmonary Affections in Asbestos Workers. *J. Ind. Hyg.*, 12:198-222, 239-257, 1930.
73. Merewether, E. R. A.: A Memorandum on Asbestosis. *Tubercle* 15:69-81, 109-118, 152-159, 1933.

-
- 74. Merewether, E. R. A. and Price, C. W.: Report on Effects of Asbestos Dust on the Lungs and Dust Suppression in the Asbestos Industry. Home Off. H. M. Stat. Off. London, 1930. Abstr., J. Ind. Hyg., 12:117, 1930.
 - 75. Mills, R. G.: Asbestosis: Case. Minnesota Med. 13:495-499, 1930.
 - 76. Mussa, G. Note cliniche e radiologiche sulla pneumoconiosi da amianto. In: Studi sulla pneumoconiosi in Italia, 1930, p. 133-139. Istit. Poligr. dello Stato, Rome.
 - 77. Oliver, T.: Pulmonary Asbestosis in its Clinical Aspects. J. Ind. Hyg., 9:483-485, 1927.
 - 78. Oliver, T.: Asbestosis in its Clinical Aspects. Brit. Med. J., 2:1026, 1927. Abstr., J. Ind. Hyg., 10:97, 1928.
 - 79. Oliver, T.: Asbestosis. Brit. Med. J., 2:204, 1929.
 - 80. Oliver, T.: Pulmonary Asbestosis, Abstract. Monthly Lab. Rev. 31:74-76, 1930.
 - 81. Oliver, T.: Pulmonary Asbestosis: Socio-Medical Study. Arch. f. Gewerbepath, u. Gewerbehyg., 1:67-76, 1930.
 - 82. Palmieri, V. M.: Asbestosis. Riforma med., 46:1207, 1930.
 - 83. Pancoast, H. K. and Pendergrass, E. P.: Pneumoconiosis. A Roentgenological Study. New York, Paul B. Hoeber, Inc., 1926, p. 155.
 - 84. Pancoast, H. K. and Pendergrass, E. P.: Review of Pneumoconiosis—Further Roentgenological and Pathological Studies. Am. J. Roentgen, 26:556, 1931.
 - 85. Pancoast, H. K. and Pendergrass, E. P.: The Roentgenological Aspects of Pneumoconiosis and its Medical-Legal Importance. J. Ind. Hyg., 15:117-135, 1933.
 - 86. Parsitano, A.: L'amiantosi professionale. Morgagni, 74:138-139, 1932.
 - 87. Pidgeon, L. M. and VanWinsen, A.: The Sorption of Water by Asbestos Fibers. Canad. J. Research, 9:153-158, 1933. Abstr., Chem. Abstr., 27:5230, 1933.
 - 88. Policard, A. and Mouriquand, V.: Reactioné Tissulaires Provoquées par l'injection intra-conjontivale de particules d'amiante. Acad. des sc., séance du May 5, 1930. Lancette française: Gaz. d. hop., 103: 737, May 17, 1930, Paris. Bull. d'histol. appl. à la pathol. et de tech. micros., 7:193-199, 1930.
 - 89. Price, C. W.: Ventilation in Asbestos Textile Works. Inst. Heat. and Vent. Proc., 30:168-172, 173-179, 1931-1932. Also in Dom. Eng. (London) 51:200-207, Oct. 10, 1931.
 - 90. Pulmonary Asbestosis. Brit. Med. J., 1:783, 1930.

- ✓ 91. Pulmonary Disease Caused by Asbestos Dust. *Monthly Lab. Rev.*, 30: 292, 1930.
- ✓ 92. Pedley, F. G.: Asbestosis. *Canad. Pub. Health J.*, 21:576-577, 1930.
- 93. Recent Studies of Pulmonary Asbestosis in Germany. *Monthly Labor Rev.*, 35:541-542, 1932.
- 94. Reports on Conference Between Employers and Inspectors Concerning Methods for Suppressing Dust in Asbestos Textile Factories. U. K. Home Off., H. M. Stat. Off., London, 1931.
95. Ross, J. G.: Chrysotile Asbestos in Canada. *Mines Branch Bull.* 707, *Canad. Dep't Mines*, 1931.
96. Rostoski, O.: Asbestosis. *Verhandl. d. Deutsch. Gesellsch. f. inn Med. Kong.*, 43:334-338, 1931.
- ✓ 97. Saupe, E.: Ueber Lungenasbestose. *München med. Wehnschr.*, 78:979, 1931.
98. Scarpa, L. G.: Industria dell'amianto e tubercolosi. XVIII^o Congr. d. soc. ital. di med. int. Rome, 1908.
- ✓ 99. Schuster, N. H.: Asbestosis in a Dog. *J. Path. and Bact.*, 34:751-757, 1931.
- 100. Seiler, H. E.: A Case of Pneumoconiosis. Result of the Inhalation of Asbestos Dust. *Brit. Med. J.*, 2:982, 1928.
- 101. Seiler, H. E. and Gilmour, M. D.: Asbestosis Case. *Brit. Med. J.*, 1:1112-1114, 1931.
- 102. Simson, F. W.: Pulmonary Asbestosis in South Africa. *Brit. Med. J.*, 1:885, 1928.
- 103. Simson, F. W. and Sutherland-Strachan, A.: Bodies in Sputum; Specimens from Fifty Workers in Asbestos Mill. *J. Path. and Bact.*, 34:1-4, 1931.
- 104. Soper, W. B.: Report of a Case of Asbestosis and Review. *Am. Rev. Tuberc.*, 22:571-584, 1930. *Abstr.*, *J. Ind. Hyg.*, 13:49-50, 1931.
- 105. Sparks, J. V.: Asbestosis. *Radiology*, 17:1249-1257, 1931.
- 106. Sparks, J. V.: Pneumoconiosis in Asbestos Workers. *Brit. Med. J.*, 2:363, 1932.
- 107. Stewart, H. L. Bucher, C. J., Coleman, E. H.: Asbestosis, Two Cases. *Arch. Path.*, 12:909-916, 1931.
- 108. Stewart, M. J.: Pulmonary Asbestosis. *Brit. Med. J.*, 2:675, 1928.
- 109. Stewart, M. J.: A Method of Examining the Sputum for Asbestos Bodies. *Brit. Med. J.*, 2:581, 1929.

- 110. Stewart, M. J.: Asbestosis Bodies in the Lungs of Guinea Pigs after 3 to 5 Months' Exposure in an Asbestos Factory. *J. Path. and Bact.*, 33:848, 1930.
- 111. Stewart, M. J. and Haddow, A. C.: The Immediate Diagnosis of Pulmonary Asbestosis at Necropsy. *Brit. Med. J.*, 2:509, 1928.
- 112. Stewart, M. J. and Haddow, A. C.: Demonstration of the Peculiar Bodies of Pulmonary Asbestosis (Asbestos Bodies) in Material Obtained by Lung Puncture and in the Sputum. *J. Path. and Bact.*, 32:172, 1929.
- 113. Stewart, M. J., Tattersall, N., Haddow, A. C.: Occurrence of Clumps of Asbestosis Bodies in Sputum of Asbestos Workers. *J. Path. and Bact.*, 35:737-741, 1932. *Abstr., J. Ind. Hyg.*, 15:78, 1933.
- 114. Stock, G. A.: Pulmonary Asbestosis. *Med. Bull. Vet. Admin.*, 10:126-129, 1933.
- 115. Terreil, A.: Analyse d'une chrysotile (serpentine fibreuse ayant l'aspect de l'asbeste); silice fibreuse résultant de l'action des acides sur les serpentines. *C. r. hebdomadaires des séances de l'acad. des sc., Paris*, 100-251, 1885.
- 116. Timmermans, F. D.: Asbestosis. *Zentralbl. f. Gewerbehyg.*, 8:280, 307, 1931.
- 117. Tylecote, F. E. and Dunn, J. S.: Asbestos-like Bodies in Lungs of Coal Miner who had Never Worked in Asbestos; Case. *Lancet*, 2:632-633, 1931.
- 118. Wahlstrom, E. E.: An unusual Occurrence of Asbestos. *Am. Mineral.* 19:178-180, 1934. *Abstr., Chem. Abstr.*, 28:6088, 1934.
- 119. Wood, W. B.: Asbestosis. Radiographic Appearances in Skiagrams of Chests of Workers in Asbestos. *Tubercle.* 10:353-363, 1929. *Abstr., J. Ind. Hyg.*, 11:210, 1929.
- 120. Wood, W. B.: Pulmonary Asbestosis. *Tubercle.* 10:23, 1929.
- 121. Wood, W. B. and Gloyne, S. R.: Pulmonary Asbestosis. *Lancet*, Dec. 22, 1934, p. 1383-1385. *Abstr., J. Ind. Hyg.*, 17:33, 1935.
- 122. Wood, W. B. and Gloyne, S. R.: Asbestosis. *Lancet*, 1:445-448, 1930. *Abstr., J. Ind. Hyg.*, 12:146, 1930.
- 123. Wood, W. B. and Gloyne, S. R.: Pulmonary Asbestosis Complicated by Pulmonary Tuberculosis. *Lancet*, 2:954, 1931. *Abstr., J. Ind. Hyg.*, 14:66, 1932.
- 124. Wood, W. B. and Page, D. S.: Asbestosis; Case. *Tubercle.* 10:457-460, 1929.
- 125. Wood, W. B. and Page, D. S.: Asbestosis; Death from Tuberculosis Two Years after First Exposure to Dust. *Tubercle.* 11:157-158, 1930. *Abstr., J. Ind. Hyg.*, 12:146, 1930.