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ASBESTOSIS

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

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

BUREAU OF INDUSTRIAL STANDARDS
JOHN CAMPBELL, *Director*

Harrisburg, Pennsylvania
September 20, 1935

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by

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BUREAU OF INDUSTRIAL STANDARDS

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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 employes that neither would be given specific information as to the physical findings of any particular workman, and that the original identity of all employes 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 holder is described. It is constructed of leather straps, in such a way that the fluid 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—$3MgO.2SiO_2.2H_2O$.

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_2O_3	Al_2O_3	Comb. H_2O
1	39.86%	40.07%	2.41%	2.67%	14.49%
2	39.36	42.15	3.32	—	14.50
3	40.42	41.86	2.89	0.82	14.37
4	39.22	40.27	2.36	3.44	14.37
5	40.57	41.89	2.81	0.50	12.53
6	41.90	42.30	0.69	0.88	14.06
7	39.30	42.97	2.36	—	12.87
8	40.42	40.46	2.98	1.32	12.46

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[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
—	[illegible]
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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 ¾ inch and longer; Crude No. 2 ranges in length from ⅜ inch up to ¾ inch. Mill fiber includes all fibers less than ⅜ 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.

Mill fiber, because of the mechanical crushing and separation given it at the mine, does not require the preliminary processing in the rim-wheel crushers as does the crude fiber. The mill fiber is fed directly into the Saco-Lowell opener, and from then on is given the same treatment as the crude fiber.

Asbestos fibers when examined microscopically do not possess the rough imbricated surfaces of other fibers such as wool. They resemble fine polished metal rods, free from any serrated surfaces. This characteristic explains the extreme difficulty encountered in attempting to spin a thread of pure asbestos. A certain amount of cotton must be added as a binder for spinning. The amount added depends on the type of fiber and the use for which the finished product is intended. Table II shows the average amount of asbestos used in the manufacture of products made in the four plants included in this survey.

TABLE II—PERCENTAGES OF ASBESTOS IN VARIOUS ASBESTOS PRODUCTS*

Material	Plant A	Plant B	Plant C	Plant D
Brake lining (woven)	[illegible]%	—	70–75%	60%
Insulating tape	—	80	80	80–95
Asbestos cloth	85–94	85	—	80–100
Commercial grade yarn	—	75	—	75–100
Gov't. Specif. yarn and cloth	—	90	—	—
Asbestos rope and wick	85–94	80	—	80
Yarn and cloth, Underwriters Spec.	—	85–88	—	—
Asbestos cements	—	—	15–20	—
Brake lining (molded)	—	—	20	—
Asbestos paper	—	—	—	95
85% magnesia insulation	—	—	—	15
Asbestos shingles and lumber	—	—	—	25

* Compiled from information supplied by the manufacturers.

Mixing—Weighed quantities of asbestos and cotton, and usually some small amounts of card waste, are dumped in alternate layers in a pile on the floor of the mixing room directly in front of the mixing picker. The batch is shoveled into the picker, which is equipped with revolving beaters. In order to secure thorough mixing, the batch is run through the same picker twice, or through two pickers arranged in series. The mixture is removed by suction to the storage bins to await carding.

Carding—Carding is necessary to remove the remaining small bits of rock, and to comb the fibers into a more or less parallel condition so that they may be spun. A card is a machine with a series of revolving cylinders covered with strips of leather, wound diagonally, and fitted with fine, close-set, sharp steel bristles. A carding unit, as used in asbestos plants, usually consists of two cards, the breaker and the finisher. The mixture of asbestos and cotton

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	70-75%	60%
	80	80-85
	—	80-100
	—	75-100
	—	—
	—	80
	—	—
	15-80	—
	30	—
	—	85
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	—	85

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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 vigilence, 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.

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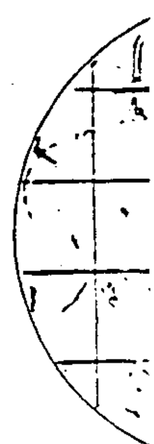

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Particle Size Determination

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 stereoptican 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-

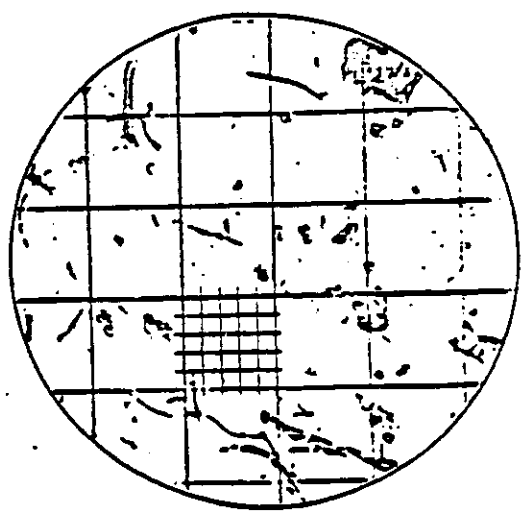

FIGURE 1. PHOTOMICROGRAPH OF DUST FROM AN ASBESTOS FABRICATING PLANT. MAGNIFICATION 600 DIAMETERS

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 dimensons, 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 microprojection 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 10 x 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 measure[illegible] longest diameters.

TABLE III—EXAMPLE (... AVERA[illegible]

Magnification—2000

mm.	μ	f
10	5.0	21
12	6.0	7
13	6.5	3
14	7.0	4
15	7.5	12
16	8.0	1
17	8.5	1
18	9.0	8
20	10.0	9
21	10.5	1
22	11.0	3
23	11.5	2
24	12.0	1
25	12.5	16
27	13.5	1
28	14.0	1
29	14.5	1
30	15.0	8
32	16.0	1
35	17.5	9
36	18.0	1
37	18.5	1
38	19.0	2
39	19.5	2
40	20.0	13
42	21.0	1
43	21.5	1
45	22.5	3
47	23.5	1
50	25.0	4
55	27.5	5
60	30.0	8
63	31.5	1
65	32.5	5
67	33.5	1
70	35.0	6
73	36.5	1
75	37.5	2
80	40.0	2
85	42.5	2
95	47.5	1
100	50.0	1
110	55.0	4
120	60.0	1
130	65.0	4
140	70.0	2
160	80.0	3
170	85.0	1
175	87.5	1
180	90.0	1
200	100.0	1
210	105.0	1
230	115.0	1
240	120.0	3
265	132.5	1
330	165.0	1
370	185.0	1
Total		200

Results—Particle size[illegible] the dust collected at va[illegible] but no appreciable vari[illegible] marked difference in the[illegible] the two general grades[illegible]

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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	135 Fields			
mm.	u	f	f_a	$f_a \times u$
10	5.0	21	0.69615	3.48075
12	6.0	7	.23205	1.39230
13	6.5	3	.09945	0.64642
14	7.0	4	.13260	0.92820
15	7.5	12	.39780	2.98350
16	8.0	1	.03315	0.26520
17	8.5	1	.03315	0.28178
18	9.0	8	.26520	2.38680
20	10.0	9	.29835	2.98350
21	10.5	1	.03315	0.34807
22	11.0	3	.09945	1.09395
23	11.5	2	.06630	0.76245
24	12.0	1	.03315	0.39780
25	12.5	16	.53040	6.63000
27	13.5	1	.03315	0.44752
28	14.0	1	.03315	0.46410
29	14.5	1	.03315	0.48067
30	15.0	8	.26520	3.97800
32	16.0	1	.03315	0.53040
35	17.5	9	.29835	5.22112
36	18.0	1	.03315	0.59670
37	18.5	1	.03315	0.61327
38	19.0	2	.06630	1.25970
39	19.5	2	.06630	1.29285
40	20.0	13	.43095	8.61900
42	21.0	1	.03315	0.69615
43	21.5	1	.03315	0.71272
45	22.5	3	.09945	2.23762
47	23.5	1	.03315	0.77902
50	25.0	4	.13260	3.31500
55	27.5	5	.16575	4.55812
60	30.0	9	.29835	8.95050
63	31.5	1	.03315	1.04422
65	32.5	5	.16575	5.38687
67	33.5	1	.03315	1.11052
70	35.0	6	.19890	6.96150
73	36.5	1	.03315	1.20997
75	37.5	2	.06630	2.48625
80	40.0	2	.06630	2.65200
85	42.5	2	.06630	2.81775
95	47.5	1	.03315	1.57462
100	50.0	1	.03315	1.65750
110	55.0	4	.13260	7.29300
120	60.0	1	.03315	1.98900
130	65.0	4	.13260	8.61900
140	70.0	2	.06630	4.64100
160	80.0	3	.09945	7.95600
170	85.0	1	.03315	2.81775
175	87.5	1	.03315	2.90062
180	90.0	1	.03315	2.98350
200	100.0	1	.03315	3.31500
210	105.0	1	.03315	3.48075
230	115.0	1	.03315	3.81225
240	120.0	3	.09945	11.93400
265	132.5	1	.03315	4.39237
330	165.0	1	.03315	5.46975
370	185.0	1	.03315	6.13275
Total		200	6.63000	174.11003

Magnification—10,000	112 Fields		
mm.	u	f	f x u
3	0.3	37	11.10
4	0.4	37	14.80
5	0.5	38	19.00
6	0.6	7	4.20
7	0.7	2	1.40
8	0.8	10	8.00
9	0.9	1	0.90
10	1.0	23	23.00
12	1.2	4	4.80
13	1.3	1	1.30
15	1.5	11	16.50
20	2.0	12	24.00
23	2.3	2	4.60
25	2.5	2	5.00
30	3.0	7	21.00
35	3.5	4	14.00
40	4.0	1	4.00
45	4.5	1	4.50
Total		200	182.10

mm. = Length of image in millimeters.

u = Length of particle in microns.

f = Frequency

$$f_a = \frac{112 \times f}{135 \times (5)^2}$$

$$\text{Average Diameter} = \frac{\Sigma (f \times u) + \Sigma (f_a \times u)}{\Sigma f + \Sigma f_a}$$

= 1.72 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-

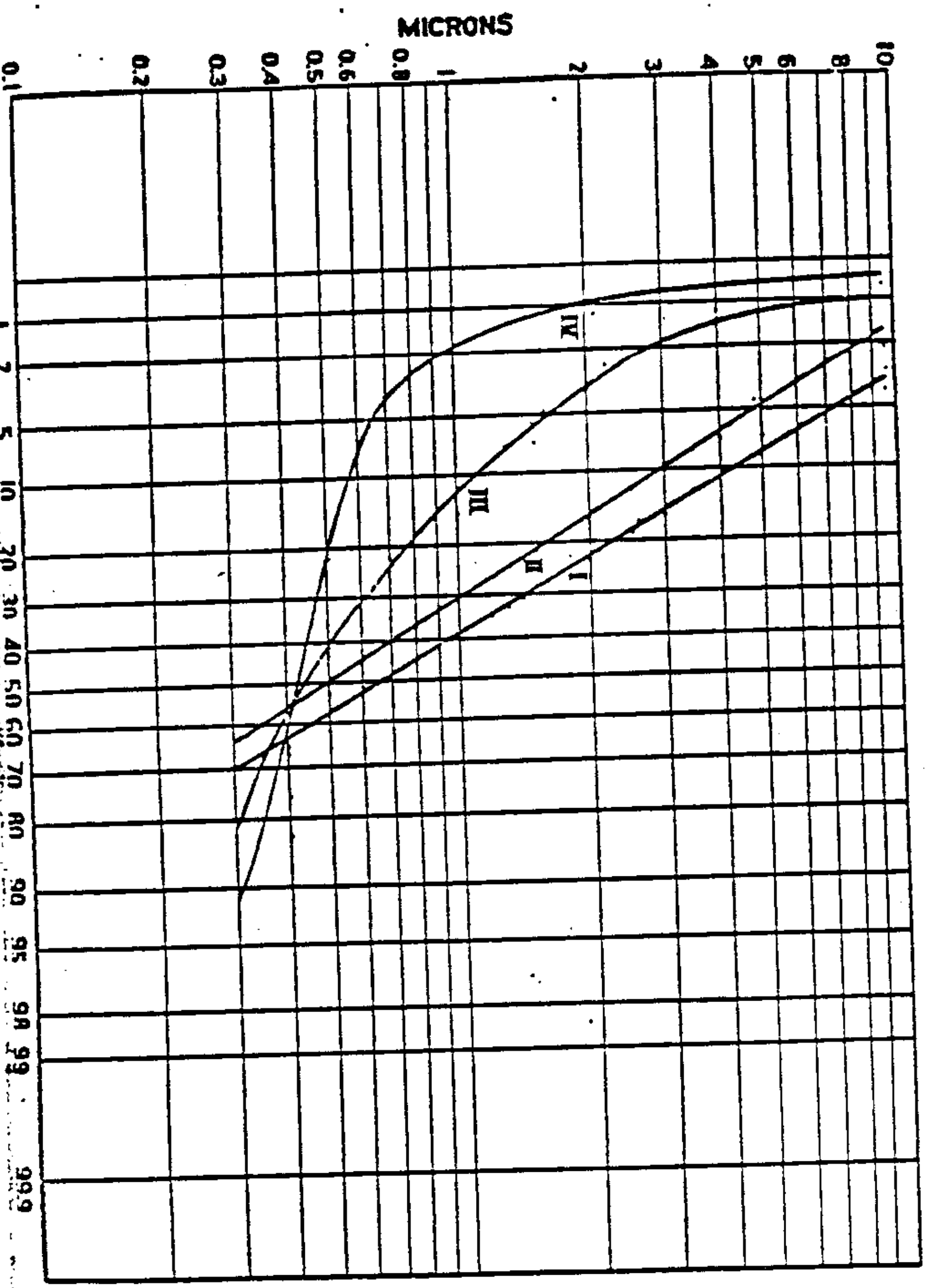

FIGURE 2. SIZE FREQUENCY CURVES FOR DUST FROM ASBESTOS FABRICATING PLANTS SHOWING PERCENTAGE LESS THAN STATED SIZE. I—LONGITUDINAL DIAMETER, CRUDE FIBER; II—LONGITUDINAL DIAMETER, MILL FIBER; III—TRANSVERSE DIAMETER, CRUDE FIBER; AND IV—TRANSVERSE DIAMETER, MILL FIBER

tudinal diameter of the d
microns, while that of
diameters were 0.60 mic
fiber respectively. The
dred and two microns.

The percentage frequ
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shows these values plo
paper.

The difference in the
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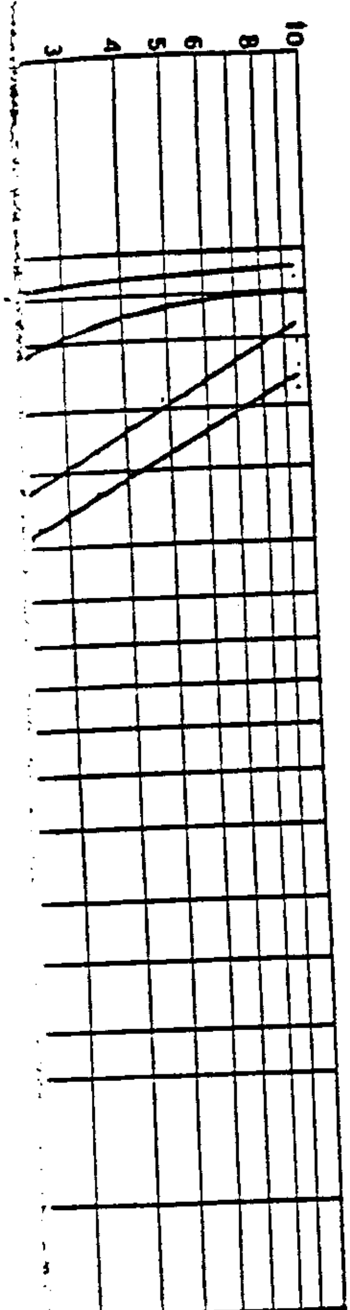
ten microns or more in
dust occurred within thes
dust was 0.5 microns or
fiber dust fell within thi

TABLE IV. SIZE FRE

Size Group in Microns
Under 0.49
0.5–0.99
1.0–1.49
1.5–1.99
2.0–2.49
2.5–2.99
3.0–3.49
3.5–3.99
4.0–4.49
4.5–4.99
5.0 and over

DUST CON

All samples were collec
Smith impinger (58) usi
hol as the collecting med
the method described in
were counted regardless
greatest diameter averag
the total. The dust cou
in Table V.



ROM ASBESTOS FAB-
THAN STATED SIZE.
II—LONGITUDINAL
TER. CRUDE FIBER:
L 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%	39.1%	46.9%	78.3%
0.5-0.99	27.4	28.0	21.8	20.3
1.0-1.49	8.2	7.8	7.3	—
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	—	2.4	—
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	1.3	3.0	0.7

Dust Concentrations in the Plants

All samples were collected by the modified form of the Greenburg-Smith impinger (58) 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 V. SUMMARY OF DUST CONCENTRATIONS IN ASBESTOS FABRICATING PLANTS

Department	Occupation	Plant A Number of Samples	Plant A Millions of particles per cu. ft. of air	Plant B Number of Samples	Plant B Millions of particles per cu. ft. of air	Plant C Number of Samples	Plant C Millions of particles per cu. ft. of air	Plant D Number of Samples	Plant D Millions of particles per cu. ft. of air
Preparation	Feeding Saco—Lowell Opener—Crude Fiber	--	----	2	29.3-37.3	--	----	--	----
	Feeding Mixing Picker—Crude Fiber	--	----	1	3.2	--	----	--	----
	Feeding Saco—Lowell Opener—Mill Fiber	--	----	3	118.4-123.3	--	----	--	----
	Feeding Mixing Picker—Mill Fiber	--	----	1	10.7	--	----	1	54.0
	Feeding Screenings into Shaker	--	----	--	----	--	----	2	50.0-74.7
	Bagging Screenings	--	----	--	----	--	----	2	53.9-58.8
Carding	Tending Card—Crude Fiber	--	----	3	0.6-1.4	--	----	--	----
	Tending Card—Mill Fiber	4	21.1-43.2	6	13.0-66.7	--	----	3	10.3-25.0
	Repairing web at back of Card—Mill Fiber	--	----	2	47.9-67.4	--	----	--	----
	Cleaning Card rolls (by hand card)	1	6.6	--	----	--	----	--	----
	Carding wick (low grade mix)	--	----	--	----	--	----	2	77.6-119.6
Weaving	Weaving Insulating Tape (dry warp—wet fill)	--	----	4	4.6-6.0	3	3.0-8.0	--	----
	Weaving Insulating Tape (dry warp—dry fill)	--	----	--	----	--	----	2	6.0-21.8
	Weaving Insulating Tape (wet warp—wet fill)	--	----	--	----	--	----	2	10.2-22.0
	Weaving Brake lining (dry warp—dry fill)	1	27.1	--	----	--	----	--	----
	Weaving Brake lining (dry warp—wet fill)	2	8.6-10.8	--	----	3	12.8-31.7	--	----
	Weaving Brake lining (wet warp—wet fill)	--	----	--	----	--	----	1	6.1
	Weaving Cloth (dry warp—dry fill)	--	----	3	25.5-44.8	--	----	1	6.2-16.3
	Weaving Cloth (dry warp—dry fill) Fans off	--	----	--	----	--	----	1	23.4
	Cleaning looms	1	76.3	--	----	--	----	--	----
Mule Spinning	Spinning—Crude fiber yarn (high grade)	--	----	3	1.9-2.5	--	----	--	----
	Spinning—Mill fiber yarn (medium grade)	--	----	3	4.4-7.0	--	----	--	----
	Spinning—Mill fiber yarn (low grade)	6	6.8-47.4	2	13.0-13.5	--	----	--	----
Winding (Spooling) Twisting	Winding—single-ply yarn	2	7.9-9.8	--	----	--	----	--	----
	Winding—two-ply yarn	--	----	6	1.0-3.7	--	----	--	
	Winding—three-ply yarn	--	----	6	2.8-6.0	--	----	--	
Warping	Winding warp on warp beams	--	----	3	0.7-1.5	--	----	--	----
Rope and Wick	Forming rope and wick	--	----	--	----	--	----	1	9.3
Ring Gasket	Forming ring gaskets	--	----	4	1.0-1.5	--	----	--	----
Braiding	Braiding ½ inch packing	--	----	3	0.3-0.6	--	----	3	7.0-7.8
	Braiding ¼ inch packing	--	----	--	----	--	----	2	14.4-20.6
	Braiding ½ inch tubing	--	----	--	----	--	----	3	9.0-9.7

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VI. This summary of t
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TABLE VI. RELATIVE

Department
Preparation and Carding
Weaving and Mule Spinning
Twisting, Winding, Rope and Gasket, etc.

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preparing room, where
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relative dustiness, do n
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Preparation—The du
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fiber after it had been r
posed to a concentratio
In the mixing room,
the degree of dustiness
the type of fiber used.
10.6 when a mixture of
mixing picker. The con

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	38	9.6	122.2	44.26
Weaving and Mule Spinning	41	1.9	74.2	16.87
Twisting, Winding, Rope and Wick, Braiding, Gasket, etc.	28	0.2	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 employe 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 employes 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-

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and of brake lining, 23.

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the time required bei
During this operation

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DUST CONC

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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	88.3–154.2
	Bagging asbestos (mill fiber)	1	120.4
	Sewing "air cell" pipe covering	1	32.4
Shingle plant	Sawing asbestos lumber	1	120.2
	Sanding asbestos lumber and tile	2	19.6–22.3
	Grooving bathroom tile	2	22.1–32.5
	Dusting tile (paint spray booth)	1	34.7
Magnesia (15% asbestos)	Filling barrels with magnesia	1	2224.6
	Shoveling magnesia on pile	1	2406.0
	Dumping barrels into mixer	1	220.2
	Cleaning pipe molds	2	163.7–180.3
	Feeding insulation into trimmer	1	1.9
	Removing insulation from trimmer	2	8.4–13.1
	Crushing and bagging scrap	2	225.0–363.0
Clutch Facing	"Skimming" facings	1	2.9
	Grinding asbestos paper clutch facings	2	406.4–412.7
	Drilling paper clutch facings	1	12.2

ASBESTOSIS—PART
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TABLE VIII. DISTRI

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OPERATIONS IN AN

Number of Samples	Concentration in Millions of particles per cubic foot of Air
2	[illegible]-184.2
1	138.4
1	[illegible]
1	130.3
2	19.6-[illegible]
2	[illegible]
1	34.7
1	[illegible]
1	[illegible]
1	[illegible]
2	[illegible]
1	1.9
2	[illegible]-13.1
2	[illegible]
1	1.9
2	454.4-[illegible]
1	12.2

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 30	30-39	40-49	50-59	60 and over
Controls	7	1	2	—	1	3
Asbestosis	14	—	7	6	—	1
Negative	43	15	12	11	3	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 involvment 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, palpatation, 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 atelectasi
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FIGURE
ASBESTOS

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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 employe 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.

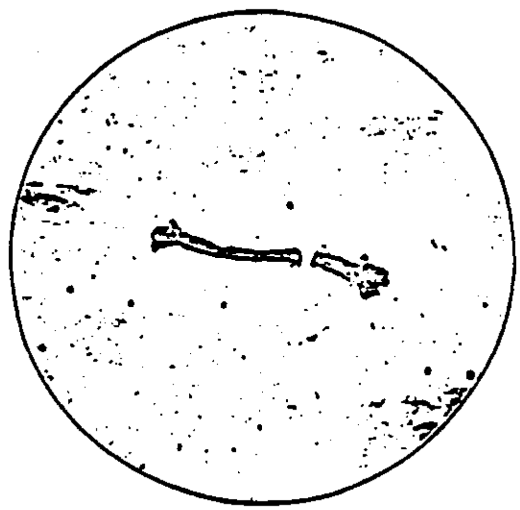

FIGURE 3. PHOTOMICROGRAPH OF ASBESTOS BODY. MAGNIFICATION 600 DIAMETERS

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 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	Negative	Asbestosis			
					Slight	Moderate	Advanced	Doubtful
Preparers and Carders	44.20	0—5	3	2	—	—	—	1
		6—10	3	—	—	3	—	—
		11—15	5	1	1	3	—	—
		16—20	2	1	1	—	—	—
		over 20	1	1	—	—	—	—
		Total	14	5	2	6	—	1
Weavers and Spinners	16.27	0—5	3	3	—	—	—	—
		6—10	4	3	1	—	—	—
		11—15	4	3	—	1	—	—
		16—20	5	3	2	—	—	—
		over 20	2	2	—	—	—	—
		Total	18	14	3	1	—	—
Winders, Twisters, Warpers, etc.	4.64	0—5	4	4	—	—	—	—
		6—10	7	6	1	—	—	—
		11—15	8	6	1	—	—	1
		16—20	1	1	—	—	—	—
		over 20	4	4	—	—	—	—
		Total	24	21	2	—	—	1
Totals			56	40	7	7	—	2

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

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