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A STUDY OF ASBESTOSIS IN THE ASBESTOS TEXTILE INDUSTRY

U. S. TREASURY DEPARTMENT
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A STUDY OF ASBESTOSIS IN THE ASBESTOS TEXTILE INDUSTRY

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ABSTRACT

Asbestosis, a lung disease caused by long-continued inhalation of asbestos dust, was the principal physical defect found on medical examination of 541 men and women employed (or recently employed) in three asbestos textile factories. The primary effect of asbestos dust seems to be initiation of fine, interstitial, pulmonary fibrosis which was not observed to progress as far as the nodular stage. This fibrosis was observed in post-mortem examinations of three former asbestos workers. During life, lung fibrosis can be detected by X-ray examination. The more important symptoms of asbestosis are progressive dyspnoea, variable cough which sometimes raises blood-streaked sputum, and loss of weight. The processes that produce dust in asbestos textile factories were studied and recommendations for dust control are incorporated in this report. Enough dust counts (242) were made in all parts of these factories so that the dust exposure of each worker can be estimated. The percentage of persons in different occupational groups who were affected by asbestosis or any of its symptoms varied with the average dust concentration to which they were subjected and with their length of employment. The only cases of asbestosis, three in number, found below 5 million particles per cubic foot were diagnosed as doubtful, well-established cases occurred at higher concentrations. It appears from these data that if asbestos dust concentrations in the air breathed are kept below this limit new cases of asbestosis would not appear.

A STUDY OF ASBESTOSIS IN THE ASBESTOS TEXTILE INDUSTRY

INTRODUCTION

Several important properties of asbestos have led to its widespread use in industry. As everyone knows, it is noncombustible and an excellent insulator against heat and electricity. Fewer people seem to be aware that its fibers are sufficiently long and flexible to be carded, spun, and woven like wool, flax, or cotton. Utilizing these properties of asbestos, industries have been developed in this country which employed more than 6,000 men and women in slightly more than 60 establishments in 1935.

Another property of asbestos has been discovered more recently. When asbestos dust is inhaled daily, year in and year out, a lung disease termed asbestosis may develop. In many respects asbestosis resembles silicosis, but it differs from silicosis in several important particulars which will be discussed in the medical section of this report.

The first record of a case of asbestosis seems to have been made by Montague Murray in 1900. The first complete description of the disease and of the "curious bodies" seen in lung tissue and sputum appeared in 1927 when Cooke (9) and McDonald (22) reported two cases of asbestosis and listed their reasons for believing that asbestosis bodies originate from asbestos fibers that reach the lungs. The publication of their papers aroused general interest in the subject and numerous papers appeared soon afterward. Hoffman (46) appears to have been the first American to call attention to the magnitude of the asbestosis problem. In 1918 he reported that 13 deaths from asbestosis had occurred among asbestos textile workers, and about the same time Pancoast, Miller, and Landis (29) reported on 17 cases of asbestosis. Mills's (26) paper was the first pathological report on asbestosis published in the United States, and in the same year, 1930, Lynch and Smith (38) reported on asbestosis bodies found in the sputum of asbestos workers.

Because several satisfactory literature reviews of asbestosis have appeared in recent years there seems to be no need to present a complete literature review in this report. Some of the more useful literature reviews have been listed in the annotated bibliography. In Merewether's (25) review emphasis is laid on the relation of asbestosis to working conditions. The clinical aspects of the subject are well treated. Gloyne's (16) discussion of the pathology of asbestosis is particularly helpful. Middleton's (47) Milroy lectures on pneumoconiosis contain a section on asbestosis. Egbert (13) has summarized the literature reports on 28 fatal cases of asbestosis. "Active pulmonary tuberculosis was present in 6 instances of the total 28 cases; the fatal outcome was primarily the result of tuberculosis in 3 instances."

OBJECTIVES OF THE STUDY

The Public Health Service was requested by the State Board of Health and the Industrial Commission (administrator of the Workmen's Compensation Act) of North Carolina to assist them in making an engineering and medical study of health hazards in the asbestos textile industry.[1] The objectives of this study were threefold: (1) To make a medical study of the effects of long-continued inhalation of asbestos dust on the human body; (2) to identify the manufacturing processes that create dust and to recommend practices and, when necessary, equipment that will reduce the dust exposure of workers, and (3) to find what concentration of asbestos dust can be tolerated without injury to health.

[1] This represents one of the first uses of Social Security funds for a cooperative project carried on by the Public Health Service and a State health department.

THE WORKING ENVIRONMENT

METHODS AND INSTRUMENTS USED IN THE STUDY OF THE WORKING ENVIRONMENT

The evaluation of the working environment and its relation to the health of workers forms the basis of all field investigations conducted by the Division of Industrial Hygiene. The procedure followed by this Division is described in Public Health Bulletin No. 217 (2). Therefore, only a brief discussion of the subject is presented in this report.

The study of an occupational dust problem begins with a preliminary survey designed to obtain data on all the occupations in a given plant. It includes the number of workers employed in each occupation and the materials used in each process. The survey also reveals the number of workers exposed to a given hazard. Following the preliminary survey an evaluation of the occupational environment is made. In the dusty trades this includes a determination of the amount of dust present in the air, its composition and particle size and the measurement of the effectiveness of exhaust systems where they are used to control dust hazards. The latter, in this instance, involved airflow measurements of several exhaust systems by means of a pitot static tube. The effectiveness of these systems was determined by dust counts.

THE MANUFACTURE OF ASBESTOS TEXTILES

Approximately 90 percent of the asbestos used in these plants is obtained from Canada. The remaining 10 percent comes from Arizona or South Africa, and, infrequently, from Russian and Australian sources.

Much of the machinery that is employed for the manufacture of asbestos textiles is identical with the machinery used for the production of cotton and woolen goods. Crude asbestos fiber is sent first to the preparation department and then, in the order named, to the carding machines, spinning frames, winding bobbins, twisting machines, spooling frames, and finally to the looms and miscellaneous fabricating devices.

The four plants investigated in the present study fall naturally into two classifications. Two plants convert crude asbestos and raw cotton into asbestos yarn and woven goods, but do not prepare the products for the ultimate consumer. The other two plants purchase both asbestos yarn and unfinished woven asbestos tape. These establishments weave brake bands and convert their own woven product, as well as purchased material, into finished goods. The practices followed in the plants studied are schematically presented in the flow sheet shown in figure 2.

PREPARATION

Crushing.—The first step in the manufacture of asbestos textiles is the crushing of the crude stock in a milling machine. This is accomplished by large iron rollers which revolve in a steel pan in which the crude material is placed. (See fig. 3.) This operation separates the fibers and loosens the impurities that survived the cobbing of the ore at the mines. The crushing operation does not produce much dust, the fibers being disintegrated by a mashing and twisting action.

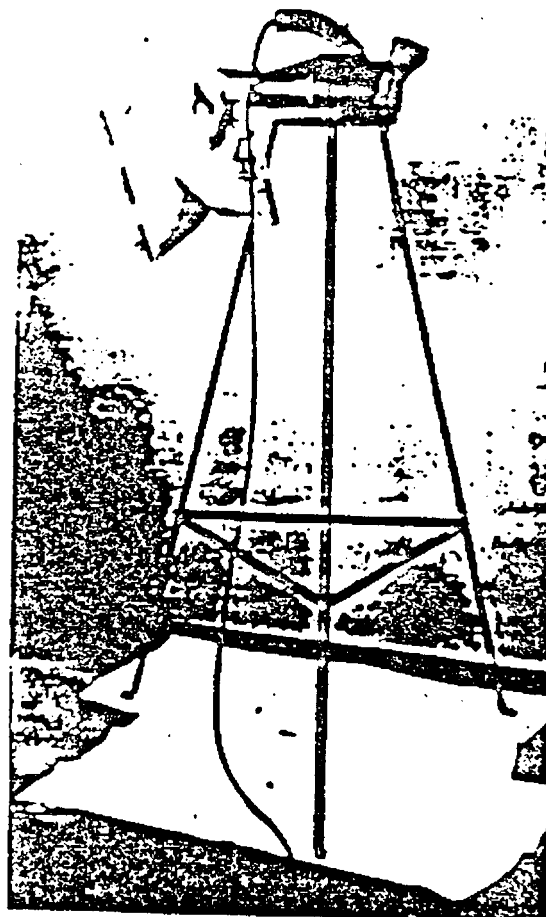

FIGURE 1.—VACUUM CLEANER BAG ARRANGEMENT FOR COLLECTING SUSPENDED DUST SAMPLES

Most crude ore must be crushed for 20 minutes, although in some cases it may be satisfactorily disintegrated in 5 minutes. The crushed asbestos has a matted appearance. Following the crushing, the asbestos is replaced by hand in the bags for delivery to the willower.

Willowing.—The willowing or opening of the asbestos is essentially a cleaning operation. The willower beats and shreds the matted

FLOW SHEET

AMERICAN PRACTICE

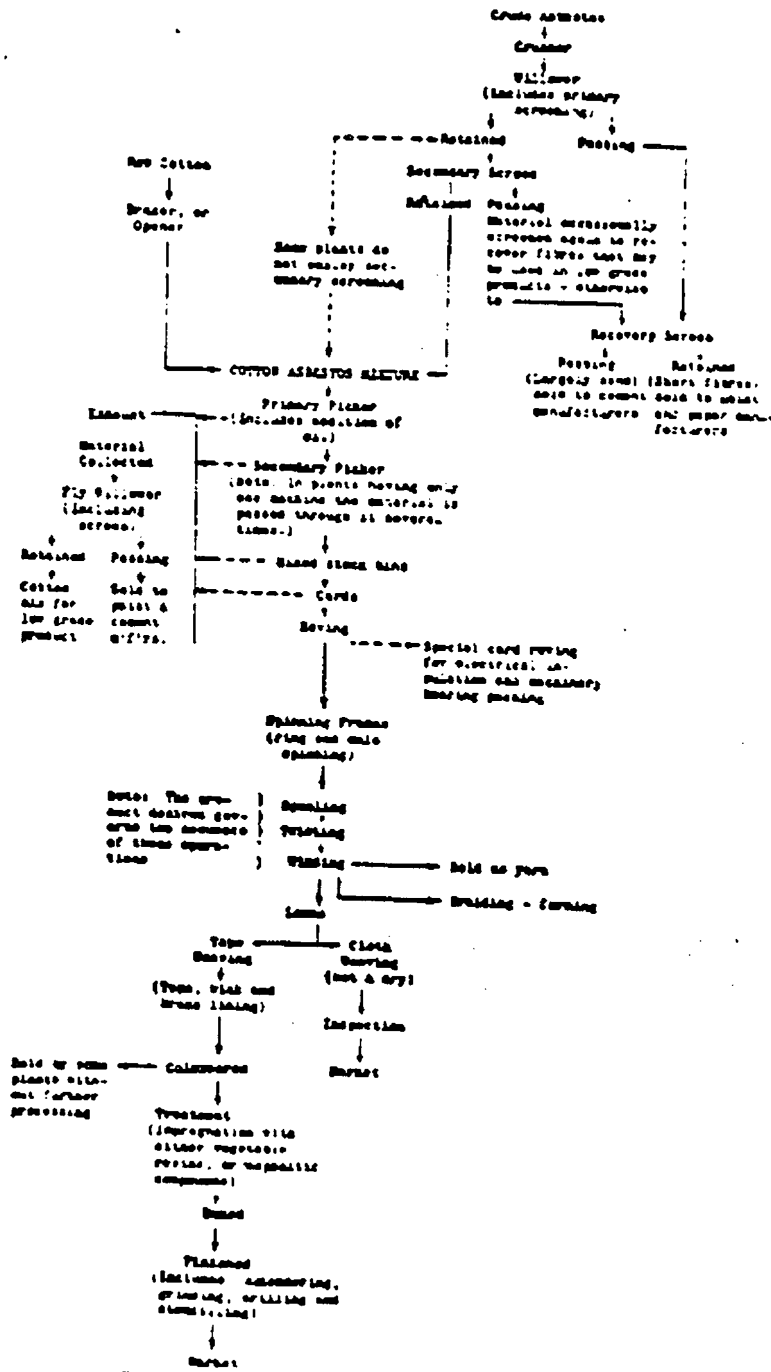

FIGURE 2 – FLOW SHEET OF AMERICAN PRACTICE

of cotton used depends upon the quality of the willowed asbest fibers used. As a rule, from 5 to 15 percent by weight of all the asbe- tos textiles produced in this country is cotton.

Piling.—At the plants studied, the mixing is accomplished in tw steps, the first consisting of placing the cotton and asbestos in alter nate layers in a pile upon the floor, and the second step of feeding th mixture into a picker machine. The batch making, or the placing o the cotton and asbestos, is known as piling. It is productive of muc dust since it is necessary to spread out both the cotton and asbesto into uniform layers, which involves the use of a rake and muc trampling of the materials.

Picking.—After the mixture is made, it is lifted into the breast high hopper of the picker machine. The material emptied into th

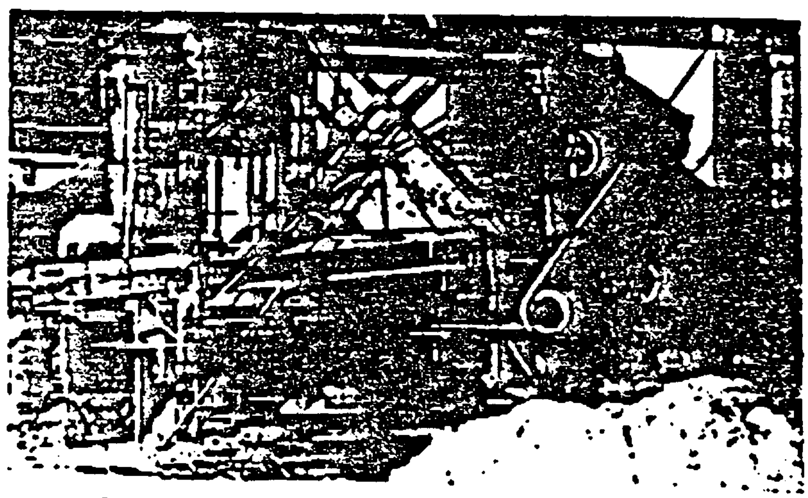

FIGURE 4.—FLY OPENER OR WILLOWER (NOTE EXHAUST).

hopper displaces air in the hopper which causes dust and fibers to escape upward into the face of the worker. In addition, the cylinder and accessory rollers of the picker machine operate at a high speed and much fine material escapes from the many small openings in the frame. The dust that is fanned out of the machine, together with that produced in the feeding operation, makes the pickerman's occupation comparatively dusty. In some plants two pickers are operated in series and in others only one, through which the material may be passed several times. In either case the picker discharges directly or by pneumatic duct into a collector bin. Where only one machine is available, however, the pickerman must move the material by pitchfork from the collector bin to the floor of the picker room for its recirculation through the picker. At one of the plants studied there are two pickers operated in series and connected by pneumatic ducts. Here the collector bin is also the storage bin. In order to prevent the mixed material from accumulating in a steep pile a man is stationed in the stock bin at all times. This occupation creates considerable dust, since the cotton-asbestos mixture is delivered into the bin by overhead duct discharge. In order to reduce the dust exposure of the stock-bin man, his position is made interchangeable with the pickerman, each of whom spends a half of every day in the stock bin and a half day at the picker. In the plant having only one picker, the mixture is trucked from the collector bin to the storage bin. At one of the plants studied, exhaust ventilation is provided for the picker machines and the mixed stock storage bins. Oil sprays are

FIGURE 5.—EXHAUSTED CARDING MACHINES.

frequently used within the picking machines in an attempt to prevent the formation of dust.

CARDING

From the storage bins the stock, as it is called, is hand-trucked to the carding machines where it may be piled upon the floor or fed into the hopper of the breaker card.

The cards perform several duties. They give the fibers an additional mixing, arrange them in parallel positions, and form them into roving. The term roving is applied to the strands of parallel fibers that are produced. A carding unit consists of two almost identical machines. The one through which the cotton-asbestos mixture passes first is termed the breaker card, and the other, the finishing card. The two machines are quite similar in that a large revolving cylinder with several accessory rollers performs the major portion of the work. (See fig. 5.) The carding operation is quite similar to that of the picker, the essential difference being that the roller and cylinder sur faces are studded with fine steel bristles rather than large hooks. Some of the rollers straighten the fibers by combing out the tangles while others doff, or remove, them from the combing rollers and the cylinder. Aside from these main features, the two units differ slightly. The breaker card is equipped with a feeding hopper similar to that used on the picking machine, while the finishing card is provided with a device for forming the carded fibers into strands. In the plant studied a system of conveyor lattices transfer the carded fibers from one machine to the other. The outside strands of roving are returned

FIGURE 6.—SPINNING MULES.

to the picker for reworking. The remainder of the roving is wound on long rollers with flanged ends, called jack spools.

The bristle-studded cylinders of the carding machines revolve at high speeds and much lint is thrown into the atmosphere. The effect produced by the revolving cylinders and wheels is similar to that of a fan, and as a result much of the dust remaining on the stock at this point, as well as asbestos and cotton fibers, is blown into the air. All carding machines studied were provided with exhaust ventilation.

While practically all of the roving is spun into yarn, some of it is marketed without further processing other than winding on spools or into coils. In this form it is used for electrical insulation and for conversion into packing for machine bearings.

SPINNING

The jack spools containing the roving may be conveyed either to the mule spinning machines shown in figure 6 or to the ring spinning frames. The spinning, on whatever machine performed, is a twisting operation which imparts strength to the strand of fibers by malocking or meshing them together. The ring spinner twists the roving as it is wound on a spindle, while the mule spinner performs the same treatment in two operations; first, spinning it in 5- or 6-foot lengths and then winding it on a spindle. The ring spinner makes a yarn that is stronger and better in many respects than that produced on the mule spinner.

WINDING, TWISTING, AND SPOOLING

The spun yarn is converted into stronger thread in two operations. It is taken first to the winding machines where it is transferred from spindles to tubes. After being wound on tubes, the yarn goes to the twisting machines where the thread from two or more tubes is brought together and twisted into one thread. In the twisting operation the thread is frequently strengthened with brass, zinc, or copper wire, or

FIGURE 7.—TWISTING MACHINE.

with cotton twine. Following the initial twisting operation the yarn may return to the winders for placing on special tubes, in which form it is marketed. Then again, it may be conveyed to the cop or twill winders where it is wound into spindles for use in the shuttles of the looms. There are a variety of winding operations that prepare the yarn in some particular manner for the market or for use on certain types of machines. Likewise, there are a variety of twisting and spooling operations. (See fig. 7.)

The winding and twisting of the yarn is followed by a number of more or less related operations. The thread may be converted into cloth, tape, wick, brake lining, tubes, braids, or formed into rope. (See figs. 8 and 9.) A small amount of the product of the winders and twisters is treated by passing through a sizing compound, and subsequently dried on reels before being wound again on tubes for the market.

WEAVING

The weaving of asbestos is done on looms that operate in the conventional manner. Both cloth looms and tape looms are used. (See figs. 10 and 11.) On the latter, brake lining, asbestos tape, and wick for oil stoves are woven. The tape looms differ from the cloth looms in that the warp is segregated into several strips of material and in that there is a shuttle for each strip of warp. The weaving of all strips proceeds simultaneously; one mechanism operates all shuttles and a single reed suffices for all warps. Looms for tape weaving are made in multiples of 6 spaces up to as many as 30. Both dry and wet weaving are employed for the production of both cloth and tape. In wet weaving the warp is passed through a shallow pan of water and the cop (for use in the shuttle) is dipped into water.

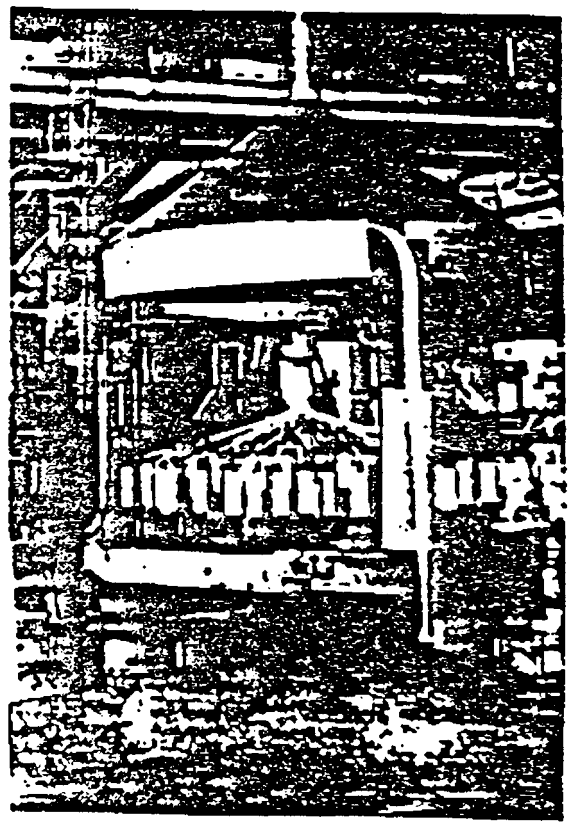

FIGURE 8.—EXHAUSTED BRAIDER

Dry weaving of broadcloth produces much lint and dust. The threads of the warp are continually rubbed past each other as they are moved from positions above or below the line of the shuttle which is shot from one side of the loom to the other at each change in position of the warp. Fiber fragments are rubbed from the threads at each change in their position and the fanning of the air by the moving machinery carries them into the atmosphere in and about the loom. The same machines are used for both wet and dry weaving.

In the manufacture of asbestos woven products at some of the plants studied, the warp is formed on individual looms by harnessing the thread from many spools which are hung on creel racks. At others the warp is first wound on a beam from the individual spools and then transferred to the looms. The latter practice makes a more compact weaving unit as creel racks occupy several times as much floor space as the loom. The creel racks are attended by a worker who is kept

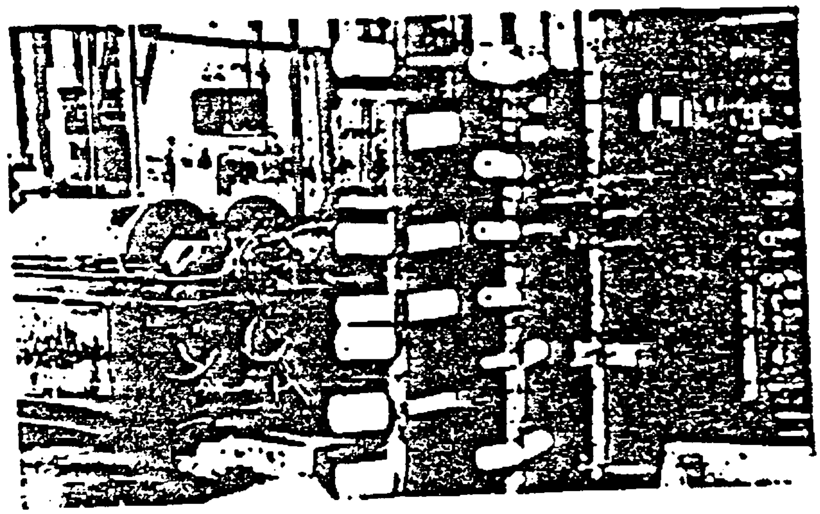

FIGURE 9.—ROPE-MAKING MACHINE.

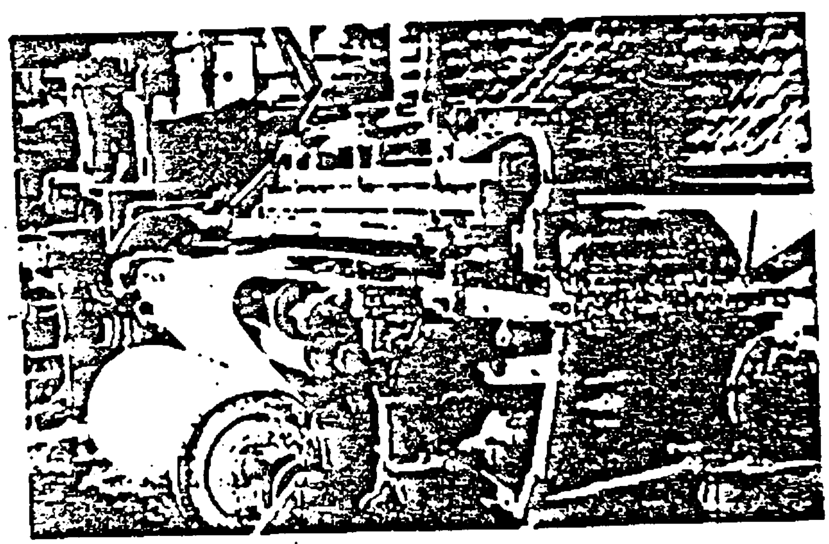

FIGURE 10.—BROADCLOTH WEAVING LOOM.

busy tying broken threads and replacing empty spools with full ones. The occupation involves an exposure to asbestos dust for which the looms are largely responsible.

The asbestos cloth is usually shipped to firms that convert it into gaskets, fireproof clothing, and other products that require a noncombustible fabric. Some asbestos wick is packed for the market without further treatment. Asbestos tape is usually sold to other industries. Some plants that weave brake bands sell it as a crude woven ribbon of fabric to finishing factories, while other manufacturers of the material convert it into finished products.

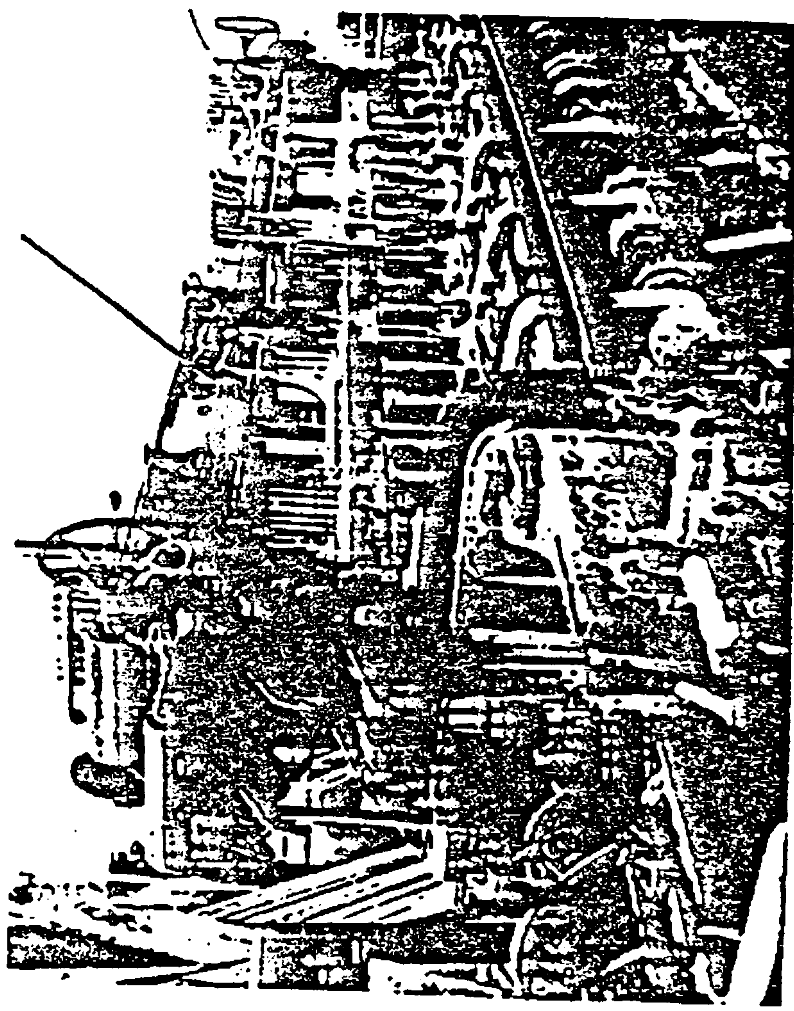

FIGURE 11. BRAKE-BAND WEAVING LOOM SHOWING THREE OF THE SIX SECTIONS WITH WOVEN BANDS

BRAKE-BAND MANUFACTURE

The manufacture of brake bands proceeds in several steps, the first being the impregnation of the woven fabric with either an asphaltic compound or a vegetable resin. The latter is the newer form of treatment and is rapidly supplanting the former. Following this operation a heat treatment is applied in a specially constructed oven. In practice the ribbon of woven asbestos passes first into a vat of the treating substances and thence immediately into a baking oven. These operations are carried on in a building that is well ventilated and which is removed from other structures sufficiently to reduce the fire hazard. The treated asbestos fabric is now calendered into uniform width and thickness and one surface is ground smooth. The brake-band material is next cut into suitable lengths and holes drilled into them according to pattern. Finally, the finished brake bands are branded and packed for the market.

In some plants molded brake bands are made of asbestos yarn and

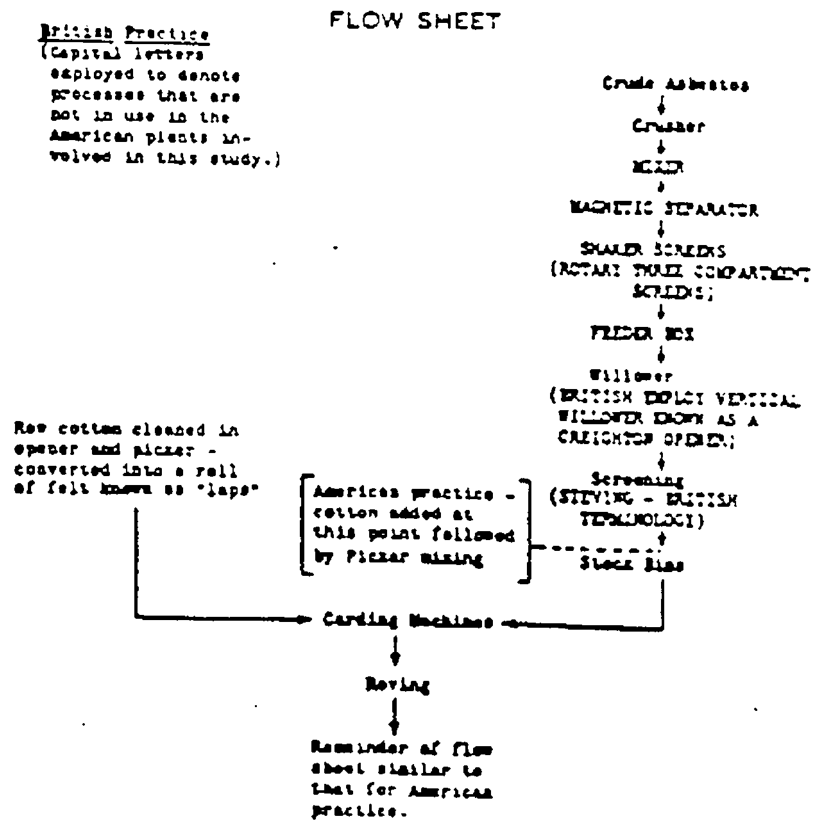

FIGURE 12.—FLOW SHEET OF BRITISH PRACTICE

a synthetic resin. The process consists of passing asbestos thread through a bath of resinous material and immediately winding it upon a spool or cylinder. Enough of the resin will adhere to the asbestos to form a matrix into which the asbestos thread will be imbedded. When the desired thickness is obtained, the spool or cylinder is given a heat treatment which hardens the resin. The baked cylinder of material is removed from the spool and cut into narrow sections. The circular bands thus formed are ground, machined, and otherwise made ready for the market.

The grinding or surfacing of the brake bands produces considerable dust. In the plants studied exhaust ventilation was used to control the exposure.

BRITISH MANUFACTURING METHODS

British practice differs in many respects from American practice. The same type of machinery is used in both countries but in British factories, dust-control equipment seems to be more generally used than in American factories. British factories specialize in the production of fine yarn and this involves numerous differences in practice.

In England the processing of the asbestos begins, as it does in the United States, with the crushing of the ore, but when this operation has been completed the manufacturing process does not parallel American practice until the fiber has been carded and is ready for spinning into yarn. (See fig. 12.)

After crushing, various grades of asbestos are blended in a machine quite similar to the conventional type of rotary concrete mixer. It is of passing interest to note that the same device is used for blending tea. The blend of asbestos is passed through a magnetic separator where certain mineral impurities are removed. It is cleaned further on rotary shaker screens where some grit and fiber fragments are eliminated. After screening, the material is fed into a willower. The British employ a vertical willower that is known as a Creighton opener. Its action is similar to that of the American willower, and the internal revolving mechanism is retained. The willowed material is subjected to a final cleaning on a second set of screens; such an operation is termed "sieving." Willowing is the last of the cleaning processes, after which the asbestos is placed into bins and is thereafter known as stock. It is now fully prepared for carding.

The practice at the plants included in this investigation is to add cotton to the asbestos and then subject the combination to a thorough mixing in a picker machine. In England cotton is added to the asbestos on the carding machine, both fibers being fed separately into the breaker card. The cotton in all probability is prepared for the carding operation on a conventional type of combination cotton textile picker machine which opens the fibers, cleans them, and forms the material into laps. The latter term is applied to the cotton which is formed into a broad ribbon of felt and then wound into a roll.

English carding machines are equipped with a feeding conveyor, or lattice, upon which first the asbestos and then the cotton are placed. The asbestos is added from a weighing box that is supported over and near the outside end of the conveyor. This box feeds asbestos in accordance with a predetermined ratio of the fiber to the cotton. When a certain weight of asbestos has accumulated in the box, a mechanism opens the bottom and allows the material to fall upon the lattice. Further along a roll of cotton felt rests upon the lattice and unwinds as the conveyor moves forward. Thus, asbestos covered with a layer of cotton felt is fed into the first machine of the carding unit. The carding operation has already been described.

The roving produced by the carding machines may be converted into yarn on either one of the two machines, both of which have been discussed. As was pointed out, the ring spinning machine produces a much finer yarn than the mule spinning device. Since the British specialize in fine yarn, the ring spinning frames are used virtually to the exclusion of the mule spinner. The preparation of yarn for the market and its conversion into woven products will not be discussed since they are similar to the processes used in this country.

OCCUPATIONAL ANALYSIS AND A DESCRIPTION OF THE CHIEF OCCUPATIONS

The occupational analysis of the four asbestos plants covered in the present investigation is shown in table 1.

TABLE 1.—*Occupational analysis of workers in the asbestos textile manufacturing industry*

Section and activity	Number of workers in— Plant A		Plant B		Plant C		Plant D		Total	
	M	F	M	F	M	F	M	F	M	F
Preparation:										
Foremen			2						2	
Crushermen	3		6						9	
Willowers	1		6						[illegible]	
Pickermen	3		6						9	
Total	7		20						[illegible]	
Carding:										
Foremen	2		3						5	
Second hand	3		3						6	
Carders	9		21						30	
[illegible]	3		15						18	
Teasers	3		3						6	
Total	20		45						65	
Spinning:										
Foremen			2						2	
Mule spinners	4		10						14	
Ring spinners	5		15						[illegible]	
Helpers	3		10						13	
Total	12		37						[illegible]	
Spooling, spoolers		9		13						22
Twisting:										
Foremen	2		2						4	
Second hands	1		2						[illegible]	
Twisters	15		15					1	30	1
Helpers	1		4						[illegible]	
Total	21		23					1	[illegible]	1

TABLE 1.—*Occupational analysis of workers in the asbestos textile manufacturing industry*—Continued

Section and activity	Number of workers in— Plant A M	Plant A F	Plant B M	Plant B F	Plant C M	Plant C F	Plant D M	Plant D F	Total M	Total F
Winding										
Foremen	1		2						3	
Winders		13		14		1				[illegible]
Yarn packers	8		3						13	
Total	9	13	7	14		1			[illegible]	[illegible]
Treating: Treaters	1			2	4		3		[illegible]	[illegible]
Cloth weaving										
Foremen	1		1						2	
Second hands	2		1						3	
Weavers	6		23						[illegible]	
Inspectors	1		3						3[illegible]	
Calenderers	3								3	
Creelers		4							3	
Cop winders		2		6						[illegible]
Helpers			1						1	[illegible]
Total	13	6	30	5					4[illegible]	
Tape and brake-band weaving										
Foremen			1						[illegible]	
Weavers, tape	6		16	4	2	1			2[illegible]	
Weavers, brake band			2		2				[illegible]	
Calenderers				2	1		9		[illegible]	
Creelers			2		1				1	
Clerk			1						[illegible]	
Total	6		29	6	6	1	9		50	
Cord, rope, and braid workers			9	12					[illegible]	
Finishing										
Treaters and driers										
Calenderers							3		3	
Strippers					1				1	
Cutters and drillers					1				1	
Braiders					3		3		6	
Coilers					1				1	
Total					7		6		13	
General labor										
Engineers	1		2		3		3		[illegible]	
Laborers	6		6				2		[illegible]	
Watchmen	2		3				1		11	
Shipping clerks			1				2		[illegible]	
Yardmen			2	1	3				[illegible]	1
Total	9		14	1	4		[illegible]		[illegible]	
Office										
Superintendents	1		3		1		1		6	
Others	9		8	3	3	3	2		[illegible]	
Total	10		11	[illegible]	[illegible]	3	[illegible]		[illegible]	
Grand total	[illegible]	[illegible]	[illegible]	[illegible]	23	3	[illegible]	1	[illegible]	[illegible]

Reference to table 1 shows that a number of men have been listed as foremen and second hands. These terms have been adopted from the cotton textile industry. They do not always mean full-time supervisory duties, as might be presumed; in most cases foremen and second hands are engaged in all the activities of the departments to which they are assigned. Further mention of these occupations is not made in the brief occupational descriptions which follow.

PREPARATION

Crushermen empty the raw asbestos, contained in 100-pound bags, into the pan of the crusher. They also operate the crusher and remove the asbestos fiber after crushing.

Willowers or openers handle crushed fiber and waste roving. The crushed ore is fed into the willowing machine by means of pitchforks. The willowed material is usually blown into a special bin. The waste accumulated by the machine is removed several times daily by the willower. Willowers also operate screens for separating coarse granular material (cebs) from the fiber.

Pickermen make up the asbestos-cotton batches (piling) according to specifications and pitch the material into the feeder hopper and the picker machine. The pickermen in some plants may hand truck to special bins the material which is blown from the machines.

CARDING

Carders operate the carding machines and clean them when necessary.

Stockmen handle the stock prepared by the pickermen. The material is conveyed by hand trucks from the stock bins to the card feeders.

Tenders look after the stock feeders and roving jack spools. The latter are removed when full, and replaced with empty jack spools. The occupations of tender and carder are in some plants interchangeable.

SPINNING

Mule spinners operate the mule spinning frames.

Ring spinners operate ring spinning machines.

Helpers (bobbin boys) assist the mule spinners and ring spinners conveying full jack spools of roving to the spinners and carrying empty spools back to the cards. They also transport the spun yarn and attend to the roving jacks and bobbins whenever required.

SPOOLING, TWISTING, WINDING, AND TREATING

Spoolers tend the spooling machines and handle spools on which the spun yarn is wound.

Twisters and helpers operate machines that twist spun material into heavier and stronger yarn.

Winders operate yarn winding machines.

Treaters pass yarn through special compounds (usually predominantly starch) and wind it on large reels for drying. In brake lining manufacture, treaters handle asphalt and resinous materials with which the product is impregnated.

Yarn packers wrap and box finished yarn.

CLOTH AND TAPE WEAVING

Broadcloth weavers operate both dry and wet weaving looms.

Tape weavers operate looms for weaving tape and brake lining materials.

Inspectors and calenderers inspect and examine all woven material for defects and pass tape and brake bands through calendering machines to achieve desired width and thickness.

Creelers attend to the creel racks on which the warp thread spools are mounted.

Cop winders operate cop-winding machines which wind thread on metal spindles for use in the loom shuttles.

Weaver helpers usually attend to the drying of broadcloth which has been woven wet. They also handle material for the creelers and weavers.

ALL OTHER

Cord, rope, and wick workers operate special cord and rope-making machines and braiding machines.

Brake-lining finishers include treaters and dryer men, calenderers who operate calendering machines for squaring uneven edges, grinders who smooth off uneven surfaces, and cutters and drillers who cut the finished band to required sizes and drill it for riveting to brake shoes for automobiles and other machines. In the plants studied, these occupations were interchangeable.

General labor includes those occupations associated with maintenance of equipment and generation of steam. They also include janitors, watchmen, and shipping clerks.

Superintendence is concerned with the supervision of all plant activities.

RESULTS OF THE ENGINEERING STUDY

DUST STUDIES

In the present study, dust counts were made by the impinger method (2), using ethyl alcohol and distilled water mixtures containing from 25- to 50-percent alcohol as a collecting fluid. Two sampling methods were used for collecting dust for chemical analysis. (1) Settled dust samples were collected at the breathing level and (2) air-suspended dust was collected with a small, hand-type, vacuum cleaner fitted with a removable, paper-bag type filter. The latter method is similar to a procedure developed by Hatch (5). (See fig. 1.) In addition to chemical analyses, petrographic analyses were made on several samples. In order to determine the particle size of asbestos dust, an Owens jet apparatus was employed (2). The samples collected were measured by means of a filar micrometer at a magnification of approximately 1,000 diameters (oil immersion). Photomicrographs were also made of dust obtained by the vacuum-cleaner device described above.

NATURE OF THE DUST FOUND IN ASBESTOS TEXTILE FACTORIES

Composition.—Table 2 shows the results of chemical analysis of settled dust samples obtained by the Hatch method (5). Examination of these tables does not reveal significant differences among the various samples.[4] It will be noted, with one or two exceptions, that the total ash (no water of crystallization present) does not vary greatly. The value of 54.5 obtained for wet weaving (sample 8) is due to the moisture content of the dust sample. Calculations of composition on an ash basis bring the values into closer agreement than indicated in either table. The results given for sample 11 in table 2 are for brake lining which has been impregnated with resinous compounds.

[4] [illegible] asbestos [illegible], the asbestos used in these factories has the following composition: [illegible] 10.12 [illegible] 1.5 [illegible] 2.50 percent. (Asbestos, Vol. 2, No. 7, January [illegible].)

TABLE 2.—*Chemical analyses of settled dust samples obtained in asbestos textile plants*

Department in which samples were collected	Average chemical composition of samples (percentage): Ash	SiO_2	R_2O_3[1]	CaO	MgO	Fe_2O_3	Remarks
1. Preparation (plant A)	83.6	37.0	10.5	0.7	35.5	8.1	
2. Preparation (plant B)	67.5	35.5	17.1	.3	34.7	14.2	Near willower
3. Carding (plant A)	83.2	36.4	13.5	1.5	34.0	10.3	Top of card [illegible]
4. Carding (plant B)	82.4	36.3	11.3	1.2	33.7	8.9	
5. Carding (plant B)	70.6	35.3	9.3	.5	34.5	6.6	Bottom of cards
6. Mule spinning (plant B)	81.2	34.1	16.1	.9	22.3	11.2	
7. Weaving (plant A)	81.5	35.6	10.8	1.0	34.0	5.7	Tape weaving loom.
8. Weaving (plant B)	54.5	24.2	5.4	.2	24.3	4.8	Wet weaving
9. Weaving (plant B)	75.3	31.0	11.0	.8	30.4	7.9	Between floor cracks.
10. Weaving (plant B)	72.[illegible]	32.0	10.9	1.0	25.5	7.7	[illegible] room.
11. Brake-lining grinding (plant C)	83.2	46.2	6.1	1.8	44.2	3.6	Garnet and metal separated with bromoform.
12. Dust from cyclone connected to exhaust system (plant B)	81.9	34.7	15.2	.8	31.2	10.6	Mostly card room dust.

[1] Combined oxides.

TABLE 3.—*Chemical analyses of suspended dust samples collected in an asbestos textile plant*

Department in which samples were collected	Average chemical composition of samples (percentage): Ash	SiO_2	R_2O_3[1]	CaO	MgO	Fe_2O_3	Remarks
13. Preparation	80.8	35.4	8.3	1.2	34.9	4.8	General air sample.
14. Carding	83.7	37.5	9.5	1.0	36.0	4.3	Do.
15. Mule spinning	85.6	33.9	18.4	.8	24.3	7.1	Between 2 mule spinners
16. Ring spinning	75.2	33.2	9.3	.8	31.6	7.8	Near ring spinning machines
17. Dry weaving[2]	79.5	35.7	8.8	.4	34.3	7.0	Broadcloth weaving
18. Wet weaving[2]	71.6	31.9	8.7	.9	30.4	6.7	Do.
19. Twisting[2]	75.9	22.7	10.4	.4	32.1	8.3	Near twisting machines
20. Spooling[2]	81.2	34.7	12.0	.9	33.4	9.8	Near spooling machines
21. Winding[2]	69.5	30.6	8.8	.7	29.6	4.8	Near winding machines

[1] Combined oxides.
[2] Operations conducted in same room.

The losses on ignition of all samples analyzed are due to the presence of cotton fiber and moisture. The 30.5 percent loss on ignition of sample 21 in table 3 is probably due to the presence of cotton fibers.

In passing, it may be pointed out that no carbonate of the order reported by Hurlibut and Williams was found in any of the samples analyzed (6).

No quartz was found in any of the samples examined petrographically.

The consistency of the results indicated in tables 2 and 3 is more remarkable when the physical characteristics of the dusts are taken into consideration. Figure 13 illustrates the gross appearance of the dust samples taken with the vacuum cleaner device above mentioned. Each sample shown in the figure represents two grams of dust. There are conspicuous differences among the samples, both in color and bulk. Preparation and carding produce granular material. Weaving

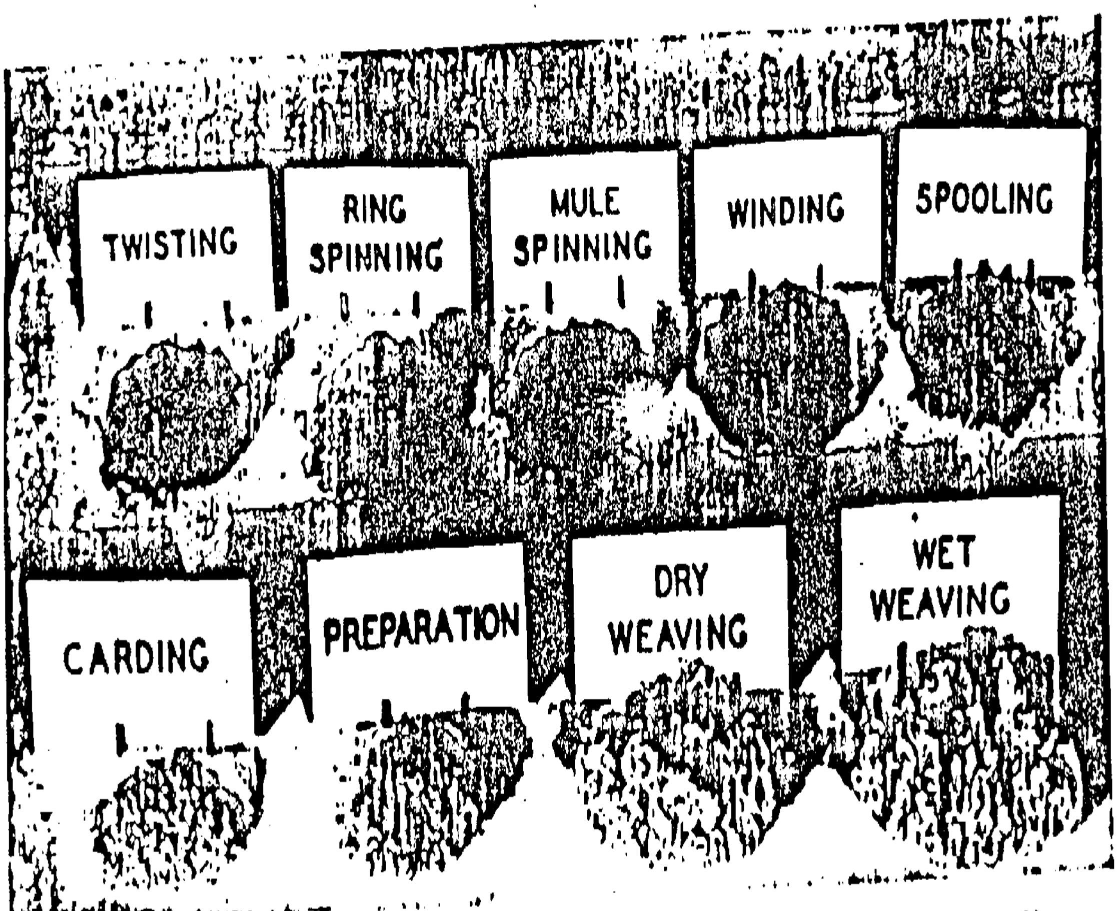

FIGURE 11 GROSS APPEARANCE OF SUSPENDED DUST COLLECTED WITH VACUUM CLEANER DEVICE (SEE FIGURE 1)

samples, on the other hand, are bulky, the difference probably bei due to the presence of long asbestos and cotton fibers in these sampl Carding and preparation samples contain cobs which are present the raw asbestos. The darker appearance of the samples shown in t top row of figure 13 is difficult to explain. It is probably due to t

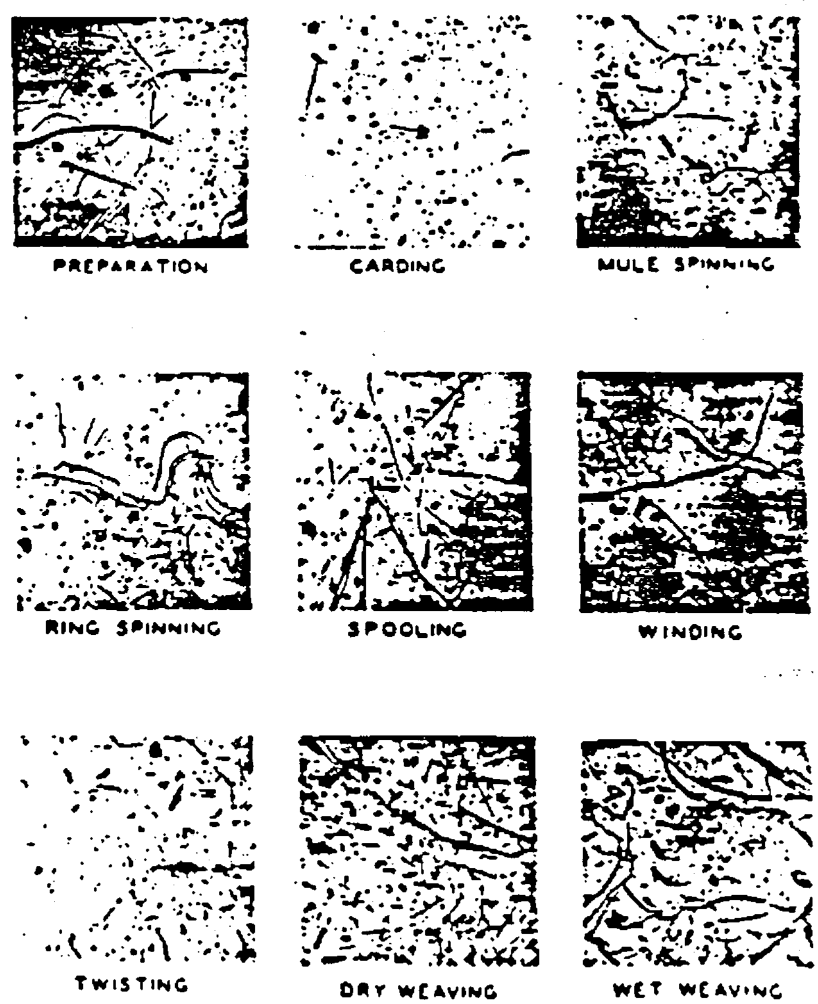

FIGURE 14 —MICROSCOPIC APPEARANCE OF SUSPENDED DUST COLLECTED A VACUUM CLEANER DEVICE. 200X

contact of the spun asbestos-cotton mixture with oily metal surfa

The microscopic appearance of the vacuum cleaner samples illustrated in figure 14. The presence of both cotton and asbest fibers and of small particulate matter is readily noted. The dust fr the carding room is most striking. It has few fibers and it h considerable particulate matter

Particle size.—The measurement of dust particles suspended in the air of asbestos textile plants is difficult because of the presence of both asbestos and cotton fibers. The differentiation of these fibers under the microscope is not always possible, especially when the fibers are short and fine. Several samples obtained with the Owens jet apparatus were examined with a petrographic microscope in order to estimate the proportion of asbestos and cotton fibers, but no satisfactory technique could be developed for this purpose. In this study, particle size determinations based on Owens jet samples were made by three methods: (1) euscope projection device; (2) a filar micrometer attachment to a microscope (using oil immersion, 1,000×), and (3) by means of photomicrographs.

Data obtained with the euscope showing the percentage of fibers (irrespective of whether they are cotton or asbestos) are presented in table 4. These are based on Owens samples and not on impinger samples. With regard to the selectivity of the device used, little information can be given, although it is known that for discrete particles, the selectivity of the Owens apparatus and the impinger are the same (2).

TABLE 4.—*Relation of fibers to particles in various Owens jet samples*

Activity	Number of fibers counted	Number of particles counted	Total count	Percent fibers
Weaving [1]	83	233	316	[illegible]
Weaving [2]	35	251	[illegible]	[illegible]
Picking [1]	24	[illegible]	[illegible]	[illegible]
Carding [1]	22	[illegible]	[illegible]	[illegible]
Twisting [1]	14	[illegible]	[illegible]	[illegible]
Twisting [2]	14	[illegible]	[illegible]	[illegible]
Crushing [1]	8	[illegible]	[illegible]	[illegible]

[1] Plant B.
[2] Plant A.

The results given in table 4 indicate that weavers are exposed to the highest percentage of fibers. This is to be expected because the warp threads fray as the shuttle crosses them. Samples collected near the pickers and carders have fewer fibers, while the dusts to which crushermen are exposed have the least proportion of fibers.

The relatively low percentage of fibers in suspended dust explains the small number of fibers observed while making dust counts of impinger samples. The latter were usually diluted to give 20 to 50 particles per quarter field. Hence, except for weaver's samples in which considerable fibers were observed, fibers are only rarely found in making counts of other samples. (Dust counts included both fibrous and nonfibrous particles, irrespective of size.)

Table 5 illustrates the size range of particulate matter. Two hundred particles in each sample have been measured by means of the euscope.

filar micrometer. As may be seen, the median size varies from 1.22 microns to twice this value. Fulton and his coworkers used an electrostatic precipitator to collect dust samples and calculated an average value for the total distribution of fibrous and nonfibrous of 1.33 microns (4). The median size for particles less than 5 microns, as deduced from data given by these investigators, is approximately 0.47 microns, which is much lower than the values given in table 5 of this report. This difference can probably be attributed largely to the type of sampling devices used in the two investigations.

TABLE 5.—*Size frequency distribution of particulate dust suspended in the air of asbestos textile plants*

Nature of process where sample was taken	Median size in microns	Geometric standard deviation	Percentage frequency of each particle size group (in microns)											
			0 to 0.49	0.5 to 0.99	1 to 1.49	1.5 to 1.99	2 to 2.49	2.5 to 2.99	3 to 3.49	3.5 to 3.99	4 to 4.49	4.5 to 4.99	5 or more	Total
Preparation	[illegible]	1.56	3	21	[illegible]	22	10	4	2	1	0	0	0	100
Carding	1.35	1.57	1	6	24	25	6	16	4	5	1	3	3	100
Mule spinning	1.60	1.31	0	1	29	36	25	4	1	1	1	0	1	100
Twisting	1.22	1.74	5	30	20	14	9	5	4	5	0	1	7	100
Weaving (brakecloth)	[illegible]	1.71	1	4	41	27	10	3	2	3	4	[illegible]	1	100
Weaving (tape)	2.44	1.74	0	3	11	24	11	12	7	13	7	3	6	100

In determining the length of fibers present in Owens samples, photomicrographs were used. It was necessary to use this method of measurement because of the curvature and matting of fibers in the microscopic field. This difficulty was overcome by using compass pointers and measuring each fiber visible across a given section of the photomicrograph. The size distribution of fibers, classified by occupation, is presented in table 6. The fibers range from as little as 2 microns (450× magnification) to as high as 400 microns. The median sizes, as may be seen by reference to the table, range from 7 to 16.3. Fulton's data indicates (assuming all particles greater than 5 microns to be fibers) a median size of 15 microns.

TABLE 6.—*Median length of fibers sampled with an Owens jet apparatus*

Activity	Median length of fibers in microns
Willowing	[illegible]
Picking	[illegible]
Carding	[illegible]
Twisting	12.8
Weaving (brakelining)	16.3

No size frequency distribution with regard to the width of fibers present in the air has been made in this study. However, it has been noted, with few exceptions, that the width of fibers collected by the

Owens jet apparatus was less than 0.5 micron. This is in agreement with the results given by Fulton, who shows more than 78 percent of the fibers measured by his projection method to be less than this size.

DUST CONCENTRATION IN DIFFERENT OCCUPATIONS

In earlier studies of the dusty trades carried on by the Public Health Service, determinations of the average dust concentration have been of great value (1) in describing the working environment, (2) in making comparisons of the effectiveness of different methods of dust control, and (3) in relating health conditions to dust exposure. In this study 242 impinger samples were taken and counted, and the results have been classified by occupation in tables 8 to 18. Each of the occupations carried on in asbestos textile factories has been discussed separately in the following section and data for the entire industry have been brought together in table 19. In this industry there are relatively few occupations in which workers do two or more kinds of work which expose them to totally different dust concentrations. In such cases the several exposures have been weighted according to the average time of exposure.

For example, in plant A, willowers are engaged in the following activities: willowing, 5 hours; picking, 1½ hours; storage-room work, 1½ hours. These activities are associated with exposures of 2.3, 36.3, and 16.4 millions of particles per cubic foot, respectively. Hence, we may tabulate exposures as follows and calculate a weighted average:

TABLE 7.—*Dust exposure of willower, plant A*

Activity	Time of exposure (hours per day) a	Average dust exposure (MPPCF) b	Millions of particle-hours per cubic foot a×b
Willowing	5	2.3	11.5
Picking	1½	36.3	54.4
Storage-room work	1½	16.4	24.6
Total	8		90.5

$$\frac{90.5 \text{ million particle-hours per cubic foot}}{8 \text{ hours}} = 11.3 \text{ million particles per cubic foot}$$

The average dust count of the 10 samples in the above table, calculated without regard to the duration of exposure, would be 18.7 million particles per cubic foot.

Preparation.—Preparation includes the occupations of crushermen, willowers, and pickermen. In plant B, these three occupations were conducted in the same room, while in plant A only crushers and willowers worked together. Picking (including piling), in the latter plant, was done in a separate room. The dust exposures are indicated in table 8.

TABLE 8.—*Dust exposure of workers in the preparation department*

Occupation	Number of samples taken	Dust concentration (MPPCF)
Crushermen	9	[illegible]
Willowers	[illegible]	11 [illegible]
Pickermen	[illegible]	[illegible]

[1] Weighted average.

It will be noted in table 8 that the crushermen's exposure is relatively low. In the plants studied, this work was carried on near an open door. However, it is doubtful that this occupation generates the quantity of dust shown in the above table. It is more than likely that willowing and picking (and even carding) contribute to the dust exposure of crushermen.

Willowing of crushed asbestos is not in itself productive of much dust (11.1 million particles per cubic foot). Only when waste roving and fly from cyclone collectors are willowed does the dust count increase. Dust counts as high as 99 million particles per cubic foot have been obtained with fly. A continuous source of dust production results from the manner in which willowing machines are fed. The material to be willowed is raised waist high by pitchfork, causing considerable spilling. Willowers also operate shaker screens.

A pickerman performs several kinds of work. This is especially true in plant B, where pickermen not only assist in piling (mixing of cotton and asbestos), but also aid in stacking the material blown from the picker machine into storage bins. This last-mentioned activity produces dust concentrations ranging as high as 211 million particles per cubic foot. Pickermen usually work in pairs and alternate in feeding the picker machine and tending to the storage bins. Piling is done by both workers together and contributes to dust counts averaging 16.2 million particles.

Picker machines, like willowers, are fed by pitchfork, a method which produces undesirable dust. This is true even where picker machines have hooded feeder boxes.

The picker machines studied were equipped with oil sprays, presumably to hold down dust. The ineffectiveness of this method of dust control is shown by the dust counts which exceed 50 million particles per cubic foot of air.

Carding.—The brushing and combing of asbestos and cotton fiber mixtures by carding machines creates considerable dust. The carding action is such that small cobs and fine talc adherent to the asbestos fiber are thrown into the air. This effect is accentuated by the fan action of the brushes. The granular and nonfibrous appearance of the dust present in the air of carding rooms has been shown in figure 10.

The exposure of workers in carding rooms is given in table 9.

TABLE 9.—*Dust exposure of workers in carding department*

Occupation	Number of samples taken	Dust concentration (MPPCF)
Carders and tenders	[illegible]	[illegible]
Stockmen	11	[illegible]

[1] Weighted average.

The average dust concentrations in both plants A and B were similar. Counts as low as 6.4 million particles per cubic foot were obtained for some carding operations where machines were operated at a relatively low speed and as high as 139 million particles for high-speed operations.

In the two plants studied which carded asbestos-cotton mixtures, all equipment was hooded and exhausted. Under the methods of operation, which required accessibility to the machines, complete enclosure was impossible. Consequently, exposed brushes, revolving at high speeds, often nullified the effect of the control system. Nor could air flows in the exhaust system be increased since a considerable amount of valuable fiber would be drawn from the brushes and this would reduce the weight of roving to an undesirable extent.

Spinning.—Both mule spinners and ring spinners are exposed to similar dust concentrations. The range shown in the following table (table 10) for each occupation is probably due to the presence of more spinning and weaving equipment where the dust concentration is higher.

TABLE 10.—*Dust exposure of workers in mule- and ring-spinning departments*

Occupation	Number of samples taken	Dust concentration (MPPCF)
Mule spinning	[illegible]	[illegible]
Ring spinning	[illegible]	[illegible]

Mule-spinning operations require considerable space and are generally separated from other activities. On the other hand, ring spinning is done in close proximity to spooling and twisting and it is possible that the dust counts are influenced by these operations. The results obtained for mule spinning check with those given by Fulton and his coworkers (4).

Spooling, twisting, and winding.—The equipment for these operations is generally grouped together and therefore it is difficult to obtain a clear-cut estimate of the amount of dust produced by each.

The average range of dust concentrations in plants A and B are shown in the accompanying table (table 11).

TABLE 11.—*Dust exposure of workers in spooling, twisting, and winding departments*

Occupation	Number of samples taken	Dust concentration (MPPCF)	Occupation	Number of samples taken	Dust concentration (MPPCF)
Spoolers	4	3.2-13.1	Roving winders	1	[illegible]
Twisters and helpers	20	3.2-13.2	Yarn packers	2	[illegible]
Universal winders	5	1.2-5.0	Yarn treaters	3	1.2-3.[illegible]

Of the occupations listed in the table, twisting appeared to contribute most of the dust in plant B and to influence the exposure of spoolers and ring spinners close by. Twisting frequently produced concentrations of over 20 million particles per cubic foot of air, yet counts below 10 million particles were not uncommon. Twisting involves a considerable amount of fraying and when low-grade materials are used, the dust production is increased.

Winders and yarn packers are exposed to lower dust concentrations than spoolers and twisters. Here again, however, because of the proximity of the latter dust-producing occupations, the amount of dust actually generated cannot be estimated. It is hard to conceive of such operations as roving winding and yarn packing producing much dust.

Broadcloth weaving.—The dust created during the weaving of broadcloth depends upon the number of warp threads per unit of width, the quality and width of the material woven, and on whether the operations are conducted dry or wet. If the warp threads are close, the fraying action which takes place during weaving produces a considerable amount of dust. With some looms the dust concentration was found to exceed 140 million particles per cubic foot. Average dust counts obtained during weaving operations are shown in table 12.

TABLE 12.—*Dust exposure of workers associated with broadcloth weaving*

Occupation	Number of samples taken	Dust concentration (MPPCF)
Weavers and helpers:		
Dry	[illegible]	[illegible]
Wet	[illegible]	[illegible]
Cleaners and helpers	4	[illegible]
Inspectors and [illegible]	3	[illegible]
Loom winders	[illegible]	[illegible]

Weaving operations are intermittent owing to frequent breakage of warp threads. Consequently, workers are exposed to alternate periods of high and low dust concentration. On the other hand, weavers must pay close attention to work and are subjected to heavy exposures while the looms are in operation.

The dust counts shown in table 12 for weavers and helpers illustrate the differences between dry and wet weaving. Both dry and wet weaving are carried out on similar looms in close proximity. However, operators are interchangeable and are not specifically designated as dry or wet weavers. Under such conditions, it is impossible to gauge the actual exposure of a weaver. The low count of 4.7 million particles per cubic foot given in table 12 for both dry and wet weaving is for a small plant with one dry and one wet loom in operation side by side. The higher counts are for a larger plant manufacturing all types of broadcloth and at the time of the survey having from 8 to 12 looms in operation.

In view of the high counts obtained during broadcloth weaving, it would be expected that creelers are exposed to comparable concentrations. That this is not the case, however, is indicated in table 12. With all looms in operation, as is frequently the case, the counts might conceivably be higher. The same is also true of inspectors, calenderers, and cop winders who work in the weaving department. These occupations do not produce large amounts of dust.

Tape, wick, and brake-band weaving.—The dust exposures for tape, wick, and brake-band weavers are indicated in table 13.

TABLE 13.—*Dust exposure of workers associated with tape, wick, and brake-band weaving*

Occupation	Number of samples taken	Dust concentration (MPPCF)
Weavers (tape and wick)	12	2.1–8.1
Weavers (brake band)	16	4.7–22.0
Creelers	3	2.4–20.3
Calenderers	1	2.6

It may be seen from this table that tape, wick, and brake-lining weavers are exposed to lower dust concentrations than broadcloth weavers. Excepting certain types of brake bands, the fraying of the warp threads during weaving is not as great as in broadcloth weaving. However, with heavy brake bands, such as are used on trucks and hoisting machinery, the dust concentrations become high and comparable to those obtained in broadcloth weaving. It is in the manufacture of such brake bands that creelers are exposed to counts of 20.3 millions of particles per cubic foot of air. Calenderers, being at some distance from the looms, have a low exposure. The dust counts obtained for the type of weaving here discussed were consistent in all four plants studied.

Cord, rope, and braid working.—Other activities found in the asbestos textiles plants are concerned with the manufacture of special products, such as cord, rope, and braid, and in treating and finishing yarn. These operations produce little dust as may be seen by reference to table 14.

TABLE 14.—*Dust exposure of workers manufacturing and finishing special products*

Occupation	Number of samples taken	Dust concentration (MPPCF)
Cord, rope, and braid workers	8	1.2–10.2
Yarn treaters	3	[illegible]

The equipment used in manufacturing these products does not operate continuously. None of the operations of cord making, rope making, or braiding requires full-time personnel, and a small group of workers perform all these jobs. The highest dust count (10.2) in t[illegible] 14 is for braiding. The counts obtained for yarn treaters are in[illegible]enced by the operations undertaken nearby.

Brake-band finishing.—This generates little dust. In the plants studied, finishing operations were conducted in separate rooms or buildings. Dust counts are shown in table 15.

TABLE 15.—*Dust exposure of workers manufacturing finished brake-band lining*

Occupation	Number of samples taken	Dust concentration (MPPCF)	Occupation	Number of samples taken	Dust concentration (MPPCF)
Treaters and driers	1	1.8	Cutters and drillers	1	[illegible]
Calenderers	1	1.2	Drummers	1	[illegible]
Grinders	1	4.2	Coilers	1	[illegible]

Workers employed in the occupations listed in this table are exposed to dust which differs in composition from the dust found elsewhere in asbestos textile plants. This is because the dust generated by grinders, cutters, and drillers of treated stock is made up of resin, asphaltum, asbestos, and metal. (See analytical results for sample 11, table 2.)

Miscellaneous occupations.—In addition to the groups directly concerned with the manufacture of textiles, a considerable number of workers (engineers, general laborers, clerks, and superintendents) are engaged in other activities. With the exception of certain foremen, these workers are exposed to low dust concentrations. The data presented in table 16 require no comment.

TABLE 16.—*Dust exposure of miscellaneous groups*

Occupation	Number of samples taken	Dust concentration (MPPCF)	Occupation	Number of samples taken	Dust concentration (MPPCF)
Engineers	2	1.3	Yardmen	2	0.10
Laborers	2	.36	Foremen (plant)	(1)	
Watchmen	1	1.2	Superintendents (office)	3	.12
Shipping clerks	1	.12	Clerks	2	[illegible]

[1] Samples and exposures depend on the activities with which they are associated.

PREVIOUS DUST EXPOSURE

The dust concentrations discussed in the preceding paragraphs represent present-day conditions. The officials of asbestos textile plants have in recent years attempted to control the dust hazard. In the plants studied, efforts have been made to exhaust picking, carding, and brake-band grinding machines. (Another plant, which will be discussed later, has extended the use of control equipment to nearly every dusty operation concerned with the manufacture of asbestos textiles.) A knowledge of the exposure of workers prior to the introduction of control equipment is important in correlating clinical findings with dust exposure.

In order to estimate past exposure, the air flow through various hoods attached to carding machines in plant A was shut off for 2 hours. Dust was allowed to accumulate for 1 hour prior to sampling. The dust thus generated caused much inconvenience to employees in the course of their work. For this reason, permission to shut off exhaust equipment was not granted in other plants studied. Carding machines are sensitive to slight air movements and are consequently difficult to regulate. Once they have been adjusted, any external disturbance affects the weight of the roving produced.

The dust counts obtained under conditions simulating those prior to the installation of the exhaust system are shown in table 17. For contrast, present exposures are included.

TABLE 17.—*Dust counts when control measures are used and when they are not in use*

Occupation	Average dust count—past (MPPCF)	Dust concentration—present (MPPCF)	Occupation	Average dust count—past (MPPCF)	Dust concentration—present (MPPCF)
[illegible]	30.2	2.3	Mule spinners	15.5	[illegible]
[illegible]	50.2	11.1	Ring spinners (variable speed frames)	[illegible]	[illegible]
[illegible]	64.0	31.1			
Carders	72.4	20.1	Weavers	[illegible]	[illegible]

The low counts obtained for the occupations listed below carders is due to a partition which separates them from the carding machines

Mule spinners are located immediately beyond this partition, and the dust count shown is due to dust which has passed through an open door.

Three dust samples obtained in the carding room 1 hour after the exhaust fans were shut off gave counts of 77, 73, and 78 million particles per cubic foot. At the end of 2 hours a sample taken in the same room gave a count of 61 million particles.

No major changes have been made in plants C and D since the start of operations. The dust counts made are essentially the same as those which have always existed. On the other hand, no data are available for past exposures in plant B. This failure can be attributed to several factors, but principally to the gradual expansion of the plant with the growth of the industry, which increased the amount of equipment, and the changes made in recent years with the exhaust system. The first of these factors appears to have affected all operations conducted in the plant, while the latter is restricted to the carding and preparation departments. In addition, it may be pointed out that plant expansion has tended to increase dust productivity, while the introduction of exhaust systems has reduced it. Hence, it may be assumed that the exposures of all occupations in plant B following carding were probably higher during the study than prior to expansion. It must also be remembered that more men have been working since the introduction of added equipment than at previous times.

INTERPRETATION OF DUST COUNTS

The average dust concentrations just discussed make a satisfactory measure of dust exposure for most purposes. In correlating medical findings with dust exposure, however, it is frequently advantageous to express the dust exposure in units which combine duration of exposure with average dust concentration. An easily calculated descriptive value was developed during statistical analysis of the results of an engineering and medical study of anthraco-silicosis (51). If a worker's dust exposure has been unchanged for all practical purposes during his period of employment the average dust count (in million particles per cubic foot) is multiplied by the duration of exposure in years. The product is used as a numerical measure of his total dust exposure. If a worker has changed his occupation (and in so doing has changed his dust exposure appreciably) a calculation such as the one shown in table 18 is made.

TABLE 18.—*Example showing the method of computing the dust exposure of asbestos textile workers*[1]

Occupation of worker	Number of years in occupation	Dust count (MPPCF)	Millions of particle-years per cubic foot of air
Carder[2]	3	72.3	216.9
Carder	2	29.1	58.2
Mule spinner	2	2.6	5.2
Total	7		280.3

[1] Plant A.
[2] Prior to installation of exhaust system.

$$\text{Weighted dust exposure} = \frac{280.3 \text{ millions of particle-years per cubic foot}}{7 \text{ years}} = 40 \text{ million particles per cubic foot}$$

The worker whose dust exposure has been calculated in table 18 would be assigned a value of 280 million particle-years in tabulations in which, for the sake of simplicity, it was desirable to have a one-term measure of dust exposure; table 42, for example. When average dust concentration and duration of exposure are to be tabulated separately, as in table 43, the individual described in table 18 would be assigned a dust concentration of 40 million particles per cubic foot.

THE CONTROL OF ASBESTOS D

The control of dust in industry often entails many practical difficulties. These difficulties pertain chiefly to the handicaps imposed by control equipment upon the performance of the work being done, and in estimating a priori the air volumes required. Both of these difficulties are inherent in the asbestos industry. The arrangement necessary for removing dust from carding machines and from looms, which demand accessibility to all parts, is self-evident. Added to this requirement is the limited information available with regard to suitable design of equipment for each dust-producing source and the requisite air volumes. The latter item is most important in the design of hoods for carding machines, inasmuch as air velocities must be kept relatively low in order to prevent the asbestos-cotton mixtures from being subjected to air currents which convey them to the exhaust system. At the same time, however, the velocities chosen must be adequate to maintain the dust below the safe or threshold limit.

The dust-control data contained in the following paragraphs are based on observations made in two plants included in the present study and on data obtained elsewhere by Assistant Public Health Engineer Richard Page (7). The data presented include operations for which control methods have been developed. In addition, the type of control equipment used in England is discussed, although no values pertaining to air requirements are available in this instance.

PREPARATION DEPARTMENT

The dust counts presented earlier in this Bulletin for the preparation department apply to uncontrolled conditions. A very high degree of control can, however, be effected under certain conditions, especially as regards willowing (opening), piling operations, and picking. The crushing machines in the plants studied were not exhausted or segregated. In England, on the other hand, it is customary to enclose and segregate crushing equipment while it is in operation.

Willowing (opening).—Willowing machines are often productive of high dust concentrations (36 MPPCF). As has been previously mentioned, this dust is caused both by the manual methods used in feeding these machines and by the action of the machines themselves. Consequently, a reduction of dust concentration may be obtained by using a conveyor feeder which eliminates raising materials to waist levels with forks and using an exhaust above the feeder box and below the machine housing. The willowed material should, of course, be pneumatically conveyed to a suitable bin which is segregated from the preparation room.

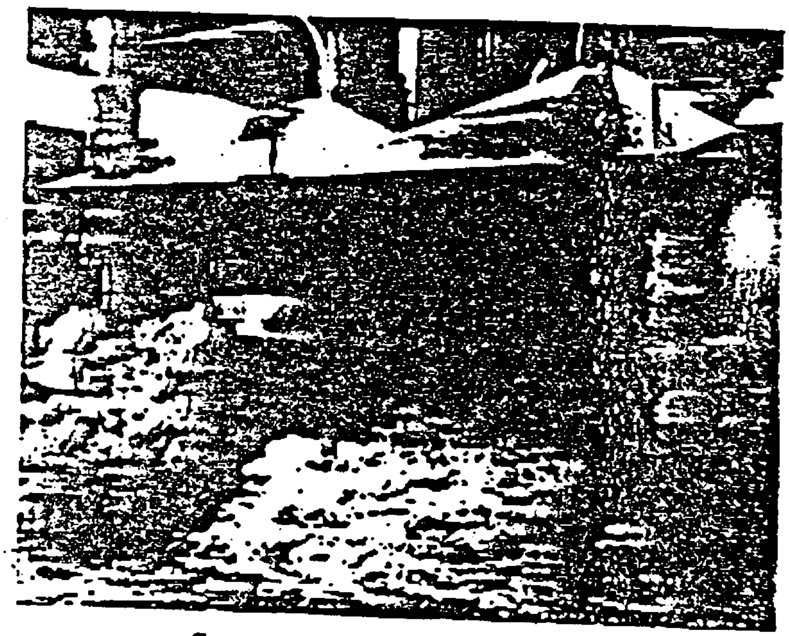

FIGURE 15.—EXHAUSTED PILING BINS.

In the case of two machines equipped with exhaust, it was found possible to reduce dust concentrations to 3.6 MPPCF. The exhaust hoods located above the feeders drew 400 CFM, while the downward exhaust below the willower housing drew amounts of air ranging from 225 CFM to 600 CFM, the latter air flow being used on a fly willower. (See fig. 4.) The air handled by the pneumatic conveyor was 1,800 CFM. For the 11-inch diameter ducts used, this corresponds to an air velocity of 2,730 feet per minute.

Piling.—Piling operations are usually conducted close to picking machines. The dust generated by this operation may be effectively controlled by using small exhausted compartments or bins. Compartments constructed as shown in figure 15 and handling approximately 1,025 CFM of air reduce the dust concentration from an average of 20 to 5.4 MPPCF.

English practice in piling consists in using exhaust manifolds close to the mixture being made (fig. 16). Air volumes are not available for the type of exhaust shown in the figure. The method appears to be cumbersome and to interfere with the process being carried on.

Picking.—The exhaust control used on picker machines is partly

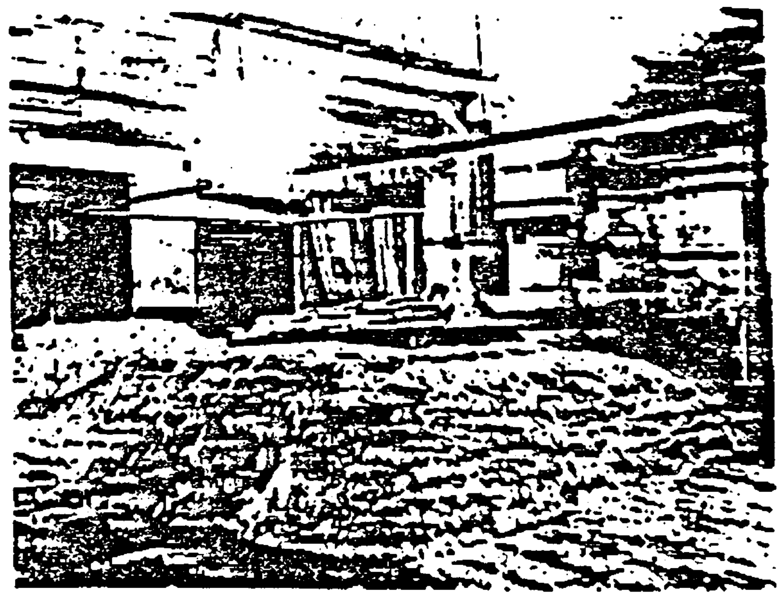

FIGURE 16.—EXHAUST VENTILATOR USED FOR PILING OPERATIONS (BRITISH PRACTICE).

shown in figure 17. One hood is connected at the feeder end and one at the discharge end. The center portion of the picker is also exhausted (not shown in figure). With this type of arrangement the dust concentration averages 6.7 MPPCF. This value is considerably lower than found among uncontrolled equipment which exceeds in many instances 74 MPPCF.

It was found that hoods above the feeder handled 500 CFM, the downward exhaust at the center measured 1,620 CFM; at the discharge end the air flow was 450 CFM. Pneumatic conveyors attached to the discharge end of some of the pickers handled 2,000 CFM. These ducts were approximately 12 inches in diameter, thus providing for a conveying velocity of 2,550 feet per minute.

It is possible with special conveyor belts operating between tl asbestos-cotton piles and the feeder mixer that the dust concentratio might be reduced below tl value of 6.4 MPPCF, indicate above.

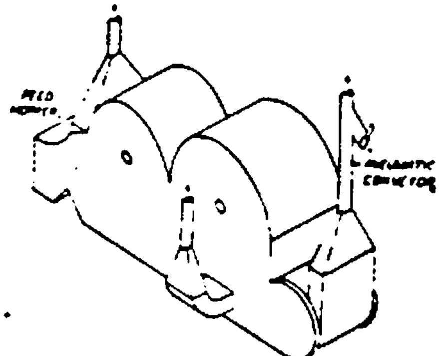

FIGURE 17.—SCHEMATIC DRAWING OF EXHAUST SYSTEM USED WITH PICKER MACHINE.

CARDING

Two types of dust-contro equipment are at present use on carding machines. The fir type consists of a hood which i located directly above the ex posed brushes of the machin (fig. 18), while the second typ is totally enclosed and ex hausted at various points (fig 5). Studies made of the firs type of exhaust systems showed a reduction in dust concentratio ranging from 72.3 MPPCF when no ventilation was applied to 20 with ventilation. The air flow for each hood averaged 870 CFM, which corresponded to six air changes per hour in the room in which the cards were located. It may be seen that the type of hood and the air flow used reduce the dust concentration to approximately one-third the amount created without ventilation.

FIGURE 18.—VERTICAL EXHAUST VENTILATION APPLIED TO AN UNENCLOSED PRIMARY CARDING MACHINE

The second type of exhaust system used proved more effective than the first in reducing dustiness. The dust concentration determined from numerous samples ranged from 1 to 3.9 million particles per cubic foot. This high degree of dust removal was accomplished with an arrangement similar to that indicated in figures 19 and 20. In the primary card, hoods a and b discharge upward. The duct c exhausts from the bottom of the card. The secondary or roving card is hooded at near the center of the machine. The openings *d*, *f* and *f'* are located at the bottom of the cards and exhaust the bottom fly which accumulates. The air volumes exhausted by each opening are indicated in the figure.

In addition to careful enclosure of the machine proper in the second type of system used, the feed box is carefully covered.

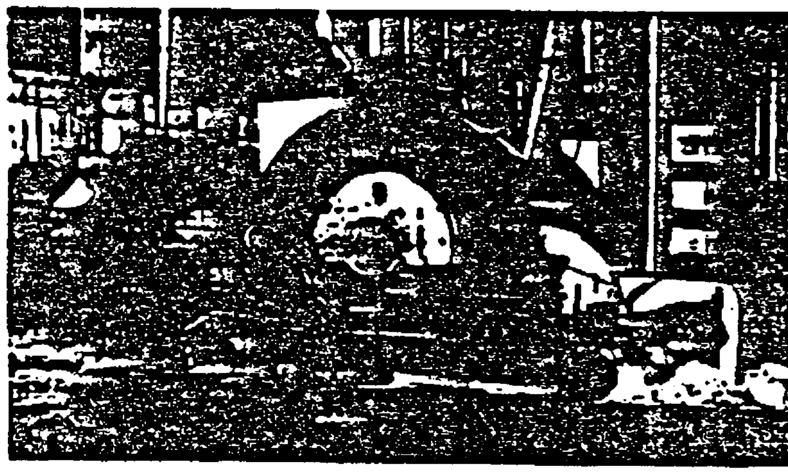

FIGURE 19.—TOTALLY ENCLOSED EXHAUSTED PRIMARY CARDING MACHINE.

The design of an exhaust system for carding machines is rendered exceedingly difficult owing to the ease with which carding material leaves the rolls. High air flows may seriously affect the quality of the roving produced. Likewise, a poorly constructed housing may create eddy currents which may prove bothersome. Any system developed requires care and experiment in design.

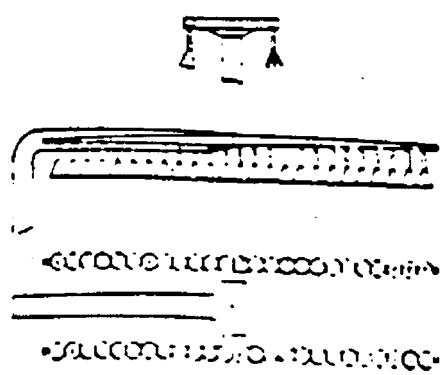

FIGURE 20.—ELEVATION AND PLAN FOR SPOOLING EXHAUST SYSTEM

SPOOLING AND TWISTING

The dust generated by spooling operations may be ingeniously controlled by a system of cones in which the spools are inserted and exhausted. Such a system is shown in figure 21. Each case is constructed so as to offer a minimum amount of interference to the work being done. In the case of four Foster winders (200 spools) each cone is 9 inches in diameter across its widest part and 2 inches at the duct connection. The cones are each 10 inches deep. Two hundred cones were found to handle an aggregate of 9,270 CFM or an average of 46.5 CFM per cone. The dust concentration averaged 2.9 MPPCF. Without the cone system discussed above, the dust concentration for the same operation was 13.1 MPPCF.

Twisting machines are more difficult to exhaust locally than spoolers. Figure 22 shows a system which has been partly completed. It consists of exhausting the lower section of the twisting machine by extending a duct with openings along the entire length of the equipment. Each system attached to the machine is intended to

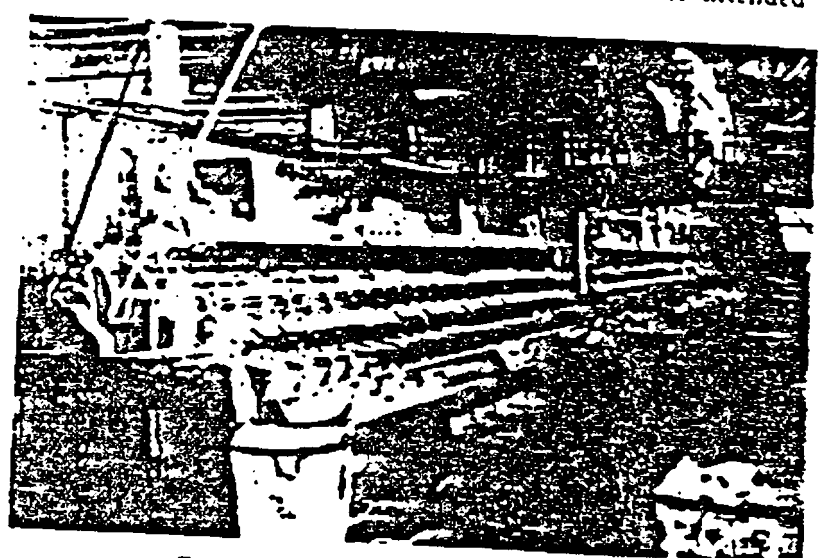

FIGURE 21.—EXHAUSTED SPOOLING FRAME.

exhaust 1,670 CFM. Dust determinations to establish the effectiveness of this system could not be made owing to the fact that only one of 10 twisting machines was equipped with exhaust and the counts obtained were affected by unexhausted machines operating close by.

WEAVING

Any system developed for removing dust generated by broad looms represents the accomplishment of one of the most difficult operations encountered in the design of exhaust equipment. Nevertheless, this has been done effectively both in this country and in England. The American system shown schematically in figures 23 and 24 consists of a downward-draft hood fitting close to the shuttle rack of the loom and a movable upper exhaust hood which operates on the surface of the woven material. The latter hood is actuated to and fro by the action of the loom lay to which it is attached. The hood is connected to the main exhaust duct by means of a flexible air tight joint. Both the downward and upward exhaust hoods are narrow and possess the advantage of high opening velocities. The upward-draft hood connected to the loom lay is segmented. Each hood used, as indicated in figure 24, handles 1,300 cubic feet of air per minute and reduces the dust concentration to an average of 0.7 MPPCF. The system is thus extremely effective, since on uncontrolled looms the concentration averages 49.7 and may exceed 140 MPPCF.

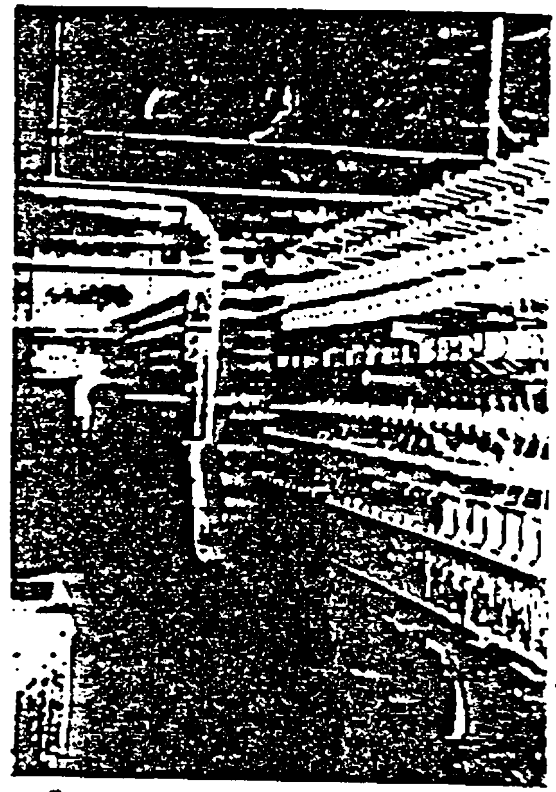

FIGURE 22.—EXHAUSTED TWISTING FRAME

The English method for exhausting looms differs considerably from American practice. In the former system all parts are stationary (fig. 25). The looms are exhausted upward by hoods located in front of the operator and resting a short distance away from the lay. The hood consists of two parts which may be turned back whenever repairs to the loom are necessary. No data as regards air volumes used in this type of equipment or its effectiveness in reducing dust are available.

INSPECTION

In some plants, asbestos cloths are brushed during inspection. The usual procedure consists in brushing the cloth from above and below as it passes over the inspection table. An inspection table of this type with exhaust hoods is shown in figure 26. The hoods used are located near the cloth brushes, and extends the full width of the cloth examined. They are, however, only one-half inch in width.

A study made of an inspection table such as discussed above indicated that two hoods located on either side of the cloth handles approximately 730 CFM each. A third brush and hood located near the jack spool at the end of the inspection table handled 192 CFM. These hoods reduced the dust generated from a value of 11.1 when no ventilation was applied to a value of 0.5 MPPCF with ventilation.

SUMMARY OF THE STUDY OF THE WORKING ENVIRONMENT

The engineering data contained in this report are based chiefly on a study of four asbestos plants. Data on dust control methods

FIGURE 23 —EXHAUSTED BROADCLOTH LOOM

have been secured in the course of a separate study undertaken in a fifth plant. Two of the four plants investigated were engaged in the manufacture of asbestos textiles directly from raw crysotile (Canadian) asbestos received in 100-pound bags. The remaining two plants began operations with yarn received from other sources and were concerned only with the manufacture of asbestos tape, braid or brake banding and with their treatment.

Dust concentrations were determined by means of the impinger technique using light field counting. In all, 242 impinger samples were taken so as to evaluate the environment of each occupation.

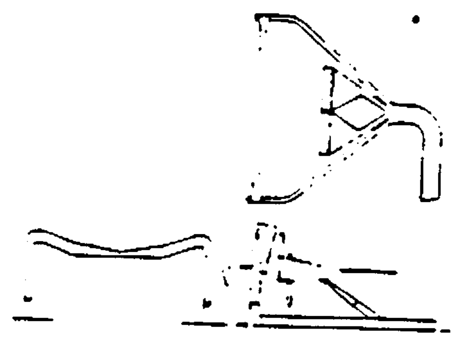

FIGURE 24.—DETAIL OF EXHAUSTED LOOM SHOWN IN FIGURE 23.

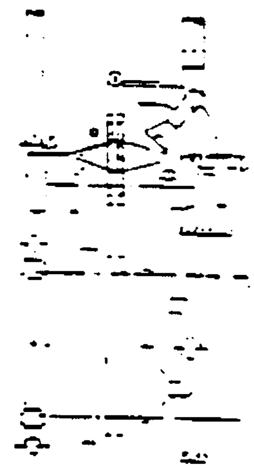

FIGURE 25.—DETAIL OF EXHAUST USED ON BRITISH TYPE LOOM

The number of workers employed, the number of dust samples taken, and the dust concentrations determined for each occupation are presented in table 18. The concentrations range from values of 0.8[illegible]

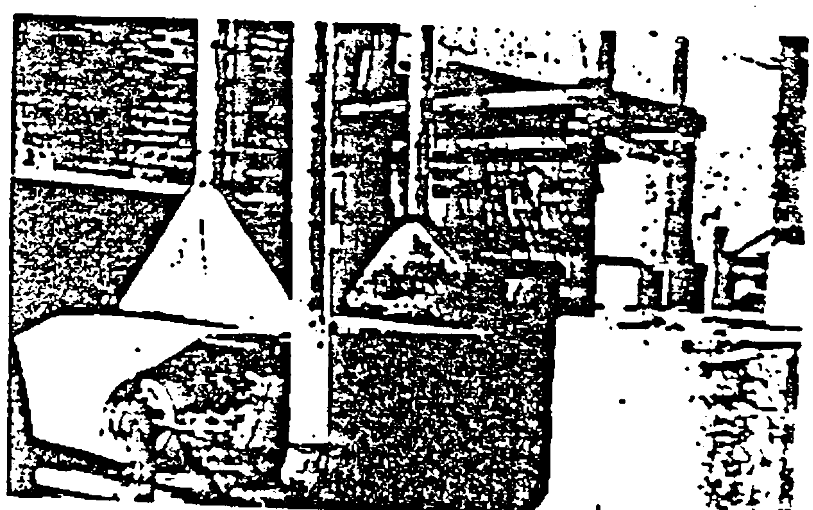

FIGURE 26.—EXHAUSTED BRUSHING AND INSPECTION TABLE

for shippers to as high as 74.3 MPPCF for pickermen. Occasional samples exceeding 100 MPPCF were found for the occupations of carding and weaving.

TABLE 19.—*Occupational dust exposure of workers in four asbestos textile plants*

Activity and occupation	Number of workers	Number of samples taken	Dust concentration (MPPCF)
Preparation			
Crushermen			
Willowers	9	9	[illegible]
Pickermen	[illegible]	[illegible]	[illegible]
Carding	6	21	[illegible]
Carders and tenders			
Stockmen	42	35	[illegible]
Spinning	18	11	[illegible]
Mule spinners and helpers			
Ring spinners and helpers	21	15	[illegible]
Steaming: Steamers	[illegible]	13	[illegible]
Twisting: Twisters and helpers	[illegible]	[illegible]	[illegible]
Winding	43	20	[illegible]
Universal winders			
Roving winders	[illegible]	3	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	13	[illegible]	[illegible]
[illegible]	12	3	[illegible]
Weavers and helpers			
Dry			
Wet	34	[illegible]	[illegible]
[illegible]			[illegible]
[illegible]	6	3	[illegible]
[illegible]	10	4	[illegible]
Tape, wick and [illegible] weaving	[illegible]	6	[illegible]
[illegible]			
[illegible]	31	12	[illegible]
[illegible]	13	14	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Cord, rope and braid workers	[illegible]	1	[illegible]
Brake-band finishing	21	5	[illegible]
Treaters and driers			
Calenderers	3	(⁴)	
Grinders	[illegible]	1	[illegible]
Cutters and drillers	[illegible]	1	[illegible]
Branders	[illegible]	1	[illegible]
Coilers	[illegible]	(⁴)	[illegible]
[illegible]	[illegible]	(⁴)	[illegible]
General labor			
Engineers			
Laborers (shippers, etc.)	7	[illegible]	
Watchmen	14	[illegible]	[illegible]
Shipping clerks	6	[illegible]	[illegible]
Yardmen	[illegible]	1	[illegible]
Office	2	(⁴)	[illegible]
Superintendents (office)			.10
Foremen (plant)	8	2	
Clerks	[illegible]		(⁵) .12
[illegible]	[illegible]	(⁴)	[illegible]
Total	[illegible]	341	

[1] Exposure weighted to take into account [illegible], breaking, and [illegible] activities.
[2] Includes exposure due to operation of [illegible].
[3] Average [illegible].
[4] Dust counts obtained from samples of other occupations having similar dust exposure.
[5] Exposure [illegible] activities.

The chemical and petrographic analyses of dust samples were determined from both settled dust samples and samples obtained directly from the air by means of a vacuum cleaner. No great differences in composition were noted between corresponding samples collected by these two methods. Total ash was approximately 77 percent for all the samples. No free silica (quartz) could be found on petrographic analysis.

Particle size determinations of Owens jet samples were made by three methods, namely, (1) with a eusecope projection device (for determining the ratio of fiber to particulate matter), (2) by means of a filar micrometer attachment to a microscope (for measuring the size particulate matter), and (3) with photomicrographs (for measurin the length of fibers). This study showed that the ratio of fibers particulate matter varied considerably from a maximum of 26 pe cent for weavers to a minimum of 1 percent for crushermen. Th median particle size (exclusive of fibers) was approximately 1 microns. The median fiber length varied from 7 to 16.3 microns. N distinction could be made between cotton and asbestos fibers.

In most of the plants studied the control of the dust hazard wa limited almost entirely to provisions of exhaust systems for the cardin machines. Data, however, are available to indicate the effectivenes with which the dust problem can be handled in an asbestos texti plant. An effective method employs the use of hoods and exhaus equipment fitted at each dust-producing source. Data showing th effectiveness of exhaust equipment is presented in table 20.

TABLE 20.—*Summary of results showing the exposure of asbestos textile work... under controlled and uncontrolled working conditions*

Equipment	Number of duct connections	Volume of air handled (C.F.M.)	[illegible] with exhaust (M.P.P.C.F.)	[illegible]
Willowing (opening)	12	625-1,070	3.1	11.1-6[illegible]
Piling	1	1,02[illegible]	2.0	[illegible]
Picking	3	2,370	6.7	14.3-74
Carding (primary)	3	1,120	[illegible]	[illegible]
Carding (roving)	4	1,440	2.0	22
Spooling	1	44.5	2.4	17
Weaving (broadloom)	2	1,9[illegible]	[illegible]	4.7-4[illegible]
Brusher calenderer	3	1,4[illegible]0	1.0	11

[1] Equipped with pneumatic conveyor.
[2] Exhausted bin or compartment.
[3] Individual cone for each spool and connected to exhaust manifold.

It is evident from the above table that the dust hazard in th asbestos industry can be greatly reduced. It is further clear tha the necessary control methods have been developed and are now in use. With the exception of pickers who are exposed to concentration of 6.7 million particles per cubic foot under controlled conditions exposure in all other occupations can be kept below 5 million particle per cubic foot. It is possible with improved methods of ventilatio to reduce even the picker's exposure to less than the figure indicated The following recommendations are made:

1. Dust should be controlled at the point of origin by means o local exhaust hoods so designed and operated that no dust is permitte to reach the breathing zone of workers or to contaminate the genera air. Dust-removal devices, which are capable of reducing the dus concentration to a level of 5 million particles per cubic foot or lower have been developed for all operations in the asbestos textile industry (7).