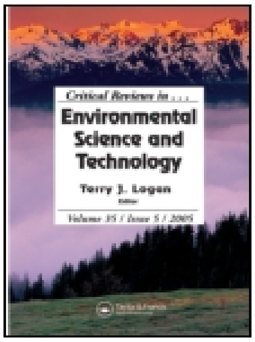

Critical Reviews in Environmental Science and Technology

ISSN: 0007-8999 (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/best18

Byssinosis

Howard E. Ayer & Kaye H. Kilburn

To cite this article: Howard E. Ayer & Kaye H. Kilburn (1972) Byssinosis, Critical Reviews in Environmental Science and Technology, 2:1-4, 207-241, DOI: 10.1080/10643387109381582

To link to this article: https://doi.org/10.1080/10643387109381582

Published online: 21 Dec 2010.

BYSSINOSIS

Author: **Howard E. Ayer**
Department of Health, Education, and Welfare
Public Health Service
National Institute for Occupational Safety and Health
Cincinnati, Ohio

Referee: Kaye H. Kilburn
Director, Division of Environmental Medicine
Duke University Medical Center
Durham, North Carolina

"For a foul and poisonous dust flied out from these materials, enters the mouth, then the throat and lungs, makes the workers cough incessantly, and by degrees brings on asthmatic troubles."[1]

INTRODUCTION

Of all the health effects connected with the environment, harmful effects connected with the occupation would appear most susceptible to control. All that need be done is to separate the worker from the harmful agent. But to accomplish this, several preliminary determinations must be made.

First, the harmful effect must be identified and connected with the occupation. For a material which is an eye and upper respiratory tract irritant, the effect and its connection with occupation are obvious. An effect which becomes evident only after years of exposure is not so readily connected with occupation. The effect must be described; it must be differentiated from other harmful effects not connected with the occupation and whether or not identical with any non-occupational harmful effect, its occupational origin must be made evident. The effects of smoking, hobbies, and off-work exposures must be considered.

Second, the harmful agent in the environment must be identified. In general, this should be easier for an occupational environment because the investigator can tabulate all the materials that are being handled and, by elementary epidemiological procedures, determine which materials are associated with the harmful effect. However, difficult problems occur when all the workers are handling complex mixtures, or when the potentially harmful agent is only a trace component of the material being handled.

Then, unless the potentially toxic material can be removed completely by substituting another material (as in the substitution of toluene for benzene or methyl chloroform for carbon tetrachloride), the airborne concentration at which harmful effects will not occur must be determined. To do this, a satisfactory method of analyzing workplace air for the contaminants must be available, and the concentrations of the suspect agent must be associated with the identified effect so that a harmless concentration may be found.

Finally, environmental control methods applicable to the processes must be designed and installed. The effect of the controls must be determined and the absence of health damage after control substantiated.

To accomplish the above objectives, it would appear that the industrial situation gives all the advantages. Inventories can be taken of materials used in the processes. The air need only be sampled in restricted locations. The worker is available every day for medical observation at specified times and locations.

Nevertheless, when the elementary principles of occupational health recounted above are applied to the problem of byssinosis, it is apparent that they are not so readily put into practice. The health effect now called byssinosis has not always been obvious to the working force, to management, or to local medical practitioners. Byssinosis has not always been readily differentiated from other non-occupational effects. In fact, several diseases appear to be present under varying circumstances, and not all of these have been or should be called byssinosis. The agent in the workplace air that causes the health effects has not yet been definitely identified. And where only indirect measure of the toxicant can be made, the concentration that is associated with disease and therefore a safe concentration is difficult to determine with certainty. If the safe concentration is uncertain, then adequate control is that much more difficult to specify. However, even though the story of byssinosis has not yet been completed, there are enough chapters written that it may fairly be termed a definite, preventable, occupational disease.

THE DISEASE

Byssinosis is generally agreed to occur among workers who handle cotton flax, and soft hemp.[2] Descriptions of the health condition of the workers have been vivid. Ramazzini, writing of "diseases of dressers of flax and hemp" in 1713, observed "likewise those who card flax and hemp so that it can be spun and given to the workers find it very irksome."[1] The great American sanitarian C-E. A. Winslow, in referrring to a nearby twine mill in 1904, spoke of "the carding room with the clouds of fine choking dust and the wet spinning room with the hot damp deadly atmosphere of a tropical forest. The women and children, some of them palpably under age, with dull eyes and feverish cheeks, stand listlessly by their machines stolidly going through the mechanical routine which brings them daily nearer to their inevitable end."[3]

Dramatic though they be, references such as the foregoing are not given in sufficient detail for us to be sure that the condition described was, indeed, byssinosis. However, the disease, without the present designation, appears to have been reported in 1831,[4] 1861,[5] and 1863.[6] These reports of the 1800's give conditions among English mill workers in the county of Lancashire. According to Caminita[7] the condition was mentioned even earlier, in 1822 and 1827, in French publications.

In 1908, Collis[8] reported, "The course of the trouble caused is as follows: – As soon as the individual begins to suffer, he finds his breathing affected. On Monday morning, or after any interval away from the dust; on resuming work he has difficulty getting his breath. This difficulty is worse the day he comes back. Once Monday is over, he is all right for the week.... The man gradually gets 'tight' or 'fast' in the chest, and he finds difficulty in filling his lungs; to use his own expression, 'the chest gets puffled up.' At the same time the man loses flesh and any fresh color he may have had. Consequently, he becomes thin in the face and body. As the chest trouble develops into a typical form of asthma, the action of the diaphragm becomes less and less effective, until the only action of this great respiratory muscle is to fix the lower ribs; at the same time the superior intercostal muscles are being brought more and more into use, and the extraordinary muscles of respiration are more and more called into play to carry on the ordinary act of breathing. The sternum becomes more prominent, and the chest becomes barrel-shaped. Meanwhile, the extra tax thrown on the lungs leads to some degree of emphysema. There is little or no sputum produced, and what little there is is expectorated with difficulty. It is not infrequently stained with blood, but I only found doubtful physical signs of phthisis in one case who so complained."

The description by Collis, with his subsequent reports and the testimony of a number of witnesses, was considered by a Departmental Committee on Dust in Card Rooms in the Cotton Industry of the British Home Office. The committee reported in October 1931 after some four years of study.[9] In response to the charge, "What is the nature of such ill-health or disease" – they concluded: "The nature of such ill-health or disease is respiratory, and the symptoms observed are attributable to the action of the dust on the mucuous membranes of the respiratory passages. Beyond its effect on the respiratory organs, there is no evidence to show that the dust in card rooms has any specific properties which cause ill-health or disease.

"The continued effect of inhaling the dust is progressive. Consequently, its main effects may be considered in three stages, but there is no sharp division between these stages, as one gradually merges into the other as the malady progresses;

"a. *The Stage of Irritation* – Irritation of the air passages causing cough and a tight feeling in the chest. This is usually of temporary duration, passing off in one or two days, but the susceptibility returns during a short absence from work, such as occurs at the weekend. It does not cause diablement and incapacity for work, and entirely disappears on removal from the dusty atmosphere.

"b. *The Stage of Temporary Disablement or Incapacity* – After the operative has been exposed to the dust for some ten or more years, the effects of the irritation become more persistent, and the operative suffers from early bronchitis or asthma, or both combined, associated with cough and mucous expectoration. This condition may cause temporary incapacity with intervals of absence from work, which are of short duration but increase in frequency, and lead in time to partial incapacity. At this stage it should be possible to determine by medical examination whether the operative should continue to be employed in a card room, since cessation from work in the dusty atmosphere is generally followed be recovery, or at any rate by marked improvement with capacity for work in another atmosphere.

"c. *The Stage of Total Disablement or Incapacity* – In this advanced stage there is chronic bronchitis, with emphysema. Cough is present with mucous or muco-purulent expectoration and shortness of breath on exertion. This condition is incurable and at this stage work in the dusty atmosphere becomes impossible, but improvement may take place and further progress of the disease be arrested or retarded by removal from the dusty environment of the card room. In the final stage of the malady the continued strain on the right side of the heart is apt to lead ultimately to cardiac failure.

The rate at which these stages of ill-health develop varies in different individuals, as it depends on two factors: (a) the amount of the injurious constituent or constituents in the dust inhaled; (b) the susceptibility of the individual. Owing to the diminution of the amount of dust, the frequency and severity of respiratory disease is now less in younger operatives, and the full effects of it probably take longer to develop than they did formerly. To pass through the various stages takes 10 to 20 years, or even longer.

"i. Radiological examination of the patient's chest has not revealed any condition which may be described as specific, as, although some degree of fibrosis of the lung is found in certain card room operatives, this is indistinguishable from that which occurs in those of the general population suffering from bronchitis.

"ii. Post-mortem examination confirms the clinical findings already descrbied but has not revealed any specific features which would enable the bronchitis of card room operatives to be distinguished from that which occurs in the general population."

The summary of the disease given above is not greatly different from that of subsequent investigators. The next advance in definition was the grading system devised by Schilling.[10] He questioned the workers about their chest conditions, and the degree of byssinosis was classified as follows:

Normal: No symptoms of chest tightness or breathlessness.
Byssinosis:

Grade I – Chest tightness and/or breathlessness on Mondays only.

Grade II – Chest tightness and/or breathlessness on Mondays and other days.

Subsequently, the grading of byssinosis was expanded[11] by adding –

Grade ½ – Occasional chest tightness on the first day of the working week.

Grade III – Grade II symptoms accompanied by evidence of permanent incapacity from diminished effort intolerance (sic) and/or reduced ventilatory capacity.

Field investigators since 1955 have almost universally used this classification for degree of byssinosis.

The Monday feeling of tightness in the chest is accompanied by a decrease in the forced vital capacity; the forced expiratory volume in the first second ($FEV_{1.0}$) or in the first 3/4 second ($FEV_{0.75}$) are the more common measures. Some investigators have reported results in terms of the indirect maximum breathing capacity (IMBC) calculated as 40 times the $FEV_{0.75}$[12] The average difference between Monday morning and Monday evening $FEV_{1.0}$ for those reporting Monday tightness has been reported in two surveys as 0.19 liters,[13] and 0.21 liters.[14] Where $FEV_{0.75}$ was measured, average decreases reported were 0.26 liters,[15] 0.19 liters,[12] 0.28 liters,[16] 0.22 liters,[17] and 0.25 liters.[18] The difference in $FEV_{1.0}$ or $FEV_{0.75}$ is somewhat less in those cardroom workers not reporting byssinosis and much less in those not exposed to dust. For cotton workers without byssinosis, cough, or phlegm, a rise in $FEV_{0.75}$ of 0.06 liters in a 6 A.M. to 2 P.M. shift, a fall of 0.05 liters on the 2 P.M. to 10 P.M. shift, and a fall of 0.08 liters on the 10 P.M. to 6 A.M. shift have been reported.[18] A subsequent study of shift workers without pulmonary disease showed an increase of 0.15 liters in $FEV_{1.0}$ during the morning shift and a fall of 0.05 liters in the afternoon shift, with no appreciable change on the night shift.[19] An average decrease in $FEV_{0.75}$ of about 0.05 liters per year has been reported for workers without byssinosis, both cotton workers and controls.[20,21]

The eventual fate of workers with byssinosis, including both active workers and those who have left the industry, is poorly defined in cotton workers. However, Bouhuys et al. have reported on a continuing study of soft hemp workers in Spain.[22-24] They found that former hemp workers, aged 50 to 69, had substantially lower respiratory functions than the controls.[25] Thirty-one percent had an $FEV_{1.0}$ less than half of predicted, versus only 4% of the control workers in that age group. Other comparisons gave similar results. About one sixth of these older workers had $FEV_{1.0}$ less than 1.0 liters. The Social Security Administration's standards for total disability from respiratory causes use as the lower limit an $FEV_{1.0}$ of 1.0 to 1.4 liters, depending on height.[26] These Spanish workers would thus have qualified as disabled under the rather rigid U.S. criteria.

The studies of Bouhuys and his collaborators in Callosa de Segura, Spain, pointed out some of the anomalies which result from studying only current mill workers. In a study of a sample of current and former hemp workers they found no significant difference in $FEV_{1.0}$ between the workers and controls in the age groups 20 to 29, 30 to 39, or 40 to 49. If this had been other than an ancient, traditional operation, the large differences in respiratory function between the older (50 to 69 years) age groups might have been attributed to a great difference in past working conditions. In the contraction of the industry which took place between the 1965 and 1967 surveys, a degree of self-selection of workers was noted. A significantly lower percentage of the active workers were affected by the hemp dust in the later study, though the dust hazard was determined to be equivalent in the two periods. More of those affected by the dust, apparently, had chosen to leave the industry. Careful analysis of smoking and respiratory function also disclosed the surprising fact that those hemp workers who smoked more had a significantly higher average $FEV_{1.0}$ than the non– or light–smoking hemp workers. The ex-smokers had a much lower $FEV_{1.0}$ than those who still smoked. A selective mechanism had apparently influenced the smoking or degree of smoking so that those most affected by the hemp dust smoked little or had completely ceased to smoke.

Markedly low $FEV_{1.0}$ and other respiratory function parameters are found in some of the active cotton mill workers in the U.S. and elsewhere, but it will require a community study – not yet performed – to determine the course of byssinosis in the United States. The degree to which self-selection out of industry influences the progression of byssinosis,such as was found in Spain, is entirely unknown in the United States.

If the reaction described above may be called byssinosis, then it must be distinguished from other conditions occurring among cotton mill operatives. The pioneers in occupational health, such as Charles Turner Thackrah, campaigned vigorously against adverse working conditions, including child labor. For example, Thackrah noted, "Children from seven to fifteen years of age go to work at half-past five in the morning, and leave at seven in the evening – or at half-past six, and leave at eight – and thus spend twelve hours a day, for five or six years, in an atmosphere of flax dust."[27] With such conditions, ill health was not unexpected.

But specific conditions other than byssinosis have been noted. Caminita et al.[7] classified the conditions reported into three general illnesses: "mill fever," byssinosis, and "weaver's cough." They said that "mill fever" might be distinguished from other conditions among cotton workers by the following criteria: "(1) Illness occurs in those who are unaccustomed or who have not been previously exposed to the cotton dust, and (2) *tolerance to the dust is developed by such persons* after a few days." They quoted from 18 accounts from English, German, French, Dutch, Russian, and American literature dating back to Thackrah's account in 1832. The account of Ritter and Nussbaum[28] may be considered typical. "Among new employees working in cotton dust about 10 to 50% develop a definite chill. The onset of this condition may take place during work on the first day but it more frequently develops after the employee returns from work to his home in the evening. This chill is followed by a fever (100° F to 103°F) that is almost invariably gone by morning. A headache usually accompanies the fever. Occasionally there is a nosebleed or nausea, even vomiting. This identical experience may be repeated for the first several nights. Such repetition of a 'dust chill' is fortunately uncommon. For the next few nights this new employee usually has only a slight recurrence of the fever and a vast sensation of exhaustion.

"Usually by the end of the first week, but almost certainly by the end of the first month of employment, these symptoms no longer develop in the individual as long as he continues in the same job. If during the first year of employment this individual should be away from work for about two weeks he will probably repeat this immunizing experience – this second bout of cotton fever is usually less than 100°F. Because of the mildness of the symptoms this recurrence is frequently overlooked. Older employees who may have spent many years at this type of work usually have to be away from the dust for a month or two before they anticipate a recurrence."

Some sources reported that the tolerance to dust acquired was limited in that illness might occur in experienced workers exposed to unusually high concentrations of dust. The cause of the illness is still unknown. The terms "weaver's fever," "cardroom fever," "dust chills," "dust fever," "cotton cold," and "cotton fever" appear to be synonyms for this disease, and the "heckling fever" among flax workers is similar to "mill fever."

A further condition, an acute illness called "weaver's cough," was reported to have occurred among cotton weavers in England in eight different years between 1910 and 1926.[29] Caminita summarizes the circumstances under which the outbreaks occurred as follows:[7] "They took place among operatives in weaving sheds who handled mildewed yarn. The thread used in the warp was sized with the usual mixture of flour, tallow, china clay and water (in some mills, canal water) from which the zinc chloride antiseptic had been omitted. In order to facilitate weaving, the yarns were allowed to retain more moisture than usual after sizing. Since some time elapses between the sizing and weaving process, such threads become mildewed. The weft thread, which is not sized, also sometimes became mildewed. Both *types of thread were incriminated in outbreaks of* illness. In addition to the presence of mildew, an unpleasant smell was noted, and several times sulfur-colored dust was seen on the looms.

"Examination of the dust and of the yarn revealed the presence of species of Penicillium, Mucor, Aspergilli and an unidentified fungus. The air over the looms contained many fragments of Mycelium and conida. There were no facilities for investigation of the harmful properties of these organisms, but the causative agent of the illness was suspected to be a mildew.

"A high percentage of operatives, both experienced and inexperienced, became ill; some were only slightly inconvenienced while others were incapacitated for work. Operatives in the same work area who handled mildewed yarn or yarn that had been properly dried after sizing were not affected. Some outbreaks subsided when sized yarn that had been properly dried was substituted for the mildewed yarn."

Middleton gave eight case histories as individual instances, with considerable variation in symptoms, having a "central picture" occurring with sufficient regularity to form a basis for diagnosis, namely, irritation in the upper air passages, a feeling of obstruction in breathing, a paroxysmal cough, and scanty, tenacious sputum.

The symptoms often followed resumption of work after an absence, usually with some history of respiratory trouble before the absence. The degree of incapacity varied markedly, even more so than the considerable variation in importance of the individual symptoms. In some cases there were gastrointestinal disturbances accompanying the respiratory symptoms.

Still another illness was described in the United States among workers handling dusty, low-grade stained cotton.[30,31] The victims included cotton mill employees, workers at a cottonseed processing plant, and members of rural families using the cotton to make mattresses. The outbreaks ceased when respiratory protective devices were used or a better grade of cotton was substituted. The illness, which began one to six hours after work started, had initial symptoms of fatigue and generalized aches, followed by anorexia, headache, nausea, and vomiting. Chills and fever – some oral temperatures over 102°F – occurred. There were complaints of abdominal pain or cramps as well as substernal discomfort or pressure so that the person was unable to take a deep breath. The disease occurred among all ages of both sexes.

POTENTIAL DUST EXPOSURES

Growing and Harvesting

Cotton plants are grown in rows, about a meter apart, with 6 to 20 plants per running meter along the row.[32] The fruiting branches on which the cotton fruit or *boll* grows produce one or two bolls per branch when spaced this closely. The boll begins as a floral bud. The floral bud is covered by three leafy parts known as *bracts*. The bracts remain as the fruit develops. Unlike the leaves, the bracts are not shed, but as the boll opens they dry up and become a major source of trash in the *seed cotton.* From the floral bud there arises a large cream-colored flower which fades and drops. At the base of the flower is the ovary, which gives rise to the developing boll. Within the developing boll are four or five parts called locks; within each lock there are seven to nine seeds. The seeds develop two layers of seed hairs, *lint* and fuzz. The lint is the cotton textile fiber. The boll is enclosed by a tough segmented carpel wall; as the growth proceeds the lint hair becomes tightly packed until the boll cracks open. The lint then fluffs out and dries and the boll is ready for picking.

Cotton in the United States prior to World War II was all hand picked.[33] Since then there has been a gradual transition to machine picking until in 1969 more than 97% of the cotton was machine picked. The human cost of hand picking has been vividly described,[34] and the replacement by machines appears to be regretted by no one. Two major types of machines are used, the spindle picker and the stripper.

The object of the spindle-type picker is to pull the seed cotton from the boll as was formerly done by hand picking. The spindle pickers are high, tractor-type motor vehicles which straddle one or more cotton rows. Two gathering shoes form a V-shaped opening and as the picker travels along the row the branches are brought into a narrow space under the machine. On either side of this space are revolving metal spindles. These spindles project into the space and as they contact the open cotton bolls the lint is wound onto the spindles, pulling the seed cotton out of the boll. The spindles are mounted on endless chains or cylinders, and after the spindles go over the plants, they are carried outward on the belt, to where the cotton is removed from the spindles and deposited in a container on the picker. The cotton is emptied from the picker into trucks or trailers for transportation to the gin. A certain amount of foreign matter, including dirt, bracts, immature cotton bolls, and leaf and stem trash is inevitably included with the cotton.

The stripper is a simpler type of picker. The stripping is done by projecting fingers, spaced too closely to let bolls pass between them. As the stripper proceeds over the cotton, the bolls are stripped from the plant and delivered to a container on the stripper. This type of picking takes the entire boll; seed cotton, pericarp, bracts, and perhaps a portion of stem. The amount of trash brought in with the seed cotton is obviously much greater than with spindle-picked cotton.

Undoubtedly, in the harvesting process there is some of the same sort of dust generated which is noted in ginning and textile manufacture. But the operation is outdoors, and the relatively slow rate of cotton processing combined with the seasonal outdoor nature of the operation should prevent the inhalation of large amounts of respirable dust. Other agricultural operations, including the widespread use of pesticides, in all likelihood present greater potential health hazards. The extent of occupational hazards in high production American agriculture are still little known. The health and safety of agricultural workers will in all likelihood be among problems having the highest priorities for investigation by the new National Institute for Occupational Safety and Health.

Ginning

The purpose of cotton ginning is to remove the lint or fiber from the seed. In addition, the foreign matter which has been included in the mechanical picking must be removed. For this reason, the modern cotton gin includes, in addition to the gin stands which separate lint and seed, dryers and cleaners before the separation and lint cleaners after the separation.[35] After the lint is separated and cleaned, it goes to a press box where the cotton bale is formed. Whereas the cleaning equipment of 1900 was less than 5% of the total machinery investment at gins, by 1962 the cleaning and drying equipment represented 70% of the machinery investment.[36]

The cotton in a modern gin is conveyed pneumatically, and most of the cleaning and drying equipment is enclosed. Nevertheless, at the gin stand and through access openings there is opportunity for dust emission. The health of cotton gin workers has been studied in Africa and Greece. Gilson et al.[12] studied three gins in Uganda. They found that there was no respiratory function change in workers in two gins processing a clean grade of cotton ("Safi"), but there were significant changes in workers in an older gin processing a dirtier grade of cotton ("Fifi"). The dust concentration measured in the latter gin was 5.8 mg/m^3 of which over half was mineral matter.

Khogali found byssinosis in 20% of gin workers in the Sudan.[37] Mean "respirable" (by Hexhlet) dust concentration was 0.6 mg/m^3. There were significant changes in $FEV_{1.0}$ in byssinotics during the work shift. Batawi reported 33% byssinosis in Egyptian gins.[38] Barnes and Simpson studied workers handling recently ginned cotton seed in Wee Waa, New South Wales, Australia.[39] Dust concentrations averaged 20 mg/m^3. Significant changes in ventilatory function were noted. As with the reports from Africa, there is little application of these findings to U.S. conditions, but they do suggest the possibility of health effects in cotton processing even when using modern methods and mechanical handling.

Considering the lack of knowledge of conditions and health hazards to cotton gin workers, it would be only prudent for gin operators to arrange for pre- and post-season tests of ventilatory function in their workers. Likewise, periodic monitoring of dust concentrations in the gin buildings, perhaps through an industry association or by a state health or labor department, would be desirable. It might be pointed out that regulations requiring these actions will probably be promulgated as part of standards called for under the Occupational Safety and Health Act of 1970.[40]

The cotton leaving the gins has been cleaned to the maximum practicable extent, using current ginning methods. Cleaning improves the grade and thus the price received for cotton. Cleaning, however, also decreases yarn strength, and the decrease in yarn strength was shown to be unacceptable if there were more than 13 seed-cotton cylinder cleaners or more than two lint cleaners.[41] Thus, there is a practical limit to the amount of foreign matter removal that can be done at the gin using present equipment.

Trash Content in Ginned Cotton

Little information is available that would give the relative amount of material in ginned cotton that might contain the biologically active agent involved in byssinosis. As an aerosolized aqueous extract from bracts will produce byssinosis symptoms, and bracts are a principal component of cotton trash, the total trash content might be of some interest. The USDA's Southern Regional Research Laboratory has reported an analysis of trash content in 950 bales of cotton of widely varied grades and staple length. The results have been presented by Graham et al.[33] and are shown in Table 1.

In the sample of Table 1, 87% of the bales had from 1 to 4% trash by the Shirley analyzer method, averaging 1.6%. The cotton a particular mill will use will depend upon the product being manufactured. Graham pointed out that a tobacco cloth or osnaburg will use a short staple, low grade, high trash content cotton, and blend back lint waste into the mix. A carded drill, twill, or sateen would use a medium staple of about strict low middling grade. A broadcloth, gingham, or bedford cord probably would be combed, using a middling grade, 1-1/8 inch to 1-1/2 inch staple length.

The difference that this can make is shown in the waste produced from two 1-3/32 inch staple length cottons, one a strict good ordinary (Mix A) and the other a strict middling grade (Mix B). These results are shown in Table 2. In each case, the card was set to remove the maximum amount of waste. Two and one half times as much waste was removed from the lower grade cotton. The

TABLE 1

Waste Analysis of 950 Cottons*
Shirley Analyzer Waste**

Bales %	Total Range %	Visible (trash & fiber) Average %	Invisible (dust) Average %	Picker & Card Waste %
0.6	0.00-1.00	0.66	0.18	6.1
27.2	1.01-2.00	1.00	0.68	6.8
41.8	2.01-3.00	1.48	1.00	7.5
17.9	3.01-4.00	2.28	1.17	8.5
5.0	4.01-5.00	3.11	1.35	9.4
3.0	5.01-6.00	3.88	1.58	10.6
1.8	6.01-7.00	4.79	1.68	11.5
1.3	7.01-8.00	5.71	1.74	12.4
1.4	8.01- up	8.57	1.71	15.0

*From 1960, 1961, and 1962 crop years.
**Determined by Shirley Analyzer Method, ASTM D 1451-67.
From Graham.[33]

TABLE 2

Effect of Cotton Grade on Textile Processing Waste

Process	Mix A %	Mix B %
Breaker and finisher picker	3.69	0.72
Card flat strips	5.90	3.35
Card cylinder and doffer strips	4.05	1.99
Motes and fly	5.80	1.67
Sweepings	0.44	0.21
Total Waste	19.88	7.94

From Graham.[33]

differences appeared in all sections of the card from which waste was collected.

Opening, Cleaning, and Picking

When the baled cotton enters the process at a textile mill, it is blended through feeders into openers, cleaners, and pickers, preparatory to going to the card.[42] The function of these units, which may be separate or combined, is to take the compressed layers of cotton from the bale, loosen the tufts of cotton, remove leaf, motes, dirt, and sand from the cotton, and deliver the cotton in a form which can be accepted by the card. The final step is usually the formation of an even flat sheet which is wound on a roller to form a *lap*.

The opening, cleaning, and picking operations involve the use of various types of beaters and/or saw cleaners, any one of which may generate dust. The machines are usually well enclosed, and many are furnished with exhaust systems to remove the dust. The exhaust is commonly recirculated to the room through a filter. The filters are designed primarily to remove visible trash and dirt and are of types which would be of only moderate efficiency for microscopic dust. In British mills this series of operations is performed in the "blow room," and it is of interest that when the two groups were reported separately, prevalence of byssinosis among blow room workers was often less than that among card room workers.

The fact that these machines are often already well enclosed and provided with exhaust ventilation means that dust problems in this area of the mill can be controlled relatively easily. If the recirculated air were treated as though it contained a dust of moderate toxicity, with efficient filtration, concentrations should be brought within acceptable limits.

The concentrations of airborne dust in these areas have not been measured until quite recently in American mills (and usually only for research studies in other nations) so that controls to provide efficient removal of "respirable" size dust particles have not been evaluated.

Carding

The process of carding is basic to the use of any natural fiber. When the cotton is brought into the card as a rolled lap from the picker it is in the form of unopened tufts of tangled fibers. The purpose of the card (from the Latin carduus, for thistle) is to separate the fibers and form them into a bundle of roughly parallel fibers for further processing. Fibers are brought in over a feed plate to a feed roll and the *licker-in*. The licker-in is a 23 cm diameter cylinder covered with wire teeth which rotates rapidly over the lap of cotton held by the feed roll, gradually opening the tufts of cotton in the lap. As the tufts are opened, dirt and trash fall out. Further short fiber and foreign matter are removed by sharp-edged bars close to the licker-in surface, the mote knives. The cotton on the licker-in is taken off by the *card cylinder*.

The standard English and American card cylinder is 127 cm in diameter and 102 cm long. It is covered with *card clothing*. A fillet card clothing consists of a multilayer fabric foundation through which hardened, tempered, round steel wires are set in the form of open staples. There are 70 to 100 wire points per square centimeter of card clothing. A metallic clothing has displaced fillet clothing for card cylinders to a major extent. The metallic clothing has punched teeth and has the major advantage that frequent grinding of the points is not required as it is with the fillet clothing.

Carding action takes place when two wire clothed surfaces are brought together with the teeth inclined in opposite directions, and the relative motions are such that the surfaces pass each other point against point. Above the card cylinder is a series of 110 narrow, cast iron flats, each covered with card clothing. The flats move very slowly – only centimeters per minute – so that relative to the rapidly moving cylinder they are standing still. Of 110 flats on a card, about 43 will be face down in working position over the cylinder. If the fibers were distributed uniformly over the cylinder, there would be about 18 cylinder points for each fiber.[43] The carding action to open and straighten the cotton fibers is therefore seen to be very vigorous compared to earlier operations.

The fibers are taken from the card cylinder by the *doffer*, a small cylinder made and clothed like the main cylinder. A fine film of fiber called the *card web* comes from the doffer and is drawn forward to the center of the front of the card through a tapered opening called the doffer trumpet. The small opening in the front part of the trumpet condenses the 100 cm to a round *silver* about 2.5 cm in diameter. The silver is coiled into tall cans for further processing.

The cotton card is undoubtedly the major dust producer in a cotton textile mill. "Dust and fly – broken and short fibers are liberated at the feed roll, the base of the back plate, between the top of the back plate and the flats, between the flats, at the stripper door, at the base of the front bottom plate, and at the doffer cylinder and comb."[33]

A major source of dust has been the "stripping and grinding" of card clothing. Strippers and grinders, when listed separately, invariably had the most severe byssinosis problem of any of the cardroom occupations. In recent years the hand stripping has been largely replaced by vacuum stripping, and where metallic clothing is used on the cylinder the frequency of hand stripping has been further reduced from one to three times per eight-hour shift to once per 120 to 144 hour week.

The cast iron frames of many textile cards may be old, but the cards have been rebuilt and greatly modified during the past two decades. The throughput of cotton has been increased by two to five times on a large proportion of the cards. Dust production has been correspondingly increased. To compensate for the increased production of dust and fly, exhaust systems have been installed as card cylinder speeds have been increased. Unfortunately, there has been no objective monitoring of airborne dust concentration before and after modifications and exhaust system installation.

Another relatively recent innovation is the installation of crush rolls on cards by many mills. These smooth steel rolls subject the entire width of card web to a high pressure, crushing friable bits of leaf and trash. The purpose is to reduce the size of the bits of trash so that they will not interfere with, and will drop out at, subsequent processes. Loss of crushed trash from the fiber occurs as the sliver size is reduced, but the greatest loss is said to be in spinning.[43] Again, there are no before-and-after environmental data, but the nature of the process would seem to assure increases in dust production at subsequent processes. The amount of respirable-sized dusts which may be added by this process is not known. As the active chemical agent in the dust is quite likely from the bract, a very friable leaf, the proportion of active agent in dust at subsequent operations must also be increased by the crush rolls.

Some card sliver is combed before subsequent processing. However, combing is only done on long staple, high grade cottons processed into fine yarns, and fine yarn production is not usually associated with byssinosis. Thus, combing is unlikely to be a significant source of air contamination.

Drawing and Roving

The sliver coming from the card goes through drawing frames, where several slivers are pulled together between rollers. The purpose is to straighten the fibers and to reduce the size of the strand which they compose. Draw frames are enclosed, are under suction, and it is not believed that they contribute seriously to the dust load in the room.[33] Air is drawn through the suction system and returned to the room through filters. As in other textile mill air cleaning systems, the filtration has not been designed for dust particles of "respirable" size.

The sliver from the drawing frames goes to roving frames, which reduce the size of the sliver by roller drawing, impart a slight twist, and wind the product on bobbins for spinning (or in some cases for another roving frame). The product ready for spinning is called *roving*. The drawing of the fibers against one another and the winding on bobbins produce an opportunity for further dust and short fiber to be released. The roving frame is not considered a major dust producer, but nowhere are measurements of dust production recorded.

Spinning

The purpose of spinning is to reduce the size of the roving to the desired yarn size, and to impart the amount of twist required for yarn strength the *draft*, the ratio of length delivered to length fed, may be as little as 10 or on the order of 50.[44] As the yarn is spun to impart the twist, it goes through a traveler on a ring. Traveler speeds may be as high as 3500 cm/sec. The combination of considerable reduction of yarn diameter and high air speeds across the yarn as it is spun creates the opportunity for release of a large proportion of the fine trash remaining at the spinning operation. More short fiber is released also, so the concentrations of fly in the air can be appreciable. It is common to have traveling blowers going alongside the spinning frames, blowing accumulated fly (and associated trash) off the spinning frames. In the absence of adequate controls, the problem of byssinosis could be expected to move forward from the cardroom to the spinning room because of the changes which have been occurring in the modern mill and in fact several investigators have noted this.

In some cases, other methods of spinning are being substituted for ring spinning. One of these methods involves, in effect, a centrifuge working at perhaps 10,000 g.[45] The dust problems of this type of spinning can be expected to be quite different from those of ring spinning. It is to be hoped that in such new developments the contribution of the process to hygienically significant dust concentrations will be considered and compensated for before their installation in textile mills.

Winding

The lengths of yarn on bobbins from spinning are too short for practical use in subsequent operations. It is usual practice, therefore,to wind the yarn onto cones or tubes, producing a larger package for more continuous subsequent operations. The winding operation is typically conducted at high yarn speeds, and apparently these high speeds can result in considerable release of that foreign matter which has been carried through from previous operations. At any rate, both high prevalence of byssinosis and relatively high dust concentrations have been noted at winding operations.[14,46]

Twisting

Two or more strands of yarn are often twisted together to form ply yarns. The position of the twisters at the end of the process of yarn production would suggest that there is little active agent left to be released at this point. It is to be emphasized, however,that preconceptions are to be avoided as to the presence or absence of byssinosis. Only actual examinations of the workers will determine with certainty whether their health has been affected.

Weaving

The statement about twisting may be applied even more strongly to weaving. While byssinosis of the severity encountered at carding would not be expected, various health effects have been noted among weavers.

Non-occupational Disease from Cotton Dust

There has been no indication that cotton dust emissions from cotton textile mills constitute an air or water pollution hazard. The principal source of cotton dust – that is, dust associated with raw cotton – is the cotton gin. It has been reported[47] that "extremely harmful effects (are) produced particularly against children with asthma by cotton gins in our area .... It is impossible . . . to protect them from the extremely irritating effects of lint, dust and smoke from cotton gins."

The emissions from cotton gins may readily be controlled by simple dust collecting systems to any degree desired. It is presumed that the air pollution problem has been or will be controlled to remove any community health hazards.

Other Health Hazards

The greatest health hazard in cotton textile mills, in terms of number of workers affected, is undoubtedly noise. Hearing loss from weave rooms has been shown,[48] and it is unlikely many of the textile mill weave sheds will be able to meet the 90 dB(A) sound level established as a standard under the Walsh-Healey Public Contracts Act,[49] and subsequently applied to all mills under the Occupational Safety and Health Act of 1970.[40]

Flax, Hemp, Jute, and Sisal

Investigations of worker health in textile mills processing flax in several countries have shown the presence of byssinosis.[50-54] It appears to be absent when chemical degumming procedures rather than biological retting are used.[54] The disease is virtually identical, and both dust control and a medical evaluation program appear desirable. Flax processing is a minor industry in the United States. In the only study of United States flax workers reported, no byssinosis was found.[55] Medical evaluations pertinent to byssinosis should be conducted on workers in flax plants on a regular basis (see Medical Evaluation).

Likewise, workers with soft hemp have shown symptoms and respiratory function changes not unlike those of cotton workers. Field studies have shown byssinosis among active workers[22, 23] and the continuing study of Bouhuys and co-workers of retired hemp workers in Spain,[25] referred to previously, is a classic of its type. Bouhuys points out that the use of hemp in Spain is decreasing rapidly as superior synthetic fibers are substituted in rope making.

Hard hemp fiber is taken from the leaf of the plant, while soft hemp comes from the stems. Investigations of those who work with hard hemp and sisal did not disclose typical byssinosis symptoms.[12,56] However, a fall in ventilatory function during the day was noted in dusty parts of the factories. Although evidence that byssinosis occurs among hard hemp and sisal workers is tenuous, such workers should have periodic medical evaluations.

The leaves and flowers of the hemp plant may also be smoked, although this is usually illegal. There is, as yet, no evidence of byssinosis connected with such an exposure.

In one investigation of jute workers, no byssinosis was found.[12] It is not believed that jute processing will ever be economically significant in the United States.

The Numbers Game in Byssinosis

One of the recognized procedures of zealous advocates of reform or change in the environment or in business practices is the use of large numbers of birds, people, fish, or wildflowers to demonstrate the importance and extent of the problem they are discussing. These numbers are invariably followed by a rebuttal by the group most directly affected by the reform, demonstrating conclusively that the numbers are truly insignificant, and that only crackpots or radicals can really believe that a problem exists. The game is best played when both sides have "official" government statistics to use in their argument.

In the debate over byssinosis, this traditional game plan has been followed. It is, in fact, an ideal subject for the game, because there is not general agreement as to the definition of byssinosis. In the British Act which established disability compensation for byssinosis, it was defined implicitly as a disabling respiratory disease. If this definition were used, then the textile mill industry associations could point to the fact that no disability compensation had been awarded for byssinosis in their state. Their argument was only slightly weakened by the absence of byssinosis from the group of occupational diseases which were covered by workmen's compensation laws or regulations.

At the other extreme were those who would at least imply that anyone who works with cotton in any stage of its processing from field to consumer was a potential byssinotic, thus producing numbers of people in the hundreds of thousands.[57]

The consensus of those who have published on this subject in the past 20 years is that byssinosis is a specific health problem, with gradations of effect from tightness in the chest on only some Mondays to total disability. In determining prevalence of byssinosis in a working population, the disabled are no longer available so that the most appropriate number to consider would reasonably be the total number of workers affected. In discussing prevalence in the following section, it is this concept that is used.

PREVALENCE OF BYSSINOSIS

As in many occupational diseases, the prevalence of unusual symptoms was first reported by local clinicians. Kay, in describing "Spinner's Phthisis" in 1831, wrote of "many cases which have presented themselves at the Ardwick and Ancoat's Dispensary" (in Manchester).[4]

Leach, in 1963,[6] writing of Surat cotton used in low, narrow, ill-ventilated rooms, reported, "The respiration is affected.... the mixers..... the willowers and scutchers suffer in the same manner as the cotton mixers.... the strippers, grinders and cardroom hands... suffer.... A carder seldom lives in a card-room beyond forty years of age... Drawers and rovers suffer very little. The mule and throstle.. hands.. look pale and sickly; but are lively, cheerful, and active.. the packers... are generally very healthy.."[6]

The fact that problems were mainly in the card-room and preceding operations was noted by virtually all investigators. In 1908 it was reported that "complaint had been made from time to time of injury to the lungs among strippers and grinders in card-rooms. Dr. Collis examined 126 men so employed in Blackburn, and found 73.8 per cent complaining of, or suffering from, an asthmatic condition, due to inhalation of dust."[8] Table 3 from Collis, relates the findings to coarseness of cotton spun.[8]

Collis also noted the association between length of employment and prevalence, "The average period of employment of 126 men examined was 14.7 years; of 33 men found unaffected it was 8.8 years."

Hill, comparing sickness rates during the period of 1923 to 1927,[58] found that male card-room operatives had two to three times as many respiratory illnesses as ring room or warehouse workers in the mills. Female card-room operatives had a smaller excess of respiratory illness, about 60 to 75 % above the ring spinners' rates. Prausnitz[59] compiled this sickness data into the graph shown in Figure 1.

The Departmental Committee on Compensation for Card-Room Workers reexamined the situation and found that respiratory illnesses

TABLE 3

Size of Cotton Yarn Produced and Effect on Workers

		No. of Strippers and Grinders				Total affected	
No. of Mills Visited	Average count* of cotton yarn	Sound	Slightly affected	Markedly affected	Total examined	No.	%
6	Below 30 (coarse)	2	8	13	23	21	91.3
17	Between 30 & 39 (medium)	23	27	32	82	59	71.95
8	40 and over (fine)	8	7	6	21	13	61.9
31	All counts	33	42	51	126	93	73.81

*The "Count" of cotton yarn is the number of 840 yard hanks in one pound of yarn.
After Collis,[8] 1908.

among card-room workers, and blow-room and cotton-room workers as well, were still in excess of those among spinners and weavers, though the excess appeared to be less than that reported by Bradford Hill.[9]

Mortality statistics in the United Kingdom are tabulated in more detail than in the United States and most other countries, They revealed a Standardized Mortality Ratio for bronchitis among cotton strippers of 5.58 for the years 1921 to 1923. It was noted that the bronchitis mortality of cotton strippers and grinders in 1921 to 1923 was 1.2 times that of 1910 to 1912, although in the general population the mortality was only 0.84 that of the earlier period.

The excess seemed to have disappeared in the 1927 British statistics published in 1938. However, Schilling and Goodman noted that an apparent excess of cardiovascular-renal deaths was actually due to a change in coding procedures for death certificates and many actually belonged in the respiratory and cor pulmonale categories.[60] The situation as of 1947 was one of uncertainty, but of no great concern.

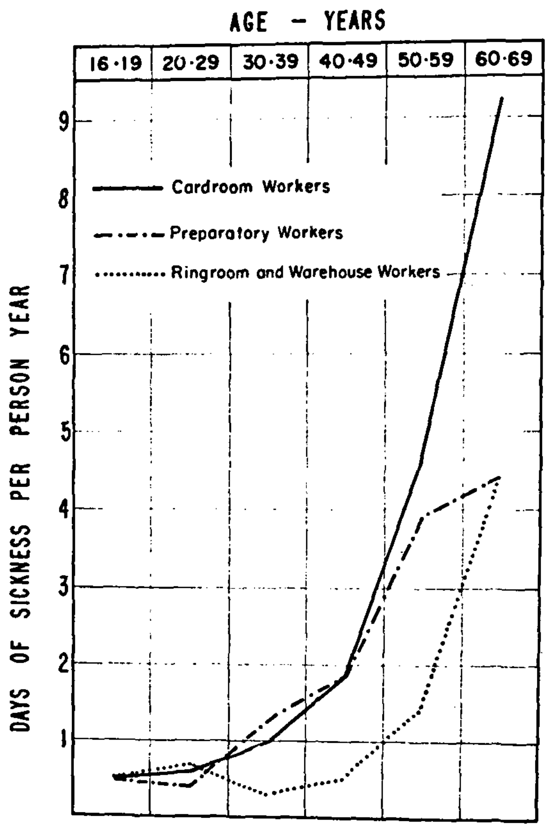

FIGURE 1. Days of sickness vs. age, male cotton operatives, Lancashire, England, 1923-1927. After Hill[53] and Prausnitz.[55]

In the United States, studies by the U. S. Public Health Service failed to find byssinosis in 1933.[61, 62] Russian experiences appeared to be similar to those in England. In no country was the proportion of textile workers affected by byssinosis known with certainty, but it was generally believed that in the industrialized countries the situation was either satisfactory or greatly improved.

Schilling's studies in Lancashire cotton mills brought order and standardization into the determination of byssinosis prevalence. The county of Lancashire has been the center of cotton textile manufacture in England since the Industrial Revolution. Its principal city, Manchester, has been used as an archetype of the production efficiency followed by inevitable stagnation of a one-industry town.[63] Indeed, the textile industry has contracted in Lancashire, and this has resulted in problems for Manchester. But Lancashire still remains one of the world's textile centers. Thus, the state of health of cotton mill operatives was a worthwhile subject for investigation by the occupational health unit in the University of Manchester. The "strippers and grinders" in 1930 to 1932 and 1947 to 1948 still showed an excess of cardiovascular and respiratory diseases, and from all appearances they had the highest dust exposures in the cotton mills.

The first studies of Schilling and his coworkers[10,20,60,64,65,67] have been a pattern for those following and deserve to be recounted in some detail. From a group of mills, they selected several spinning raw cotton into coarse grades of yarn. (The "count" of yarn is the number of 840 yard hanks that it takes to make one pound. Thus, the lower the count, the coarser the yarn. Few of the reports actually listed the count of yarn that was spun. Collis'1909 classification of "coarse", "medium," and "fine" is given in Table 3.) Careful examinations of all men in the group were done for blood pressure. The mean systolic and diastolic blood pressures were higher in the experimental card- and blow-room workers than in the control weave-room workers. Observer error, obesity, heredity, and renal disease were examined and rejected as reasons for the differences. This left the possibility of byssinosis as a reason. All of the men were questioned about symptoms, and 63% were found to be affected by byssinosis, Grades I, II, or

III. The workers with byssinosis had higher blood pressures and a higher prevalence of hypertension than the symptom-free workers, but the differences were not statistically significant.

The finding in the study related to cardiovascular disease of 63% byssinosis prompted further studies. In a group of 190 card- and blow-room workers, it was found that 39% were normal, 35% had Grade I byssinosis, and 25% had Grade II byssinosis. None of the control group from engineering factories in the same district had the characteristic chest tightness symptoms of byssinosis. Further analyses of the data showed that 45% of the carders and 65% of the strippers and grinders and blow-room workers had byssinosis.

The study of 28 mills was compared with two previous studies of card- and blow-room workers with proportions affected by byssinosis as shown in Table 4 and Table 5.

Byssinosis was found in all three geographical areas. The highest prevalence among card-room workers and "blow-room" (picking and opening in the U.S.) workers, as shown in Table 5, is consistent with findings back to those of Collis.[8]

The objective, standardized methods of Schilling have been used since 1950 by investigators throughout the world. A number of prevalence studies are summarized in Table 6, which is far from all-inclusive.

In addition to the countries listed in Table 6, prevalence studies in one or more mills have been reported from India,[74] Italy,[11] Israel,[75] Egypt,[38] Uganda,[12] and Yugoslavia,[76] with results, in general, comparable to those shown. It is evident that the prevalence has decreased since Collis'

TABLE 4

Relative Prevalence of Byssinosis in Male Cotton Mill Workers Aged 40 to 50

Group	No. examined	Normal	No. with byssinosis I	II	Total(%)
28 mills - Oldham	190	75	67	48	60
17 mills - Oldham	107	51	33	23	52
4 mills - Ashton under Lyne	44	10	17	17	54

From Schilling et al.[20]

TABLE 5

Prevalence of Byssinosis in Card-Room Workers and Spinners Aged 40 to 59 in Six Mills

Operation Group	Sex	No.	Mean Age	Mean Yrs. Exposure	Normal	Byssinosis I	II	Total(%)
Card and blow-room workers	M	56	48	25	21	22	13	62
Card, draw frame, slubber tenders	F	109	49	27	58	37	14	47
Intermediate and rover tenders	F	109	48	27	84	17	8	23
Mule spinners	M	62	50	29	55	5	2	11
Ring spinners	F	61	48	28	59	1	1	3

From Schilling et al.[20]

lecture in 1915, but prevalence of byssinosis in card rooms reported during the 1960's varied from less than 10% to over 60%.

Although the general method of Schilling has been used in all the studies since 1950, the prevalence figures shown in Table 6 and reported in the various studies are not strictly comparable. The studies may include only the workers in dustier jobs or all workers. The definition of byssinosis may include byssinosis Grade 1/2 (tightness in the chest on some Mondays) or only byssinosis Grade I (tightness in the chest on every Monday) and greater. Mills spinning "coarse" cotton only may be studied, or "fine" and "medium" mills may also be included. The largest study by far was the prospective study of Molyneux and Tombleson,[21] in which over 1500 cotton textile mill workers, in ten occupations, were examined. When Schilling's methods were finally used to study cotton mills in the United States, it was found that significant proportions of workers had byssinosis, though in the three studies included.[13,72,73] the percentage of workers affected was lower than in many of the European cotton textile mills. It is evident also that the distribution of byssinosis throughout the mill is changing as the processes and facilities for cotton textile manufacture are changed. It appears that byssinosis is now found more frequently among mill workers in processes subsequent to the card room. Even in winding, byssinosis is appearing.

The trends in prevalence of byssinosis are far from clear. Molyneux and Tombleson's report of their study of the period 1963 to 1966[21] shows little if any difference from Schilling's studies of ten years earlier. Meaningful studies in the U.S. have only been performed in the past few years so that no trend is as yet apparent. The trends in prevalence should follow trends in exposures to the agent causing byssinosis; as will be seen, these are also unclear.

The Environmental Agent

It has been evident since the first descriptions of byssinosis in cotton textile mills that the disease was caused by foreign matter rather than the

TABLE 6

Prevalence of Byssinosis in Cotton Workers

Country	Year Reported	Opening and Picking	Carding	Stripping and Grinding	Spinning	Other	References	Remarks
		←		%		→		
England	1915			91			8	Coarse
England	1915			72			8	Medium
England	1915			62			8	Fine
England	1950			43			67	
England	1955	66	43	65		42	20	
England	1956		39		7		68	
England	1960		51		2		66	Coarse
England	1960		6				66	Fine
Belgium	1961		8				69	
W. Germany	1963		62				11	
England	1964		14		2		70	
Netherlands	1964		18		2		70	
Sweden	1964		62			52	15	Other card room
England	1966		30				71	
England	1966		62				71	
England	1967					18	14	Winding
U. S.	1969		26		29		13	
U. S.	1969		25		12		72	
England	1970	24	24	49	25*	4	21	Medium (10-50)
England	1970	14	32	48	29*	9	21	Coarse (1-24)
U. S.	1970	15	29		10	7	73	

*Includes drawframe tenter, speedframe tenter, and comber tenter.

cotton lint. Collis, in 1915, spoke of "dust arising from cotton husk and debris which is thrown in a fine cloud into the air." A successor as H. M. Medical Inspector of Factories, E. L. Middleton investigated the dust to which card strippers and grinders were exposed. He reported: "The cause of the disability produced among these workers must, therefore, be a matter of conjecture until further investigations are carried out. The constituents of the dust are emery, cotton hairs, other parts of cotton, mold fungus (mycelium, conidia, and spores), and extraneous mineral matter."[77] The mineral matter was dismissed in this and subsequent studies as being of little or no importance to health. Concentrations of mineral matter in cotton textile mills are trivial compared with those in mineral industries. Neither symptoms of "tightness in the chest" nor the decrease in $FEV_{1.0}$ during the day is found in mineral industry workers. In reviewing the world-wide literature to 1947 in *Mode of Action of Cotton Dust* Caminita et al. concluded that "there is some positive evidence to show that the dust can act as a mechanical irritant, as a source of microbiological toxins, of histamine, and allergens. The evidence is negative with reference to its acting as a source of silica, of infectious micro-organisms or of gossypol."[7]

Following Schilling's discovery that byssinosis was still a problem in Lancashire textile mills,[20] there was further work on the mode of action of cotton dust. The "mechanical irritant" suggestion of Caminita has not been noted in further publications. There has been no suggestion of any material in the vegetable dusts in cotton textile mills that would cause mechanical irritation more readily than other organic dusts or mineral dusts. The concentrations of "respirable" dust are much lower in textile mills than in dusty industries, yet workers in the latter do not display the characteristic symptoms of byssinosis.

Schilling examined the possibility that byssinosis might be an allergenic reaction.[68] He concluded that the course of the disease was not consistent with an allergenic response. Cayton et al.,[78] in a thorough examination, showed that non-cotton workers and non-byssinotic cotton textile workers and byssinotics reacted similarly to extracts of cotton dust in skin tests regardless of the type of cotton dust sample or the method of extracting the dust that was used. Although there are undoubtedly individuals who are allergic to cotton dust (as allergies exist to many other materials) it appears unlikely that allergy in the usual way plays an important part in byssinosis. However, Gernex-Rieux et al. found a correlation between Monday symptoms and skin reactions,[79] and Massoud and Taylor described an antibody directed against an antigen present in the cotton plant.[80] They found the antibody titers higher in card room workers than in normals and highest in those with byssinosis.

The possibility that a bacteria-produced endotoxin may have a role in the induction of byssinosis has been investigated by Cavagna et al.[81] They pointed out that the "mill fever" syndrome had been associated with bacterial endotoxins and suggested that the tolerance developed during the working week was not unlike a refractiveness induced in a host by endotoxins. They showed that in the cotton textile mill studied, the concentration of endotoxin-like material in the card room was about 90 times that in the spinning room. The prevalence of byssinosis was 32% in the card room and not shown in the spinning room. The concentration of total dust in the card room was more than ten times as high as the concentration in the spinning room, however, and the active agent in the spinning room would thus have been below the level which would cause a reaction whether it was an endotoxin or some other type of material. In the Cavagna investigations a reaction somewhat similar to that which has been shown in byssinotics was created in human volunteers by a bacterial endotoxin, and the animal experiments conducted provided some further support. The presence of endotoxins in dust in cotton textile mills in general was not demonstrated.

The Industrial Health Foundation has noted what they consider "a strong relationship between physiologic response and levels of enzyme activity" and suggests that "an enzyme or combination of enzymes found in cotton mill dust" may be "the specific etiologic agent in byssinosis."[82]

Hitchcock et al. reported that bracts contained a steam-volatile component which released histamine from chopped human autopsy lungs. This component had similar physicochemical behavior to methyl piperonylate. Synthetic methyl piperonylate also released histamine from chopped human lung. The authors concluded, "Steam volatile component may contain the principal bronchoconstrictor agent of bracts, and methyl piperonylate may be this agent."[83]

The postulation of an active agent in a steam volatile fraction would be consistent with lessened effects of cotton dust on reactive individuals when steam-treated cotton is used. Such an improvement has been noted in experiments conducted in cooperation with Burlington Industries by Duke University, the North Carolina State Board of Health, and the National Institute for Occupational Safety and Health.

The presence of histamines in cotton dust was demonstrated by several investigators in the 1930's, and the possibility that histamine, a normal component of many vegetable dusts, was at least partially a cause of byssinosis was investigated.[84,85] Prausnitz, in his study following the Home Office Departmental Committee Report, wrote, "Whether this principle plays a pronounced role in causing the respiratory disease of cotton operatives is doubtful."[59] Haworth and MacDonald found more histamine in the blood of card-room workers than in controls.[86] However, the amounts of histamine found in cotton dust appear too small to result in effects comparable to those found.[87,88]

The possibility that some component of the cotton dust was capable of releasing histamine in the lung was suggested in the 1930's by those who found histamine in cotton dust. Bouhuys et al. postulated again that a histamine releasing substance was responsible for at least some of the symptoms of byssinosis.[88] He based this hypothesis on human dust inhalation experiments and animal experiments. Antweiler confirmed the liberation of histamine in animals by aqueous extracts of cotton dust.[87] Bouhuys and Lindell also demonstrated the liberation of histamine in human lung tissue; the amount released when cotton dust extract was present was about double that released in the absence of cotton dust.[89] One conclusion that might be drawn from these experiments is that those workers who develop byssinosis are the ones that are unusually sensitive to histamine. However, Bouhuys has shown that byssinotic flax workers are no more sensitive to inhaled histamine than controls. (In this study patients with bronchial asthma, unconnected with cotton work, had previously been shown to be much more sensitive to histamine.[90])

Although there was no doubt that some active agent in the cotton dust was causing symptoms of byssinosis, the evidence for histamine release as the mechanism was still inferential. Davenport and Paton studied the action of a group of cotton dust extracts and jute dust extract on smooth muscle from guinea pig ileum, guinea pig trachea, rat stomach strip, and rat duodenum.[91] The cotton dust extracts, and to a lesser extent the jute dust extract, contained smooth muscle contracting activity. They found histamine in one dust sample but not in the others and some 5-hydroxytryptamine but not enough to account for the muscle contraction. The unknown muscle contractor substance was heat stable and dialysable and was not destroyed by proteolytic enzymes. However, with whole animal experiments they noted other effects which suggested that symptoms of byssinosis might be caused by the release of some other broncho-constrictive substance in the tissues. A small amount of histamine was released in rats by the dust extracts, but similar releases were not noted in guinea pigs or cats. They suggested that the smooth muscle-contracting substances in the extracts and the release of broncho-constrictive substance in the tissues might be responsible for different symptoms of byssinosis. It was pointed out, however, that it was difficult to draw definite conclusions about the human disease from even extensive animal experimentation.

Nicholls, in concurrent, independent animal experiments, confirmed the findings of Davenport and Paton. He further noted that the action of the aqueous extracts was not due to contained histamine, although some samples did contain detectable amounts of histamine.[92] He used, in addition to cotton mill dust extracts, extracts from the stems, bracts, and pericarps of cotton plants. The extract of the stems and pericarps were found to produce reactions in the animal preparation similar in magnitude to extracts of the textile mill dust. In the perfused isolated guinea pig heart, histamine and textile mill dusts produced reactions, but the histamine reaction was blocked by mepyramine, while the action of the dust extracts was not. In perfused rat hindquarters, dust extracts, pericarp extracts, and compound 48/80 (Burroughs-Wellcome) produced reactions, but cotton linter extracts and cotton seed extracts did not. Injections of the dust extracts and extracts of pericarp, bract, and flax produced effects that were similar to but not identical with those produced by histamine, or the histamine liberating

Compound 48/80. Application of the various extracts on the human forearm of volunteers produced no reaction. He observed that the action of the smooth muscle contracting substance was similar in extracts from cotton, flax, and jute, though they are phylogenetically different plants, suggesting that a similar material is involved in each. He noted that histamine release might best explain the "Monday symptoms" of cotton workers but was doubtful that this could explain all the activity. The possibility of biological assays of textile mill dusts to determine their potency was discussed, but he pointed out that a comparison with the effects on mill workers was necessary before conclusions could be drawn.

Nicholls et al. investigated the release of histamine from preparations of animal lung, using aqueous extracts and Compound 48/80.[93] They used extracts of English and Dutch cotton textile mill dust and of the bracts and pericarps from South Carolina cotton bolls. Compound 48/80 released histamine from cat, rat, guinea pig, and human lung tissue, but the dust and bract extracts released significant amounts of histamine from only the human lung. The histamine release reported was in only one human lung, but findings were similar to the earlier findings of Bouhuys and Lindell.[89]

The action of aqueous extracts was further studied in human volunteers.[94] It was found that inhalation of an aerosolized extract of the bracts produced both subjective symptoms of respiratory distress and increase in pulmonary flow resistance in three of four volunteers. One volunteer did not report subjective distress; changes in lung function were noted, but not all her changes were statistically significant. The extract of pericarps was without effect. Exposure to bract extract aerosol 24 hours after the first experiment did not produce repetition of the symptoms, but a repetition of the exposure six to eight days later produced subjective symptoms similar to those of the first day.

The evidence presented by Dr. Bouhuys and his collaborators for a histamine-releasing agent, probably from the bract of the cotton plant, as the active material causing byssinosis is impressive. It is also difficult to quarrel with his contention that the effect on human subjects is more important than the results of experiments with other species whether in vivo or in vitro. However, this transient airway narrowing may bear no relationship to the chronic disease which eventually results in disability. The active agent, whatever its mechanism of action, has not been identified. A correlation of byssinosis prevalence with nitrogen content of dust has been noted.[66] Other investigators have reported that the correlation of byssinosis with carbohydrate content of dust appears better than with nitrogen.[95] The active ingredient is suggested to be a polysaccharide,[76,92] perhaps an amino-polysaccharide. If the active agent in the cotton dust is indeed contained in the bract, then a correlation with nitrogen would be expected, inasmuch as the organic trash, principally leaf, contains about 10% nitrogen.[96] Since clean cotton fibers contain only 0.1% nitrogen, an analysis of nitrogen in airborne dust samples would be an indirect analysis of organic trash in the samples. It is not unlikely that carbohydrate concentrations might show a similar indirect correlation, depending on the concentration of the carbohydrate in the leaf trash.

Taylor et al. have reported the extraction of a condensed polyphenol based on leucocyanidin from cotton bracts.[97] This material was shown to react with human sera. Significant differences in reactivity were noted between byssinotic and non-byssinotics and between controls and card-room workers. An aerosol of a solution of the material produced symptoms of byssinosis in byssinotic card-room workers, but not in non-byssinotics or controls, The aerosol did not produce changes in $FEV_{1.0}$ or FVC. Since this material is from the bract, any measurement of airborne bract dust or another component to bract dust would be an indirect measurement of this material.

When and if the active agent (s) responsible for byssinosis in textile workers is isolated, it is doubtful that it will be of much use in controlling byssinosis hazards in textile mills. The analysis for the active agent is almost certain to be too complex for routine use in the evaluation of textile mill air quality. Nevertheless, it would be of considerable value for research studies to be able to analyze definitely for an active agent responsible for disease.

The influence of the active agent in cotton dust is not the only environmental factor related to respiratory symptoms among cotton textile mill workers. It is well known that particulate and sulfur oxide air pollution in the Lancashire area is relatively high compared with that in many other industrial areas. Monthly average particulate concentrations in the winter months at three stations in Lancashire in the 1960 to 1962 period ranged from 115 to 716 $\mu g/m$.[3,70] Average sulfur dioxide concentrations in the same period were 90 to 809 $\mu g/m$.[3] A comparison of English and Dutch workers in similar textile mills showed that prevalence of byssinosis was quite similar in the two groups. Thirteen and one half percent of the English card-room workers were affected versus 17% of the Dutch. However, in both carding and spinning rooms the English workers reported significantly more persistent phlegm, persistent cough, and wheezing than the Dutch workers. Further, the $FEV_{0.75}$ was lower among English workers than among Dutch workers. Contraction of the Lancashire cotton textile industry was thought to account for the fact that fewer advanced byssinosis cases were found in England – another disadvantage of comparing "survivor" populations.

The relative lack of air pollution in the Southeastern United States' communities in which the majority of textile mills are located is another plausible reason why the obvious morbidity and mortality excesses of Lancashire have not been noted in the United States.

Cigarette smoking is an obvious cause of respiratory symptoms and in certain cases may outweigh exposure to less active vegetable dust.[55] Bouhuys et al. have suggested, "No synergism exists between the long-term effects of cigarette smoking and of hemp dust inhalation on the $FEV_{1.0}$."[98]

In American cotton textile mills, on the other hand, Merchant and his co-workers have observed that combined effects of cotton dust exposure and cigarette smoking produced an increased prevalence of byssinosis.[99] Significantly higher prevalence of byssinosis and chronic bronchitis occurred in smokers at both higher and lower levels of dust exposure, and prevalence was increased by higher dust levels for both smokers and non-smokers.

The environmental agent responsible for byssinosis is not yet known. From material published to date it appears that, in cotton dust, a trash component – most likely from the bract of the cotton plant – is responsible. This material is water soluble, stable to boiling water temperatures, and dialysable. It may well act upon the lung by causing histamine release which, in turn, results in broncho-constriction. It has properties consistent with peptides or polysaccharides. The connection of this active agent, with its acute response and long-term respiratory disability, is only inferential. It seems that workers with a greater acute response are more likely to suffer irreversible lung function changes, but the evidence is inconclusive.

There remains a high probability that the acute response to byssinosis and the chronic bronchitis which eventually produces disability is byssinotics are causally connected [25,68]

Similar Responses to Active Agents

The only industry where respiratory function effects similar to those found in byssinosis are seen is in the use of diisocyanates to manufacture polyurethane foam.[100, 101] Groups of polyurethane foam workers have shown drops in $FEV_{1.0}$ during the day comparable to those seen in byssinosis. At the low concentrations of isocyanate found, tightness in the chest was not noted. (Personal experience of the author is that an unbearable sensation of chest tightness occurred during the first breath past a loosely-fitted respirator in a concentration of 3 mg/m^3 of methylene bisphenyl isocyanate (MDI), over 90% of it >12 micrometer diameter particulate. No respiratory function tests were made on that occasion, and the experience was not one which would suggest human experimentation at similar concentration.[102])

The occurrence of sensitization to toluene diisocyanate has been reported, with immune reaction on reexposure to the isocyanate.[103]

A long-term exposure to isocyanate has been shown to produce cumulative effect on the lungs. A decline of $FEV_{1.0}$ of 0.3 liters in 2.5 years was noted after subtracting the normal decrease caused by increasing age.[104,105] The workers with the greatest acute response tended to be those with the larger chronic changes. The need is apparent for a prospective study in an American cotton textile mill similar to that done in the polyurethane foam manufacturing operation. A prospective study in a United States cotton textile mill, including both symptoms and respiratory function measurements, is underway,[106] but results were not available at time of writing.

DUST MEASUREMENT

In the 1920's and early 1930's the U.S. Public

Health Service undertook to survey the hazards to workers from various dusts. Surveys of worker disease and dust concentration were made among coal miners, granite cutters, Portland cement manufacturing workers, asbestos textile workers, abrasive workers, silverware manufacturers, street cleaners, talc miners and millers, and textile workers.

In reading that list one is struck by the fact that with the exception of textile workers, the surveys were primarily among those who worked with inorganic mineral dusts. One may dispute the findings of no significant respiratory disease among textile workers, but the findings[61,62] of low dustiness *compared with the mineral industries* is beyond question. Nor is it surprising that health problems in the cotton textile industry would seem insignificant compared with exposures which produced silicosis in 80% of the workers with more than 10 years' experience. At any rate, the evaluation of textile mill dust was made using an instrument designed for the evaluation of mineral dusts and without knowledge of the kind of dust responsible for health effects.

The first relatively thorough evaluation of dustiness in cotton textile mills was that of Middleton.[77] He noted that there was mineral matter present (but not in hygienically significant amounts), and a variety of vegetable matter, including short cotton hairs, plant debris, and various spores and fungi. His examination was made by microscopic methods.

Research on the site of particle deposition by size has been performed by a number of investigators.[107] It is evident from autopsy results that few particles having an aerodynamic diameter (that is, the diameter of a unit density sphere equivalent in terminal falling velocity to the particle in question) larger than 5 micrometers (μm) are retained in the lung for periods of months. However, about one half the 5 μm aerodynamic diameter particles are deposited and retained in the lung for 24 hours,[108] suggesting deposition in the non-ciliated portion of the lung. For 8 μm particles, the proportion so deposited and retained for 24 hours is only about 4%. Somewhere in the neighborhood of 10 μm is the upper limit for particle penetration to the pulmonary air spaces. If the action of the cotton dust is presumed to be due to a pharmacologic action of a soluble material absorbed into the blood, then pulmonary deposition would appear to be the site of interest. It is desirable, therefore, to fractionate the dust in cotton textile mills into several size fractions so that only the sizes of interest are measured.

American upland cottons have mean fiber diameters of 13.5 to 17 μm, while Egyptian and Sea Island cottons have mean fiber diameters of 11.5 to 14.5 μm.[109] The falling speed of glass fibers in air, and by inference of the less regular shaped cotton fibers, is a function of diameter, rather than length.[110] For fibers with the diameter and density of single cotton fibers, the falling speed in air would be about a centimeter per second (cm/sec). Usual room air currents will be 10 to 25 cm/sec, so that single fibers could remain suspended long enough to move a considerable lateral distance. Where traveling blow systems are used, local air velocities will be in the thousand cm/sec range, and considerable quantities of short cotton fiber will remain suspended.

The leaf and other vegetable trash will have no characteristic dimension but is visible in the bales and throughout the mill as millimeter size bits. This may be crushed or broken to microscopic size by cotton picking, by cleaning processes in the gin and the mill, and by the crush rolls on the card.

The mineral matter which comes in with the cotton will tend to be of microscopic sizes; most larger particles of sand and dirt will be removed at the gin and in mill cleaning processes.

Particulate air pollution is a not inconsiderable factor in some locations. In industrial communities during the winter, particulate concentrations can reach almost the mg/m^3 level; Lammers et al. reported a monthly average particulate level of 0.7 mg/m^3 in the Bolton area (Lancashire) in both the 1960 to 1961 and the 1961 to 1962 season.[70] Of the particulate air pollution in American communities, about half is "respirable," or less than about 5μm in aerodynamic diameter. Concentrations of community particulate air pollution indoors will be less than outdoors; the majority of that penetrating from outdoors is in the "respirable" range. With filtration of incoming air and a considerable degree of recirculation in ventilation systems, indoor concentrations of community particulate air pollution will be well under 0.1 mg/m^3 even in highly polluted industrial areas. The Southeastern United States communities, in which the bulk of U. S. textile production is done, tend to be smaller cities with relatively low levels of community air pollution. The almost universal ventilation systems with high recirculation rates make community particulate air pollution a negligible factor inside these mills.

The Dust to be Measured

The cotton fibers which are in the air of a textile mill are of importance from the standpoint of fire and general housekeeping. They have no hygienic significance. Not only is the cellulose of the fibers biologically inert but also the fibers are generally too large to be inspired, and all are too large to penetrate any distance into the human respiratory tract. If the cotton fibers were in a reasonably constant ratio to the dust of hygienic significance, then it would make little difference whether they were included or excluded from the sample. If, however, as appears to be the case, the concentration of cotton fibers can varv by an order of magnitude for a given concentration of hygienically significant dust,[13] then the cotton fiber must be excluded from the sample.

No data on the subject have been noted, but it appears reasonable to suppose that the proportion of trash of hygienically significant sizes will vary widely, depending on the treatment to which the cotton has been subjected in gin and mill. If so, it is important to exclude that larger size fraction of trash which is of no hygienic significance.

The mineral matter in the usual cotton textile mill dust is of little or no hygienic significance, and the concentration of mineral matter can be as much as half the dust in certain finer fractions.[66] If the proportion of mineral matter varies among different cottons, as seems likely, then it would be desirable to report air quality evaluations in the mills on a mineral-matter-free basis.

Particulate community air pollution is of little or no importance as a source of exposure inside the mills. However, in situations where there is heavy community air pollution and no intake air filtration, the particulate air pollution may amount to a significant and quite variable proportion of the fine airborne particulate. A categorization of cotton dust and its probable size and effect on the respiratory tract are presented in Table 7.

Methods of Dust Measurement

The methods of dust measurement used in textile mills have been of both size-selective and "total dust" types. A "total dust" sampler would presumably collect all the particulate matter in a given volume of air. Unfortunately, the proportion of very large particulate matter collected is a function of both the orientation of the dust sampler inlet and the inlet velocity. In sampling for particulate within air ducts, one can obtain a "true" sample by facing the sampler inlet into the direction of air flow and adjusting the inlet velocity so that it equals the local duct velocity (isokinetic sampling). This is not possible for general air sampling. In a room, an upward-facing

TABLE 7

"Cottor Dust": Size and Deposition Site

Constituent	Aerodynamic= diameter (μm)	Remarks
Lint and fuzz fibers	> 20	Essentially no deposition in respiratory tract
Vegetable trash	> 15	Essentially no deposition in respiratory tract
Vegetable trash	8-15	Mainly oronasal and tracheal deposition
Vegetable trash	> 8	Some deposition in pulmonary spaces–proportion increasing as size decreases
Mineral matter	> 8	Some deposition in pulmonary spaces–proportion increasing as size decreases
Air pollution	> 8	Some deposition in pulmonary spaces–proportion increasing as size decreases

sampler inlet will be biased toward larger particulate; a downward-facing sampler inlet will be biased against large particulate, and a sampler inlet in the vertical plane will collect a variable proportion of large particulate depending upon the sampler inlet velocity and the predominant air velocities in the vicinity of the sampler. The Hexhlet sampler[111] (used to collect samples in the studies that were the basis for the current Threshold Limit Value[112]) has the inlet in a vertical plane and an inlet velocity of 27 cm/sec. Sampling to apply the TLV should, one would assume, be conducted with samplers having vertical plane inlets and inlet velocities on the order of 25 cm/sec.

The size-selective samplers available for cotton dust sampling were developed for sampling pneumoconiosis-producing and radioactive dusts.[111,113,114] The Hexhlet, which has been used most widely, was developed to conform to the Johannesburg criteria[115] for a sampler to measure "respirable" dust, that is, dust which can penetrate to, and be retained in, the pulmonary spaces of the lung. The instrument is a parallel plate horizontal elutriator, which passes no dust larger than 7.1 μm aerodynamic diameter, 50% of the 5 μm dust, and almost all the dust smaller than 2 μm. When the instrument was used in cotton textile mills, it was noted that cotton fibers were collecting on the plates and interfering with the operation. A wire gauge with 2-mm mesh spacing was placed on the inlet of the Hexhlet to remove this "fly," which was periodically wiped off and save. Three size-fractions of particulate were identified.[66] The "coarse" was that material collected on the 2-mm screen. The "fine" was that material which passed the parallel plate size-selector. The "medium" was determined by difference, using a similar sampler without a size-selecting section for the "total" dust.

The use of a "high volume" sampler with a cyclone-type size selector[113] has been reported.[116] This sampler had a perforated metal screen, and a small amount of air was drawn off through a filter at the bottom of the cyclone to retain fly. This modified Aerotec sampler was considered by Lynch to be too bulky for routine use in cotton mills.[116] Alternative size-selective sampling units used in American cotton mill sampling include a personal sampling unit with an attached elutriating section, and a sampler developed by Lynch and Lumsden to use the principle of air elutriation and a higher air volume than is possible with personal sampling. This sampler is shown in Figure 2.

The personal sampler as used had a size cut-off of about 29 μm aerodynamic diameter. The vertical elutriator cotton dust sampler was developed to have a size cut-off at 15 μm; the cut-off could be changed by using a different airflow through the instrument.

A practical problem in the use of these size-selective samplers is that as a smaller size cut-off is used, the amount of dust collected decreases. As weight is proportional to the cube of particle diameter, the mass of dust passing the size selector drops off rapidly as cut-off diameter is decreased. Where gravity elutriation is the principle used in

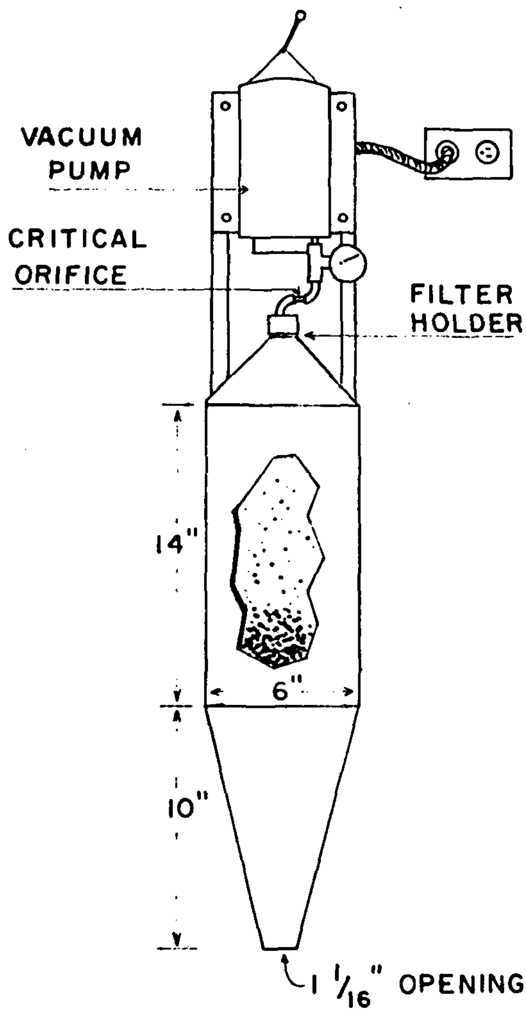

FIGURE 2. Vertical elutriator cotton dust sampler. Air flow = 7.4 liters per minute. By Lynch and Lumsden.

size selection, the airflow through a given sampler must be proportional to the reciprocal of the square of the cut-off diameter. A reduction in cut-off diameter from 15 μm to 10 μm would require a decrease in sampling rate to less than half. The amount of dust collected in a sampler will decrease rapidly as cut-off size is lowered. As samples become smaller, therefore, weighing becomes more difficult, as does chemical analysis.

Acceptable Concentrations of Airborne Cotton Dust

The Threshold Limit Value (TLV) of the American Conference of Governmental Industrial Hygienists (ACGIH) for cotton dust[117] is based on the study of Roach and Schilling in Lancashire cotton mills. They found a correlation coefficient of 0.93 for prevalence of byssinosis versus total dust concentration. The highest partial correlation for total dust was with protein (measured as total nitrogen). The highest partial correlation for protein was with the "medium" size fraction. Because of the high correlation of byssinosis and total dust concentration they proposed the classification of Table 8. This grouped work areas $<1 mg/m^3$ in the "safe" category, but only if the total dust concentration exceeded 2.5 mg/m^3 was dust control "essential."

The Threshold Limit Values committee of the ACGIH selected 1 mg/m^3 for the ACGIH limit which is, by reference, part of U. S. Department of Labor standards for occupational exposures.

Roach has recently suggested[118] that the risk of contracting byssinosis would be less than 1 in 50 if the concentration of dust, excluding fly, were less than 1.5 mg/m^3. He suggested categorizing dust exposures as shown in Table 9. One cannot decide from Table 9 whether a mill

TABLE 8

Classification of Work Area by Total Dust Concentration

Grade of Dustiness	Concentration Total Dust
A. Safe, with medical supervision of workers	$< 1 mg/m^3$
B. Dust control desirable and medical control essential	$1 - 2.5 mg/m^3$
C. Dust control and medical supervision essential	$> 2.5 mg/m^3$

From Roach and Schilling.[66]

TABLE 9

Categorization of Work Areas by Eight-Hour, "Fly-Free" Cotton Dust Concentration

Dust Category	Concentration Averaged over 8 hours (mg/m^3)
Negligible	0.0 - 0.4
Low	0.5 - 1.4
Moderate	1.5 - 15.0
High	> 15.0

From Roach.[114]

should stay in the "negligible" category ($<0.5 mg/m^3$) or whether the "low" category (0.5 to 1.4 mg/m^3) would be adequate.

Other tables in Roach's paper, which is similar to a proposal to the British Occupational Hygiene Society's Hygiene Standards Committee, Subcommittee on Vegetable Dusts, summarize the data from field studies on which his recommendations are based. The dust concentrations are specified as excluding that dust collected on a 2 mm screen or dust larger than 15 μm aerodynamic diameter. The data suggest that there is about 10% byssinosis (all grades), and <2% grade II byssinosis at 3.0 mg/m^3 total dust, including fly. As the fly is customarily more than half the total dust sample, a limit of 1.5 mg/m^3 is suggested.

While the Roach and Schilling study indicated that the "medium" size fraction was most closely correlated with byssinosis, human exposure experiments by McKerrow et al. demonstrated that the "fine" fraction of cotton dust could account for virtually all the effect on respiratory function.[119] A substantial reduction in "coarse" and "medium" dust without significant reduction in either "fine" dust or byssinosis symptoms has been reported by Wood and Roach.[120] This has led to recommendations for sampling the "fine" or "respirable" fraction of dust. The original recommendation of Roach for "total" dust sampling on the basis of simplicity and good correlation with health effect does not fit well with the varying dust types in modern mills if the effect is from the <7 μm dust. On the other hand, with no corrections for inert mineral matter, or for particulate community air pollution, the concentration of "fine" or "respirable" dust may not always correlate well with byssinosis prevalence. The use of a rather arbitrary 15 μm cut-off for dust sampling seems to have the advantages of eliminating the inert and variable fly while limiting the influence of the mineral matter and community air pollution fractions on the determination.

Allowable Dust Concentrations – Future Trends

As noted, Roach has suggested a limit of 1.5 mg/m^3 fly-free dust. This contrasts with the ACGIH TLV of 1.0 mg/m^3 for "total" dust. The latter limit is virtually meaningless in the absence of a "standard method" for measuring "total" dust. Bouhuys has suggested that revision downward of the TLV may be necessary. Considering these various factors, it would seem reasonable that a <15 μm dust limit, excluding ash, might lie between 0.5 mg/m^3 and 1.0 mg/m^3. A limit of 0.5 mg/m^3 of <15 μm dust is, in this reviewer's opinion, the lowest practicable. But symptoms of byssinosis and changes in $FEV_{1.0}$ have been observed at levels of <10 μm dust that approached 0.1 mg/m^3, and some textile mill operations are currently well under 0.5 mg/m^3 [121] Byssinosis was significantly reduced by washing or steam treatment of cotton prior to processing.

CONTROL OF BYSSINOSIS

Control of Environmental Exposures

The more basic the approach to prevention of byssinosis, the more likely it is to be successful. When and if the active agent causing byssinosis is identified, the plant geneticists may be able to develop a cotton plant with a greatly lowered concentration of active material. Any further improvements in gin technology which result in less foreign matter in cotton entering the mill will reduce the hazard. Where treatment can include washing or steaming cotton before carding, it appears that the byssinosis hazard is greatly reduced or eliminated. Early trials of this pre-treatment concept have been encouraging from the standpoint of byssinosis prevention; it remains to be seen whether the concept is technically sound and economically feasible for textile mills.

Except where prewashing or steaming may prove feasible, the foregoing are merely long-range possibilities. For the immediate future, the environmental control is going to have to be by in-mill dust reduction. There has been a great deal of work done on ventilating the American textile mill. A large proportion of the mills are air-conditioned. Exhaust ventilation has been applied to opening, blending, picking, and carding operations. A considerable amount of ventilation has been applied to spinning operations. There is no doubt that the textile mills in the United States are as comfortable as any in the world.

Unfortunately, the air conditioning has all been done without regard to potential hazards from dust of a size which can penetrate to the pulmonary air spaces. Temperatures and humidities are measured, but air cleanliness has been merely a matter of subjective appearance. Before-and-after measurements have not been made to see whether the conditions are better or worse than previously when card capacity is increased and ventilation is added. The dust collectors attached to card-room ventilation systems have not been provided with filters adequate to prevent recirculation of microscopic size dust. Air cleaning systems for recirculation of conditioned air have been designed to prevent accumulations on the coils rather than to prevent reentry of respirable dust.

The principles of air cleaning which are general knowledge where toxic particulates or mineral dusts are handled have not been applied in the textile industry. For example, there is no indication that "absolute" filters will ever be required for the recirculation of air in textile mills processing cotton, but there is reason to believe that something more than a "condenser" is needed. And the low efficiency filter media which have been universally used in textile mill ventilation systems are little more than lint condensers. As the pressure drop in the recirculating air filters builds up with fiber accumulation, the filters may become relatively efficient for the 0.5 to 5 μm dust particles which are of particular concern from a health protection point of view, but this is by happenstance rather than design. There are a number of filter media which are more than 90% efficient for 1 to 2 μm dust, and a 90% efficiency in each pass at this particle size would assure that recirculated air was always below the 0.05 mg/m^3 recommended by Lynch.[116] These more efficient filter media are customarily operated at low velocities, so the greatest problem in installing adequate recirculation air controls may not be filter cost or power cost but floor space for the size air filters required.

The object of the exhaust ventilation in card rooms must be twofold. The large quantities of fly and dirt must be removed from the air so that the manufacturing processes can operate properly. In addition, the escape of dust in amounts sufficient to affect health must be prevented. The ventilation systems so far installed have approached the former objective but not the latter. The reasonable first approach in dust control is enclosure. The manufacturing process does require access to the machinery, but enclosure has not been carried nearly to the extent that it can be while still permitting ready access.

With enclosure must come local exhaust ventilation. The better the enclosure the less need be the total amount of ventilation. But with the high linear speeds of the licker-in, the cylinder, and other parts of the card, air currents are created which must be overcome by the velocity of the air entering the enclosure. This is recognized implicitly in the Shirley pressure point and subsequent systems of card ventilation but has not, to this author's knowledge, been specified explicitly.

One way of providing specifications for control is to provide diagrams of adequate enclosures, with specification of total exhaust volume per machine, volume per individual takeoff, minimum slot or inlet velocities, and the like. This is undoubtedly the method that ventilation consultants and contractors would prefer. It gives quantities with which they are familiar, and the job is a straightforward one of providing sheet metal and of moving air. It is also the method easiest for government inspectors (who may soon be appearing where they have never been seen before) to use to determine whether a manufacturer is "in compliance;" the inspector needs only a Velometer and a scale.

The second method of specifying control is by performance of installed system. For cotton dust the specification might require that with all machinery running, the concentration of dust less than 15 μm in aerodynamic diameter not exceed, say, 0.5 mg/m^3. This is, as a matter of fact, exactly what the mill operator wants and exactly what is needed for health protection. But it requires more knowledge than the designer usually possesses. How much of this dust is produced by the system in the absence of controls? How much dust is coming from adjacent areas? What results have previous systems obtained? As the designer does not have these data, he can proceed in one of several ways. He may design the system as he has done previous systems, on the assumption that they are satisfactory. He may overdesign to the extent that costs would be prohibitive, and without knowledge of the problem he still might not meet specifications. In either event, the manufacturer must either have on his staff, or rent the services of, someone capable of determining the actual dust concentration in air before and after the installation.

Both methods of specification have their place in textile mill ventilation. What should be avoided is the letting of contracts for ventilation with neither detailed specifications for the enclosures, hoods, and airflows nor a guarantee of any specific degree of dust control. It is to be hoped that the industry associations, the workmen's compensation insurance carriers, the Industrial Ventilation Committee of the American Conference of Governmental Industrial Hygienists, or one of the textile engineering schools can come out with specific operation designs such as those in *Industrial Ventilation.*[122] It is also to be hoped that one or more of the ventilation equipment and design firms working with the textile industry will have the confidence to guarantee their systems to meet specified concentration limits.

For any dust control system installed in textile plants in the future, the job must be undertaken with a knowledge of the concentration of dust present. If the ventilation is in connection with improvements in machinery or operations, the machinery supplier should be prepared to furnish information on dust to be expected, and guarantees of performance might not be unreasonable. In any case, the relevant information can only be obtained from dust concentration measurements. It is important that these be made by a method which excludes fly and yet includes the entire size fraction of interest. The previously illustrated vertical elutriator sampler (available commercially) will produce samples which meet this requirement. The relatively small weights expected (1 mg/m^3 of dust will give only 3.5 mg of sample in an eight-hour shift) require analytical balances more sensitive than the average textile mill might be expected to have, but the weight determinations are simple for any laboratory having suitable equipment. The ash determination suggested previously is, at this time, for research only. A simple mass concentration is preferable for use with a limit or a specification; it is both simpler and less susceptible to widely varying conditions.

Medical Evaluation of Cotton Workers

Without a direct measurement for the environmental agent responsible for byssinosis, environmental measurements cannot be totally relied upon. In any occupational setting, the effects are finally measured only by comparing the health of the workers (and former workers) with that of others who have not followed the calling in question. Where cotton (or flax or soft hemp) is processed, it has been shown that effects on the respiratory tract are manifested in the first-day-back chest tightness and the reduction during the day of certain pulmonary function indices. The $FEV_{1.0}$ is probably the simplest of these respiratory function parameters to measure. Measurement of the $FEV_{1.0}$ before work and during the latter part of the shift on the first working day of the week will permit averaging results from all workers at the same operation and allow relatively small effects to be seen. It will also permit the identification of those whom Bouhuys and others have called "reactors" – individuals who appear to be extraordinarily susceptible to the effects of cotton dust and who probably would be better off not working with cotton.

If there is a significant decrease in the average $FEV_{1.0}$ during work, it is an indication that dust control is not adequate at that operation. If dust control is inadequate, it should be improved. But how does one define an extraordinarily susceptible person – or "reactor" – and given a definition, then what should be done? Clearly, if more than 1 worker in 20 is affected to the "reactor" level, however this may be defined, then the problem is not one of "hypersusceptibility." It is rather a case of the level of active agent in the air being too high.

What should be done with, to, or for those individuals who have already been affected adversely by cotton dust and are now working at dust levels which do not affect 95% of the workers? The problem arises when these individuals – often with no skill other than that at which they are working – number too many to be placed in non-exposure jobs at equal pay. They may be, in fact, disabled for their usual trade, but disability benefits from whatever source are an extremely poor substitute for gainful employment. This reviewer has not seen an acceptable solution published nor does he have one to offer.

Early identification of "reactors," with advice that work with cotton is undesirable for them, would no doubt be worth the effort. For those "reactors" who prefer working with cotton to the alternatives they see, discharge from cotton employment is not a socially acceptable solution. A problem remains.

Bouhuys, Gilson, and Schilling[123] have summarized a 1968 International Conference on Respiratory Disease in Textile Workers. A classification of functional grades in byssinosis from no demonstrable effect on lung function (FO) to a moderate to severe irreversible impairment of ventilatory capacity (F3) was proposed at that meeting. This grading system is based upon the difference in $FEV_{1.0}$ before and after work on the first working day of the week and upon the relationship of measured $FEV_{1.0}$ to predicted $FEV_{1.0}$ It forms the basis for the expanded scheme shown in the "Recommendations" section.

Respiratory Protective Devices

The simplest method of reducing exposure of workers to particulate air contaminants often appears to be the use of half-mask, filter-type respirators. However, use of respirators as a primary control measure is seldom, if ever, recommended by industrial hygienists or industrial physicians. Eight-hour, routine wearing of a mask proves not to be acceptable to the workers concerned. Facial irritation, discomfort, interference with speech, and breathing resistance are cited as reasons why respirators cannot be worn in such circumstances.

Respirators are ordinarily specified at temporary or occasional tasks which are not susceptible to dust reduction by engineering control. If a respirator need only be worn for brief periods, totaling no more than, say, one half hour per day, an effective respirator control program is possible. An effective respirator program involves not merely the issuing of respirators. Training of workers, fitting the respirators to the worker, and a maintenance program for the respirators are also necessary.[124] Where intermittent, high exposures are a problem, a respirator program should be considered.

No respirators are specifically approved for cotton dust by official agencies such as the U. S. Bureau of Mines or the National Institute for

Occupational Safety and Health. However, there is nothing unique in the filtration characteristics of the dust in cotton textile mills. Any respirator suitable for pneumoconiosis-producing dusts would also be suitable for cotton dust. In fact, some of the inexpensive disposable nuisance dust respirators might be satisfactory for certain applications. As with engineering control, the test should be performance. Given a worker with the characteristic symptoms and signs of byssinosis, does the respirator in question prevent a sensation of chest tightness and a drop in $FEV_{1.0}$ on the first working day of the week? Is it acceptable over the period of time it must be worn? If it meets these tests, then it is satisfactory for this worker, even though it lacks the performance characteristics necessary for a general overall approval.

No systematic, objective studies of use of respirators in textile mills have been reported. Such studies would be relatively easy, and a proper subject for cooperative projects involving textile mills, respirator manufacturers, and governmental agencies.

RECOMMENDATIONS ON BYSSINOSIS

The investigators who have participated in research studies on byssinosis have invariably recommended dust control. As information on the physiological effects on individual workers has accumulated, medical surveillance and management has also been recommended.[123] Although in great part based upon previous recommendations of Schilling, Bouhuys, and others, the recommendations of the organizing committee of the National Conference on Cotton Dust and Health held in Charlotte, North Carolina, in 1970 were made specifically for cotton textile mills in the United States. These recommendations concern dust sampling and control, identification of reactors, and medical surveillance and management, as discussed in the following sections.[125]

Dust Sampling and Control

A respirable dust level at which not more than 5% of exposed workers develop symptoms or have a decrease in $FEV_{1.0}$ must replace the present TLV of 1 mg/m^3 of total lint and dust. The vertical elutriator which samples particles with an aerodynamic diameter below 15 micrometers appears to be a simple and reproducible sampling technique. Vertical elutriators devised by Lynch and Lumsden are being used during current prevalence studies to provide essential comparisons between levels of respirable dust and symptoms of byssinosis and decreases in $FEV_{1.0}$ during exposure. Until such standards can be achieved it is recommended that:

1. Dust control should be applied to every cotton gin and those textile mills working with raw cotton. All machinery in opening, blending, picking, and carding should have the maximal enclosure consistent with the process and be provided with local exhaust ventilation adequate to keep dust concentrations inhaled by workers below recommended limits.
2. General ventilation of all operations subsequent to carding sufficient to keep inhalable dust concentrations below recommended values should be provided. All recirculated air should be filtered, with no more than 0.05 mg/m^3 of particulate matter in the return air.
3. Lint-free inhalable dust concentrations of a size below 15 micrometers, aerodynamic diameter, should be measured periodically in all mills processing raw cotton, using sampling devices such as the vertical elutriator cotton dust sampler.

Identification of Reactors

Schilling's grading system based on symptoms is the standard method for classifying byssinosis.

Grade 0 – No evidence of Monday chest tightness, or breathing difficulty.
Grade 1/2 – Occasional chest tightness on the first day of the working week.
Grade 1 – Chest tightness, on every first day of the working week.
Grade 2 – Chest tightness, every first and other days of the working week.
Grade 3 – Grade 2 symptoms accompanied by evidence of permanent incapacity from diminished effort tolerance and/or reduced ventilatory capacity.

Skin tests and chest x-rays do not identify reactors. Serological tests will not differentiate the exposed non-reactor from the exposed reactor. Inhalation challenges with aqueous extracts of cotton dust may establish an individual's sensitivity. However, the lack of a chemically defined test material and the non-specific effects of aerosols frustrate the use of challenge testing as a diagnostic measure.

In contrast, most persons with chest tightness show a decrement in expiratory flow rates after six hours of dust exposure after two or more days without exposure. Flow measured at 50% of vital capacity is sensitive to small changes. However, forced expiratory volume in one second ($FEV_{1.0}$) has been measured in most studies of byssinosis. Measurement of $FEV_{1.0}$ and forced vital capacity (FVC) before and after six hours of exposure to determine whether exposure caused a decrease should be included in surveys for byssinosis. The initial $FEV_{1.0}$ provides a baseline measurement to categorize ventilatory capacity and the presence of a decrease after exposure identifies reactors. A functional grading scheme based on that proposed by Bouhuys is recommended for assessment and management of the exposed worker. At least four forced expirations should be obtained and the two best $FEV_{1.0}$ values averaged for each observation. These criteria are summarized in Table 10.

Most individuals with grade I, II, and III byssinosis have a moderate to marked decrease of $FEV_{1.0}$ after six hours of dust exposure. However, evidence of no decrement in $FEV_{1.0}$ does not preclude the diagnosis of byssinosis in persons with symptoms. Asymptomatic individuals who have a reproducible decrement in $FEV_{1.0}$ of 10% or more should be managed as if they have byssinosis. All individuals with byssinosis must stop smoking cigarettes, particularly if they remain in a dusty area.

Medical Surveillance and Management

Every prospective employee in a textile plant spinning cotton yarn should have administered a modified British Medical Research Council respiratory questionnaire adapted for byssinosis to assess chronic bronchitis, byssinosis, dyspnea, smoking history, and occupational history. In addition, a baseline $FEV_{1.0}$ and FVC should be determined.

1. Prospective employees with recurrent or

TABLE 10

Recommendations for Classification and Management

Functional Severity	$FEV_{1.0}$* (% of predicted)	$\Delta FEV_{1.0}$** (%)	Interpretation of $FEV_{1.0}$	Recommendations for Employment
F_0	>80 (no evidence of chronic ventilatory impairment)	a) -4 to); or +	minimal or no acute effect of dust on ventilatory capacity	No change; annual $FEV_{1.0}$
		b) -9 to -5	moderate acute effect of dust on ventilatory capacity	No change; 6 mo. $FEV_{1.0}$
		c0 -10+	definite and marked acute effect of dust on ventilatory capacity	Move to lower risk area; 6 mo. $FEV_{1.0}$
F_1	60-79 (Evidence of slight to moderate irreversible impairment of ventilatory capacity)	a) -4 to 0; or +	As above	No change; 6 mo. $FEV_{1.0}$
		b0 -5+	As above	Move to lower risk area, 6 mo. $FEV_{1.0}$
F_2	<60 to severe irreversible impairment of ventilatory capacity)	—	—	Work requiring no cotton dust exposure, detailed pulmonary examination

*$FEV_{1.0}$ in absence of dust exposure (2 days or longer)
**Difference between $FEV_{1.0}$ before and after 6+ hours of cotton dust exposure on a first working day.

chronic respiratory disorders or grade 2+ dyspnea, and moderate to heavy cigarette smokers should be placed in low or no risk areas, If that is not possible, they should be advised to work elsewhere.

2. Employees with an $FEV_{1.0}$ which is 60 to 79% of the predicted $FEV_{1.0}$ should be placed in a low to no risk area and those below 60% of predicted should not be exposed to any cotton dust.

3. Within a month of employment, an $FEV_{1.0}$ before and after six hours of exposure on the first working day of a week should be obtained and the worker reassigned if necessary (see Table 10).

4. Workers exposed to high levels of dust, e.g., dust house, stripping, and grinding cards, should use efficient, comfortable personal air-filtering respirators or self-contained air supplies.

5. Workers with grade III byssinosis (those with pulmonary disability) should have detailed evaluations. A minimal workup should include a detailed clinical, environmental, and occupational history with information about the plant(s) in which he has been employed and his acute response to exposure. Also, a posteroanterior and lateral chest x-ray, measurement of FVC and $FEV_{1.0}$, and arterial blood gases at rest and during steady state exercise (treadmill walking) should be obtained. In addition, other tests for uniformity of ventilation, air, and gas transfer may be helpful.

6. These results should be used in the compensation process as dictated by state and/or federal laws.

CONCLUSION

Byssinosis is a condition affecting people working with raw cotton, flax, or soft hemp. Its effects grade from tightmess of the chest on some Mondays to total disability. It can be found in all countries where cotton is processed, including the United States. The agent(s) responsible for the effect has not been definitely identified but is in the non-lint (trash) fraction of cotton. The disease can be completely prevented by a combination of dust control and medical evaluation. It *will* be prevented when industry, medicine, and government work together to assure its elimination.

Acknowledgments

The author acknowledges the Industrial Health Foundation for an international bibliography of respiratory conditions in textile manufacturing, R. V. Andrews for library services, L. Ede and A. F. Henschel for editorial assistance, E. M. Ayer for constructive suggestions, and M. Jacobs for secretarial help.

REFERENCES

1. Ramazzini, B., *Diseases of Workers*, Ed. of 1713, Translated from the Latin text *De Morbis Artificum* by W. C. Wright, Hafner Pub. Co., New York, 1964, Chap. XXVII.

2. Bouhuys, A., Gilson, J. C., and Schilling, R.S.F., Byssinosis in the textile industry, *Arch. Environ. Health*, 21, 475, 1970.

3. Winslow, C. -E. A., The sanitary dangers of certain occupations, *J. Mass. Ass. Bds. Health*, 14, 92, 1904.

4. Kay, J. P., *New Eng. Med. Surg.* J. 1, 357, 1831. quoted in Thackrah, C. T., *The Effects of Arts, Trades and Professions*, 2nd ed., 1832, Livingstone, Edinburgh, 1957, 147.

5. Greenhow, E. H., *Third Report of the Medical Officer of the Privy Council*, 1860, London, App. VI.

6. Leach, J., Surat cotton as it bodily affects operatives in cotton mills. *Lancet*, 648, 1843. App. I in Report of the Departmental Committee on Dust in Card Rooms in the Cotton Industry, M.S.O., London, 1932, 63.

7. Caminita, B. H., Baum, W. F., Neal, P. A., Schneiter, P. A Review of the Literature Relating to Affections of the Respiratory Tract in Individuals Exposed to Cotton Dust, Public Health Bull. 297, U. S. Government Printing Office, Washington D.C., 1947.

8. Collis, E. L., Investigation into present health of cardroom strippers and grinders, Annual Report of the Chief Inspector for Factories, 1908, 203. Also, in Report of the Departmental Committee on Dust in Card Rooms in the Cotton Industry. Home Office, H.M.S.O., London, 1932, 65.

9. Jackson, J. (Chairman), Report of the Departmental Committee on Dust in Card Rooms in the Cotton Industry, Home Office, H.M.S.O., London, 1932.

10. Schilling, R.S.F., Hughes, J.P.W., and Dingwall-Fordyce, I, Disagreement between observers in an epidemiological study of respiratory disease, *Brit. Med. J.*, 1, 65, 1955.

11. Schilling, R.S.F., Vigliani, E. C., Lammers, E., Valic, F., and Gilson, J. C., A report on a conference on byssinosis, *Proc. XIV Int. Congr. Occup. Health, Madrid*, 2, Exerpta Medica, Amsterdam, 1963, 137.

12. Gilson, J. C., Stott, H., Hopwood, B.E.C., Roach, S. A., McKerrow, G. B., and Schilling, R.S.F., Byssinosis: The acute effect on ventilatory capacity of dusts in cotton ginneries, cotton, sisal, and jute mills. *Brit. J. Ind. Med.*, 19, 9, 1962.

13. Bouhuys, A., Wolfson, R. L., Horner, D. W., Brain, J. D., and Zuskin, E., Byssinosis in cotton textile workers. Respiratory survey of a mill with rapid labor turnover, *Ann. Intern. Med.*, 71, 257, 1969.

14. Mekky, S., Roach, S. A., and Schilling, R.S.F., Byssinosis among winders in the cotton textile industry, *Brit. J. Industr. Med.*, 24, 123, 1967.

15. Belin, L., Bouhuys, A., Hockstra, W., Johansson, M. -B., Lindell, S. -E., and Pool, J., Byssinosis in cardroom workers in Swedish cotton mills, *Brit. J. Industr. Med.*, 22, 101, 1965.

16. McKerrow, C. B., McDermott, M., Gilson, J. C., and Schilling, R.S.F., Respiratory function during the day in cotton workers: A study in byssinosis, *Brit. J. Industr. Med.*, 15, 75, 1958.

17. McKerrow, C. B. and Schilling, R.S.F., A pilot enquiry into byssinosis in two cotton mills in the United States, *J. A. M. A.*, 177, 850, 1961.

18. Walford, J., Lammers, B., Schilling, R.S.F., van den Hoven van Genderen, D., and van den Veen, Y. G., Diurnal variation in ventilatory capacity, an epidemiological study of cotton and other factory workers employed on shift work, *Brit. J. Industr. Med.*, 23, 142, 1966.

19. Guberan, E., Williams, M. K., Walford, J., and Smith, M. M., Circadian variation of FEV in shift workers, *Brit. J. Industr. Med.*, 26, 121, 1969.

20. Schilling, R.S.F., Hughes, J.P.W., Dingwall-Fordyce, I., and Gilson, J. C., An epidemiological study of byssinosis among Lancashire cotton workers, *Brit. J. Industr. Med.*, 12, 217, 1955.

21. Molyneux, M. K. B. and Tombleson, J. B. L., An epidemiological study of respiratory symptoms in Lancashire mills, 1963-66,| *Brit. J. Industr. Med.*, 27, 225, 1970.

22. Barbero, A. and Flores, R., Dust disease in hemp workers, *Arch.Environ. Health*, 14, 529, 1967.

23. Bouhuys, A., Barbero, A., Lindell, S. -E., Roach, S. A., and Schilling R.S.F., Byssinosis in hemp workers, *Arch. Environ. Health*, 14, 533, 1967.

24. Bouhuys, A., van de Woestijne, K. P., Kane, G., and van Wayenburg, J., Respiratory mechanics and dust exposure in byssinosis, *J. Clin. Invest.*, 49, 106, 1970.

25. Bouhuys, A., Barbero, A., Schilling, R.S.F., van de Woestijne, K. P., Kalavsky, S., Kane, G., Toren, M., and van Wayenburg, J., Chronic respiratory disease in hemp workers, *Amer. J. Med.*, 46, 526, 1969.

26. Medical Advisory Committee to the Social Security Administration, Wright, G. W., Chairman, Disability Evaluation Under Social Security, SSI-89, U.S. Government Printing Office, Baltimore, 1969.

27. Thackrah, C. T., *The Effect of Arts, Trades and Professions, on Health and Longevity*,2nd ed., 1832, republished in *The Life, Work and Times of Charles Turner Thackrah* by A. Meiklejohn, Livingstone, Edinburgh, 1957, 78.

28. Ritter, W. L. and Nussbaum, M. A., Occupational illnesses in cotton industries. I. "Cotton Fever", *The Mississippi Doctor*, 22,96, Sept. 1944.

29. Middleton, E. L., Weavers cough, *J. Industr. Hyg.*, 8, 428, 1926.

30. Spolyer, L. W., Respiratory disturbance from low-grade cotton dusts, *Monthly Bull. Indiana State Board of Health*, 44, 135, 1941.

31. Neal, P. A., Schneiter, R., and Caminita, B. H., Report on acute illness among rural mattress makers using low-grade, stained cotton, *J.A.M.A.*, 119, 1074, 1942.

32. Kerr, T., The cotton plant, in *American Cotton Handbook*, 3rd ed., Vol 1, Hamby, D. S., Ed., Interscience, New York, 1965, Chap. 2.

33. Graham, C. O., Jr., Kingsbery, E. C., and Rusca, R. A., Factors influencing dust levels during cotton processing, *Trans. National Conference on Cotton Dust and Health*, University of North Carolina, Chapel Hill,1971.

34. Agee, J. and Evans, W., *Let Us Now Praise Famous Men*, Houghton Mifflin, Boston, 1960

35. Martin, W. J., Harvesting and ginning, in *American Cotton Handbook*, 3rd ed., Vol 1, Hamby, D. S., Ed., 1965, Chap. 4.

36. Shaw, C. S. and Franks, G. N., Cleaning and extracting, in *Handbook for Cotton Ginners*, U.S. Dept. of Agric. Handbook 260, U.S. Government Printing Office, Washington D.C., 1964.

37. Khogali, M., A population study in cotton ginnery workers in the Sudan, *Brit. J. Industr. Med.*, 26, 308, 1969.

38. Batawi, M. A. El, Byssinosis in the cotton industry of Egypt, *Brit. J. Industr. Med.*, 19, 126, 1962.

39. Barnes, R. and Simpson, G. R., Ventilatory capacity changes on exposure to cotton dust, *Med. J. Australia*, 897, 1968.

40. Occupational Safety and Health Act of 1970, P.L. 91-596, 84 Stat. 1590 et seq.

41. Griffin, A. C., Effects of gin machinery on cotton quality, in *Handbook for Cotton Ginners*, Agric. Handbook 260. U.S. Government Printing Office, Washington, 1964.

42 Martin, F. H., Opening and picking, in *American Cotton Handbook*, 3rd ed., Vol. 1, Hamby, D.S., Ed., 1965,Chap. 7.

43. Bogdon, J. F. Carding and combing, in *American Cotton Handbook*, 3rd ed., Vol. 1, Hamby, D.S., Ed., 1965, Chap. 8.

44. Hance, L. H., Spinning, in *American Cotton Handbook*, 3rd ed., Vol 1, Hamby, D.S., Ed., 1965, Chap 10.

45. Unattributed comment, *Trans. National Conference on Cotton Dust and Health*, University of North Carolina, Chapel Hill, 1971.

46. Schilling, R.S.F., The history of byssinosis and the British experience, *Trans. National Conference on Cotton Dust and Health*, University of North Carolina, 1971.

47. Pugh, D. F., Letter to Texas State Department of Health, in *Control and Disposal of Cotton Ginning Wastes*, PHS Pub. 999 AP31, Cincinnati, 1967.

48. Yaffe, C. D. and Jones, H. H., *Noise and Hearing*, PHS Publication 850, U. S. Government Printing Office, Washington, D.C., 1961.

49. Walsh-Healy regulations on Noise, 41 CFR 50.204.10.

50. Smiley, J. A., Background to byssinosis in Ulster, *Brit. J. Industr. Med.*, 18, 1, 1961.

51. Bouhuys, A., van Duyn, J., and van Lennep, H. J., Byssinosis in flax workers, *Arch. Environ. Health*, 3, 499, 1961.

52. Anon., Byssinosis in flax workers, *Brit. Med. J.*, 1, 1375, June 4, 1966.

53. El Batawi, M. A. and Hussein, M., Endemic byssinosis in an Egyptian village, *Brit. J. Industr. Med.*, 21, 231, 1964.

54. Bouhuys, A., Hartogenesis, E., and Korfage, H.J.H., Byssinosis Prevalence and flax processing, *Brit. J. Industr. Med.*, 20, 320, 1963.

55. Ferris, B. G., Anderson, D. O., and Burgess, W. A., Prevalence of respiratory disease in a flax mill in the United States, *Brit. J. Industr. Med.*, 19, 180, 1962.

56. McKerrow, C. B., Gilson, J. C., Schilling, R.S.F., and Skidmore, J. W., Respiratory function and symptoms in rope makers, *Brit. J. Industr. Med.*, 22, 204, 1965.

57. Perkel, G., Panel presentation in current studies of the problem, *Trans. of the National Conference on Cotton Dust and Health*, University of North Carolina, Chapel Hill, 1971.

58. Hill, A. B., Sickness amongst operatives in Lancashire cotton mills, with special reference to the cardroom, Rep. Ind. Health Res. Board 59, H.M.S.O., London, 1930.

59. Prausnitz, C., Investigations on Respiratory Dust Disease in Operatives in the Cotton Industry, Medical Research Council, H.M.S.O.,London, 1936, 12.

60. Schilling, R. and Goodman, N., Cardiovascular disease in cotton workers: Part I, *Brit. J. Industr. Med.*, 8, 77, 1951.

61. Britten, R. H., Bloomfield, J. J., and Goddard, J. C., *The Health of Workers in a Textile Plant*, Pub. Health Bull. 207, U. S. Government Printing Office, Washington, D. C., 1933.

62. Thompson, L. R., Russell, A. E., and Bloomfield, J. J., The Health of Workers in DustyTrades: General Statement and Summary of Findings, Pub. Health Bull. 208, U. S. Government Printing Office, Washington, D.C., 1933.

63. Jacobs, J., *The Economy of Cities*, Random House, New York, 1969.

64. Schilling, R. S. F., Goodman, N., and O'Sullivan, J. G., Cardiovascular disease in cotton workers, Part II: A clinical study with special reference to hypertension, *Brit. J. Industr. Med.*, 9, 146, 1952.

65. Schilling, R.S.F., The epidemiology of byssinosis - adventure and misadventure, *J. Occ. Med.*, 1, 33, 1959.

66. Roach, S. A. and Schilling, R.S.F., A clinical and environmental study of byssinosis in the Lancashire cotton industry, *Brit. J. Industr. Med.*, 17, 1, 1960.

67. Schilling, R.S.F., Byssinosis in the British cotton textile industry, *Brit. Med. Bull.*, 7, 52, 1950.

68. Schilling, R.S.F., Byssinosis in cotton and other textile workers, *Lancet*, 2, 261, and 319, 1956 (two parts).

69. Tuypens, E., Byssinosis among cotton workers in Belgium, *Brit. J. Industr. Med.*, 18, 117, 1961.

70. Lammers, B., Schilling, R.S.F., and Walford, J., with Meadows, L., Roach, S. A., Van den Hoven, van Genderen, D., Van den Vean, Y. G., and Wood, C. H., A study of byssinosis, chronic respiratory symptoms and ventilatory capacity in English and Dutch cotton workers with special reference to atmospheric pollution, *Brit. J. Industr. Med.*, 21, 124, 1964.

71. Dingwall-Fordyce, I and O'Sullivan, J. G., Byssinosis in the waste cotton industry, *Brit. J. Industr. Med.*, 23, 53, 1966.

72. Zuskin, E., Wolfson, R. E., Harpel, G., Welborn, J. W., and Bouhuys, A., Byssinosis in carding and spinning workers, *Arch. Environ. Health*, 19, 666, 1969.

73. Schrag, P. E. and Gullett, A. D., Byssinosis in cotton textile mills, *Amer. Rev. Resp. Dis.*, 101, 497, 1970.

74. Gupta, K. C., Byssinosis in textile industry of Ahmenedabad, Proc. Second Asian Conference on Occupational Health, Calcutta, India, 1958.

75. Chwatt, M. and Mordish, M., Respiratory symptoms and byssinosis among textile workers in Israel *Proc. XV Int. Cong. Occup. Med.*, Vol. 3, 277, Wien, 1966.

76. Valic, F., Panel presentation in current status and studies of the problem, *Trans. National Conference on Cotton Dust and Health*, University of North Carolina, Chapel Hill, 1971.

77. Middleton, E. L., Dust in cotton card rooms, *J. Industr. Hyg.*, 8, 436, 1926.

78. Cayton, H. R., Fuiness, G., and Maitland, H. B., Studies on cotton dust in relation to byssinosis, Part II: Skin tests for allergy with extracts of cotton dust, *Brit. J. Industr. Med.*, *9, 186, 1952.*

79. Gernex-Rieux, C., Voisin, C., Jacob, M., Corsin, M., Corsin, L., and Lefevre, J., Enguete allergologizue chez 40 ouvriers de filature de coton souffrant de troubles dyspneique au travail, *LePoumon et le Couer,* 18, 651, 1962.

80. Massoud, A. and Taylor, G., Byssinosis: Antibody to cotton antigens in normal subjects and in cotton card-room workers, *Lancet*, 2, 607, 1964.

81. Cavagna, G., Foa, V., and Vigliani, E. C., Effects in man and rabbits of inhalation of cotton dust or extracts and purified endotoxins, *Brit. J. Industr. Med.*, 26, 314, 1969.

82. *Proteolytic Enzymes in Cotton Mill Dust – A Possible Cause of Byssinosis*, Medical Series Bulletin No. 18-71, Industrial Health Foundation, Pittsburgh, 1971.

83. Hitchcock, M., Piscitelli, D. M., and Bouhuys, A., Histamine release from human lung by a component of cotton bracts, (Abstract), *Fed. Proc.*, 30, 682, Abs., 1971.

84. Macdonald, A. D. and Prausnitz, C., The histamine problem in Investigations on Respiratory Dust Disease in Operatives in the Cotton Industry, H.M.S.O., London, 1936, 26.

85. Maitland, H. B., Heap, H., and Macdonald, A. D., The presence of histamine in cotton dust, The Report of the Departmental Committee on Dust in Card Rooms in the Cotton Industry, H.M.S.O., London, 1932, Appendix VI.

86. Haworth, E. and Macdonald, A. D., Histamine in cotton dust and in blood of cotton workers, *J. Hyg.*, 37, 234, 1937.

87. Antweiler, H., Observations about a histamine liberating substance in cotton dust, *Ann. Occup. Hyg.*, 1, 152, 1960.

88. Bouhuys, A., Lindell, A. -E., and Lundin, G., Experimental studies on byssinosis, *Brit. Med. J.*, 1, 324, 1960.

89. Bouhuys, A. and Lindell, S. -E., Release of histamine by cotton dust extracts from human lung tissue *in vitro, Separatum Experientia,* 17, 211, 1961.

90. Bouhuys, A., Response to inhaled histamine in bronchial asthma and in byssinosis, *Rev. Resp. Dis.*, 95, 89, 1967.

91. Davenport, A. and Paton, W.D.M., The pharmocological activity of extracts of cotton dust, *Brit. J. Industr. Med.*, 19, 19, 1962.

92. Nicholls, P. J., Some pharmacological actions of cotton dusts and other vegetable dusts, *Brit, J. Industr. Med.*, 19, 33, 1962.

93. Nicholls, P. J., Nicholls, G. R., and Bouhuys, A., Histamine release by compound 48/80 and textile dusts from lung tissue *in vitro*, in *Inhaled Particles and Vapours,* II, Davies, C. N., Ed., Pergamon Press, Oxford, 1967, 69.

94. Bouhuys, A., and Nicholls, P. J., The effect of cotton dust on respiratory mechanics in man and in guinea pigs, in *Inhaled Particles and Vapours,* II, Davies, C. N., Ed., Pergamon Press, Oxford, 1967, 75.

95. Noweir, M. H., Panel presentation in Current status and studies of the problem, *Trans. National Conference on Cotton Dust and Health*, University of North Carolina, Chapel Hill, 1971.

96. Silverman, L. and Viles, F. J., Jr., The determination of cottton textile dusts in air, *Textile Res. J.*, 20, 109, 1950.

97. Taylor, Geoffrey, Massoud, A. A. E., and Lucas, F., Studies on the aetiology of byssinosis, *Brit. J. Industr. Med.*, 28, 143, 1971.

98. Bouhuys, A., Schilling, R.S.F., and van de Woestijne, K. P., Cigarette smoking, occupational dust exposure and ventilatory capacity, *Arch. Environ. Health*, 19, 793, 1969.

99. Merchant, J. A., Kilburn, K. H., Lumsden, J. C., and Hamilton, J., Byssinosis and chronic bronchitis among cotton textile workers, in preparation.

100. Gandevia, B., Studies of ventilatory capacity and histamine response during exposure to isocyanate vapour in polyurethane foam manufacture, *Brit. J. Industr, Med.*, 20, 204, 1963.

101. Peters, J. M., Murphy, R.L.H., Pagnotto, L. D., and Van Ganse, W. F., Acute respiratory effects in workers exposed to low levels of toluene diisocyanate (TDI), *Arch. Environ. Health*, 16, 642, 1968.

102. Ayer, H. E., Fitzpatrick, M. S., and Scheel, L. D., Report of Survey: Airborne Diisocyanate during Spray application of Polyurethane Foam, TR-2, Division of Occupational Health, Cincinnati, 1963.

103. Bruckner, H. C., Avery, S. B., Stetson, D. M., Dodson, V. N., and Ronayne, J. J., Clinical and immunological appraisal of workers exposed to diisocyanates, *Arch. Environ. Health*, 16, 619, 1968.

104. Peters, J. M., Murphy, R.L.H., and Ferris, B. G., A longitudinal study of workers exposed to toluene diisocyanate (TDI) presented at the XVI International Congress on Occupational Health, Tokyo, 1969.

105. Bouhuys, A. and Peters, J. M., Control of environmental lung disease, *New Eng. J. Med.*, 283, 573, 1970.

106. Merchant, J. A., Panel presentaion in Current status and studies of the problem, *Trans. National Conference On Cotton Dust and Health*, University of North Carolina, Chapel Hill, 1971.

107. Hatch, T. F. and Gross, P., *Pulmonary Deposition and Retention of Inhaled Aerosols*, Academic Press, New York, 1964.

108. Albert, R. E., Lippmann, M., Spiegelman, J., Strehlow, C., Briscoe, W., Wolfson, P., and Nelson, N., The clearance of radioactive particles from the human lung, in *Inhaled Particles and Vapours*, II, Davies, C. N., Ed., Pergamon Press, Oxford, 1967, 361.

109. Rollins, M. L., The cotton fiber, in *American Cotton Handbook*, Vol. 1, Hamby D. S., Ed., Interscience, New York, 1965.

110. Timbrell, V., The Inhalation of Fibrous Dusts. Human Exposure to Asbestos: Dust control and standards, *Ann. N. Y. Acad. Sci.*, 132, Art 1, 255, 1965.

111. Wright, B. M., A size-selecting sampler for airborne dust, *Brit. J. Industr. Med.*, 11, 284, 1954.

112. Elkins, H., Ed., Documentation of Threshold Limit Values, Amer. Conference of Governmental Industrial Hygienists, Cincinnati, 1971.

113. Harris, W. B. and Eisenbud, M., Dust sampler which simulates upper and lower lung deposition, *Arch. Ind. Hyg. Occup. Med.*, 8, 446, 1953.

114. Lippmann, M. and Harris, W. B., Size-selective samplers for estimating "respirable" dust concentrations, *Health Phys.*, 8, 155, 1962.

115. Orenstein, A. J., Ed., *Proc. Pneumoconiosis Conf., Johannesburg, 1959,* J. and A. Churchill, Ltd., London, 1960.

116. Lynch, J. R., Air sampling for cotton dust, Trans. National Conference On Cotton Dust and Health, University of North Carolina, Chapel Hill, 1971.

117. Committee on Threshold Limit Values for Airborne Contaminants, Threshold Limit Values for 1970, American Conference of Governmental Industrial Hygienists, Cincinnati, 1970.

118. Roach, S. A., Dust levels and disease, Trans. National Conference on Cotton Dust and Health, University of North Carolina, Chapel Hill, 1971.

119. McKerrow, C. B., Roach, S. A., Gilson, J. C., and Schilling, R.S.F., The size of cotton dust particles causing byssinosis: an environmental and physiological study, *Brit. J. Industr. Med.*, 19, 1, 1961.

120. Wood, C. H. and Roach, S. A., Dust in card rooms: A continuing problem in the cotton-spinning industry, *Brit. J. Industr. Med.*, 21, 180, 1964.

121. Merchant, J., Preprocessing cotton to prevent byssinosis in a model cardroom. Presented before the American Thoracic Society, Los Angeles, Calif., May 19, 1971.

122. Committee on Industrial Ventilation, Industrial Ventilation: A Manual of Recommended Practice, American Conference of Governmental Industrial Hygienists, Lansing, 1970.

123. Bouhuys, A., Gilson, J. C., and Schilling, R.S.F., Byssinosis in the textile industry, *Arch. Environ. Health*, 21, 475, 1970.

124. American National Standard Practices for Respiratory Protection, Z88-2, American National Standards Institute, New York, 1969.

125. Editorial, Status of byssinosis in the United States; a summary of the National Conference on Cotton Dust and Health and the recommendations of the organizing committee; *Arch. Environ. Health*, 23, 1971, in press.