III. BIOLOGIC EFFECTS OF EXPOSURE

Extent of Exposure

The growing of cotton and its processing into textiles and other products are among the major agricultural and manufacturing industries of the United States. Between August 1, 1972 and July 31, 1973, 13.2 million bales (about 3.3 million tons) of cotton were produced in the United States. About 7.4 million bales were processed in this country. [1] The number of workers involved in cotton fiber processing in 1973 was estimated at 800,000 by the Occupational Safety and Health Administration. [2]

The production and manufacture of cotton and cotton products involve highly complex equipment and processes. These have been described in detail in the American Cotton Handbook [3] from which much of the following has been taken.

(a) Growing and Harvesting

Cotton plants are grown in rows, about a meter apart, with six to twenty plants to each running meter along the row. [4] The fruiting branches on which the cotton fruit or boll grows produce one or two bolls on each 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. When the boll cracks open the lint fluffs out and the boll is ready for picking.

In the United States prior to World War II cotton was handpicked. [5] Since then there has been a gradual transition to machine-picking until in 1969 more than 97% of the cotton was machine-picked. 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 handpicking. Two gathering shoes form a V-shaped opening at the front of the picker 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. 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 the stem. The amount of trash brought in with the seed cotton is 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 however, and the relatively slow rate of cotton harvesting combined with the seasonal nature of the operation should prevent worker inhalation of large amounts of dust.

(b) 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. [6] After the lint is separated and cleaned, it goes to a press box where the cotton bale is formed.

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 cotton leaving the gin has been cleaned to an optimal degree based on current ginning methods. Cleaning improves the grade, and thus the price received for cotton. Cleaning, however, also decreases yarn strength. [7] There is therefore a practical limit to the amount of foreign matter that can be removed at the gin using present equipment.

Little information is available that would give the relative amount of material in ginned cotton that might contain the biologically active agent causing byssinosis, a respiratory disease of cotton workers. Because

inhalation of an aerosolized aqueous extract from bracts will produce byssinosis symptoms [8] and because bracts are a principal component of cotton trash, the total trash content must be of concern. Graham et al [5] of the United States Department of Agriculture's Southern Regional Research Laboratory reported the analysis of trash content of cotton of widely varied grades and staple length. The results are presented in Table XII-1. Eighty-seven percent of the bales had a trash content ranging from 1-4% (average 1.6%) as determined by the Shirley Analyzer method, [9] an analytical method used by the industry to determine the nonlint or trash content of cotton. In processing these bales, an nonvisible waste loss of 0.95% was experienced. This loss is composed of fine dust and fiber particles which escape the collection and air filtration systems. The cotton used by a particular mill will depend upon the product being manufactured. Graham pointed out that a tobacco cloth and 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 middling grade, 1-1/8 inch to 1-1/2 inch staple length. Cotton grades are, from high to low, as follows: "middling fair", "strict good middling", "good middling", "strict middling", "middling", "strict low middling", "low middling", "strict good ordinary", "good ordinary".

The difference that trash content (Table XII-2) can make is shown in the waste produced from two 1-3/32 inch staple length cottons, one a strict middling grade and the other a strict good ordinary. 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 difference appeared in all sections of the card from which waste was collected.

(c) Opening, Cleaning, 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. [10] 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 of cotton 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 air 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 dust of small particle size

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.

(d) 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 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.

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 many narrow, cast iron flats, each covered with card clothing. The flats move very slowly - only centimeters per minute - so that compared to the rapidly moving cylinder they are standing still. The carding action to open and straighten the cotton fibers is therefore 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 web to a round sliver about 2.5 cm in diameter. The sliver 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. [5]

A major source of dust has been the "stripping and grinding" of card clothing. Strippers and grinders, invariably had the most severe byssinosis problem of any of the cardroom occupations. In recent years hand stripping has been largely replaced by vacuum stripping where metallic clothing is used on the cylinder, the frequency of hand stripping has been further reduced from one to three times every eight-hour shift to once every 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 have been only a few studies of dust concentrations before and after modification and/or exhaust system installation. Wood and Roach [11] investigated environmental conditions in four cardrooms to determine the effect of the latest system of exhaust ventilation. They found marked improvement insofar as total dust concentrations were concerned, but little change in the concentrations of the fine and medium sized fractions, ie, dust less than 2 mm in size.

Another relatively recent innovation is the installation of crush rolls on cards in 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 appears to be in spinning. [12] 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 lint-free dusts which may be added by this process is not known. Because the active chemical agent in the dust is likely from the bract, a very friable leaf, the proportion of active agent in dust at subsequent operations may also be increased by the crush rolls.

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

(e) 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 do not, it is believed, [5] contribute seriously to the dust load in the room.

Air is drawn through the suction system and is returned to the room through filters. As in other textile mill air cleaning systems, the filtration has not been designed to control respirable dust particles.

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 [5], but environmental dust levels produced by this equipment have not been reported.

(f) 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 ten or on the order of fifty. [12] As the yarn is spun to impart the twist, it goes through a traveler on a ring. Traveler speeds may be as high as 3,500 cm/sec. The combination of considerable reduction in 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 fibers are also released 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 occurring in the modern mill. This has been noted by several investigators. [13-16]

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. The dust problems of this type of spinning can be expected to be different from those of ring spinning.

(g) Winding

The lengths of yarn wound 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 the 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 in winding operations.

(h) 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.

(i) 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. [17-19]

(j) Flax, Hemp, Jute, and Sisal

Epidemiologic studies of workers exposed to dust from vegetable fibers other than cotton have shown no consistency between the fibers studied. While soft hemp and flax have been reported to cause byssinosis, [20-30] hard hemp and sisal have given equivocal results, and no byssinosis has been found in jute workers. [31,32] Although environmental limits recommended in this document are not applicable, medical evaluations of

flax, hemp, jute, and sisal workers should be performed along with determination of dust concentrations to which they are exposed.

In summary, the principal sources of dust in cotton textile manufacture are in the yarn mills with the fiber preparation and carding areas usually producing the highest amount of dust, followed by winding and spinning. Slashing and weaving are of lesser hazard. Other mills using cotton, eg, mattress making, will have exposures similar to (and possibly worse than) fiber preparation and carding in cotton textile manufacture. Dust exposures in cotton ginning may be high, but neither the level nor the character of the dust have yet been well evaluated.

Historical Reports

Descriptions of the health conditions in the textile mills of the past have been vivid. Ramazzini, writing in 1713 of "diseases of dressers of flax and hemp" observed that "a foul and poisonous dust flies out from these materials, enters the mouth, then the throat and lungs, makes the workers cough incessantly, and by degrees brings on asthmatic troubles." [33]

(a) Byssinosis

As with many occupational diseases, the prevalence of unusual symptoms have been first reported by local clinicians. Kay [34] in describing "Spinner's Phthisis" in 1831 wrote of "Many cases which have presented themselves at the Ardwick and Ancoat's Dispensary" (in Manchester.)

According to Caminita et al, [35] similar conditions were reported even earlier, in 1822 and 1827, in French publications. The disease was

mentioned by Greenhow [36] in the 1860 report of the Medical Officer of the Privy Council.

Leach, writing in 1863 [37] of Surat cotton used in low, narrow, ill-ventilated rooms, observed that the respiration of workers was affected. He reported that the willowers and scutchers suffered in the same manner as the cotton mixers. The strippers, grinders, and cardroom hands were also affected and a carder seldom lived beyond forty years of age. Drawers and rovers suffered very little while the mule and throstle hands looked pale and sickly but were lively, cheerful, and active. The packers were generally very healthy.

The fact that problems were mainly in the cardroom 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 cardrooms. Collis [38] examined 126 men so employed in Blackburn, and found 73.8 percent complaining of, or suffering from, an asthmatic condition, due to inhalation of dust." Table XII-3 from Collis relates the health effects to coarseness of cotton processed. [38]

Collis also noted the association between length of employment and prevalence and reported that "The average period of employment of 126 men examined was 14.6 years; of 33 men found unaffected it was 8.8 years."

In addition Collis [38] described the symptoms and course of the disease:

"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 flesh colour 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. [39] In response to the question "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 mucous 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 week-end. It does not cause disablement 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 by 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 described 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.

Hill, [40] comparing sickness rates during the period of 1923 to 1927 found that male cardroom operatives had two to three times as many respiratory illnesses as ringroom or warehouse workers in the mills. Female cardroom operatives had a smaller excess of respiratory illness, about 60-75% above the ring spinners' rates. Prausnitz [41] compiled this sickness data into the graph shown in Figure XII-1.

The Departmental Committee on Compensation for Card Room Workers [39] reexamined the situation and found that respiratory illnesses among cardroom workers, and blowroom 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 Hill. [40]

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 year 1921-1923. It was noted that the bronchitis mortality of cotton strippers and grinders in 1921-1923 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 [42] noted that an apparent excess of cardiovascular-renal deaths was actually due to a change in coding procedures of death certificates and many actually belonged in the respiratory and cor pulmonale categories.

In the United States, studies by the US Public Health Service [43,44] in 1933 led to the conclusion that dust concentrations in cotton mills were too low to adversely affect the health of workers. In no

country was the proportion of textile workers affected by byssinosis known with certainty.

(b) Other Respiratory Conditions

Specific conditions other than byssinosis have been noted in workers exposed to cotton dust. Caminita et al [35] classified the conditions of workers exposed to cotton and other fiber dusts into three general illnesses: byssinosis, mill fever, 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 eighteen accounts from English, German, French, Dutch, Russian, and American literature dating back to Thackrah's [24] account in 1832. Middleton [45] stated that weaver's cough which occurred several times in England between 1900 and 1926 was due apparently to inhalation of fungus from mildewed thread.

Effects on Humans

(a) Byssinosis

Of the occupational diseases affecting workers exposed to cotton dust byssinosis is by far the most important. In 1955 Schilling [46] devised a grading system for this disease which has been used by the majority of other recent investigators. 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 Monday only.

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

Subsequently, the grading of byssinosis was expanded [47] by adding

Grade 1/2 - 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.

*Arabic numbers are now frequently used to denote the grades of byssinosis.

The Monday feeling of tightness in the chest is generally accompanied by a decrease in the forced vital capacity; the forced expiratory volume in the first second (FEV 1) 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 forty times the FEV 0.75. [31] The average difference

between Monday morning and Monday evening FEV 1 for those reporting Monday tightness has been noted in two surveys as 0.19 liter [48] and 0.21 liter. [49] Where FEV 0.75 was measured, average decreases reported were 0.26 liter, [50] 0.19 liter, [31] 0.28 liter, [51] 0.22 liter, [52] and 0.25 liter. [53] The differences in FEV 1 or FEV 0.75 is somewhat less in those cardroom workers not reporting symptoms, and much less in those not exposed to dust. For cotton workers without byssinosis, cough, or phlegm, a smaller decrease in FEV 0.75 (with occasional rise in FEV 0.75 among workers on the 6:00 A.M. - 2:00 P.M. shift) has been reported. [53] A subsequent study of shift workers without pulmonary diseases showed an increase of 0.15 liter in FEV 1 during the morning shift and an average fall of 0.05 liter in the afternoon shift, with no appreciable change on the night shift. [54] An average decrease in FEV 0.75 of about 0.05 liter a year has been reported for both cotton workers without byssinosis and the controls. [13,55]

Berry et al [56] found that the mean Monday fall in FEV was higher in cotton than in synthetic fiber mills and was correlated with present dust levels. The annual decline in FEV was not found to be related to symptoms of byssinosis or bronchitis, to dust levels, or bioactivity of the dust. Fox et al [16] reported in 1973 that even symptom-free cotton-workers showed a 10% excess in the rate of the deterioration of FEV 1 with age.

Imbus and Suh [17] found that "FEV 1, (P)% [P=predicted normal FEV] does not tend to decrease with length of employment in nonsmoking nonbyssinotic males, whereas in nonsmoking byssinotic males it begins to drop off sharply after almost 18 years of employment. Nonbyssinotic

smokers always have a lower FEV 1, which tends to become increasingly lower with time. The values for smoking byssinotics are much lower than those for nonsmoking byssinotics for approximately 20 years; then the difference narrows."

According to the Recommendations of the 1970 National Conference on Cotton Dust and Health [57] "Most individuals with Grade 1,2, and 3 byssinosis have a moderate to marked decrease of FEV 1 after six hours of dust exposure. However the evidence of no decrement in FEV 1 does not preclude the diagnosis of byssinosis in persons with symptoms. Asymptomatic individuals who have a reproducible decrement in FEV 1 of 10% or more should be managed as if they have byssinosis."

Braun et al [58] criticized the criteria based on tightness of chest as relying on subjective findings. They consider a drop of 10% in FEV 1, during the workday as being more significant. As far as chronic or progressive effect is concerned, they feel that minimal evidence should be an FEV 1 of <80% of predicted value, plus either loss in FEV 1 during the shift or tightness in the chest.

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. [20-22] They found that former hemp workers, ages 50-69, had substantially lower respiratory function than the controls. [23] Thirty-one percent had an FEV 1 less than half of predicted versus only 4% of the control workers in that age group. Other comparisons gave similar results. About 1/6 of these older workers had FEV 1 <1 liter. The Social Security Administration's [59] standard for total disability from

respiratory causes uses as the lower limit an FEV 1 of 1-1.4 liters, depending on height. Accordingly, these Spanish workers could have been classified as disabled under the US criteria.

The studies of Bouhuys and his collaborators [20-22] 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 between the workers and controls in the age groups 20-29, 30-39, or 40-49. If this had been other than an ancient, traditional operation, the large differences in respiratory function between the older (50-69) age groups might have been attributed to a great difference in past working conditions. In the reduction in size 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 had, apparently, chosen to leave the industry. Careful analysis of smoking habits and respiratory function also disclosed the surprising fact that of those hemp workers who smoked more had a higher average FEV 1 than the non- or light-smoking hemp workers. The ex-smokers had a much lower FEV 1 than those who still smoked. A selective mechanism had possibly influenced the smoking or degree of smoking, so that those most affected by the hemp dust smoked little or had completely ceased to smoke.

According to Harris and co-workers, [60] "The conclusion that acute byssinosis becomes chronic is supported only by histories of patients who had become disabled, but have not been studied prospectively over a

sufficient number of years. Because the chronic process is neither understood nor defined, the acute process manifested by chest tightness, bronchoconstriction and decrease in flowrate has been studied almost exclusively. Most investigators of the mechanism of byssinosis have assumed that the agent responsible for these acute effects of cotton dust is the same agent which is responsible for pulmonary disability. This is still an important question." The same authors also note [60]: "Physical examinations and chest X-ray of byssinotic individuals are initially normal. When pulmonary impairment develops, these individuals are usually diagnosed as having bronchitis and emphysema." A report in 1968 by Ruttner et al [61] attributes a single case of pulmonary fibrosis to cotton dust inhalation. This must be considered unusual since similar findings have not previously been reported or appeared in more recent literature on byssinosis.

In summary, manufacturing workers using cotton may experience tightness in the chest. Such chest tightness will occur initially on the first day of work following an absence of two or more days. Subsequently, the tightness may extend to other days of the week. Even when the subjective impression of tightness is not noted, workers may experience a decrease in FEV 1 from morning to evening which is most pronounced on Mondays and otherwise follows the same pattern as the chest tightness. The Monday morning tightness and/or decrease in FEV 1 over the Monday work shift when working with cotton (or flax or hemp) are the principal characteristics of byssinosis. Inhalation of cotton dust may also result in chronic lung disease.

(b) Bronchitis

There is ample evidence that chronic bronchitis, indistinguishable from that produced by different etiology, is far more common among cotton textile mill workers where byssinosis is found by symptoms and spirometry. [62] This chronic bronchitis is indistinguishable from that found elsewhere. Like other chronic bronchitis, the condition may progress to the point of disability.

Elwood and co-workers [63] noted the presence of bronchitis as well as byssinosis in flax workers in Northern Ireland. They recognized two grades of bronchitis, differing largely in the persistence and quantity of production of phlegm from the chest. They observed that the similarity in the clinical pictures of advanced byssinosis and chronic bronchitis had been stressed by other writers. [25,41,64] Harris et al [60] in a review of the respiratory diseases of cotton workers stated that chronic bronchitis is a frequent finding in textile workers and specifically among those who have been diagnosed as byssinotic. Elwood et al [63] suggested "that byssinosis represents an acute specific effect of certain textile dusts on the respiratory system, superimposed on a non-specific chronic bronchitis process." The clinical symptoms of the two diseases, as listed by Harris and associates, [60] are very similar.

Imbus and Suh [17] noted a marked relationship between the prevalence of byssinosis and bronchitis. Berry et al [65] found the prevalence of bronchitis, unlike that of byssinosis, to be unrelated to dust levels. However, the prevalence of bronchitis among cotton mill workers was higher than in workers in synthetic fiber mills.

(c) Other Conditions

According to Harris et al, [60] mill fever is used to describe a symptom complex of unknown cause which occurs in some workers not accustomed to breathing cotton dust. The symptoms which develop may include malaise, cough, fever, chills, and upper respiratory symptoms shortly after exposure. They disappear after acclimatization occurs but may reappear after an absence from exposure or with a marked increased exposure to dust. [35,66] The relationship between mill fever and the Monday morning illness of byssinosis is unknown. [60]

Periodic outbreaks of an acute respiratory illness termed weaver's cough have occurred among weavers. [35,45] It appears as a sudden epidemic affecting both old and new workers. Earlier reports [39,45] have associated its occurrence with mildewed yarn while other reports [67] have incriminated tamarind seed powder, a constituent used in some yarn-sizing materials, while unidentified sizing materials have been incriminated in others. Since weaver's cough is primarily associated with weaving operations where a low prevelance of byssinosis is expected, it appears that the occurrence of this illness among cotton workers depends upon unique situations involving mildewed yarns, sizing, or other unknown agents and not upon cotton dust as generally experienced by workers

Still another illness was described in the United States by Spolyer [68] and Neal et al [69] in workers handling dusty, low-grade stained cotton. The victims included cotton mill employees, workers at a cotton seed processing plant, and members of rural families using 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

1-6 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, cramps, and substernal discomfort or pressure impairing deep breathing. The disease occurred at any age in both sexes. Bacteriologic examination of cotton samples being processed when the symptoms occurred revealed the presence of a gram negative, rod shaped microorganism. It was concluded that the illness was caused by this microorganism or its products. [69]

To summarize the foregoing, there are respiratory conditions other than byssinosis which have been noted in people working with cotton. Mill fever is an acute, transitory condition somewhat resembling metal fume fever. Weaver's cough is an acute condition believed to be caused by a mildew on cotton yarn. Still another acute illness has been reported from the use of low grade, stained cotton, with Aerobacter cloacae as a suspected cause. Of these conditions, only mill fever appears to be of current interest.

(d) The Causative Agent of Byssinosis

It has been evident since the first descriptions of byssinosis in cotton textile mills that the disease was caused by foreign matter rather than by the cotton lint. In 1915, Collis [70] spoke of "dust arising from cotton husk and debris which is thrown in a fine cloud into the air." His successor as H.M. Medical Inspector of Factories, E.L. Middleton, [71] investigated the dust to which card strippers and grinders were exposed. He wrote: "The cause of the disability produced among these workers must, therefore, be a matter of conjecture until further investigations are made.

The constituents of the dust are emery, cotton hairs, other parts of cotton, mold fungus (mycelium, conidia, and spores), and extraneous mineral matter." 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 during the day are found in mineral industry workers. In reviewing the world-wide literature of 1947 in Mode of Action of Cotton Dust, Caminita et al [35] 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 of allergens. The evidence is negative with reference to its acting as a source of silica, of infectious micro-organisms or of gossypol."

Schilling's [55] discovery in 1955 that byssinosis was still a problem in Lancashire textile mills initiated 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 characteristics symptoms of byssinosis.

Schilling [64] examined the possibility that byssinosis might be an allergenic reaction. He concluded that the course of the disease was not consistent with an allergenic response. Cayton et al, [72] in a thorough examination, showed that noncotton workers, nonbyssinotic 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 used for extracting the dust. Although there may be individuals who are allergic to cotton dust, it appears unlikely that allergy in the usual way plays an important part in byssinosis. However, Gernex-Rieux et al [73] found a correlation between Monday symptoms and skin reactions and Massoud and Taylor [74] described an antibody directed against an antigen present in the cotton plant. They found the antibody titers higher in cardroom 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 was investigated by Cavagna et al. [75] 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 cardroom was about 90 times that present in the spinning room. A 32% prevalence of byssinosis was evident in the cardroom but no prevalence appeared in the spinning room however. The active agent in the spinning room could 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 in byssinotics was produced in human volunteers by a bacterial endotoxin. The animal experiments conducted provided some further support. The presence of endotoxins in dust in cotton textile mills in general was demonstrated.

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. [76,77] Prausnitz, [41] 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." Haworth and Macdonald [78] found more histamine in the blood of cardroom workers than in controls. However, the amounts of histamine found in cotton dust appear too small to result in effects comparable to those found. [79,80]

The possiblity 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. [78] Bouhuys et al [80] postulated again that a histamine releasing substance was responsible for at least some of the symptoms of byssinosis. They based this hypothesis on human dust inhalation experiments and animal experiments. Bouhuys and Lindell [81] 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. One conclusion that might be drawn from these experiments is that the workers who develop byssinosis are those unusually sensitive to histamine. However, Bouhuys [82] 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 much more sensitive to histamine.) In contrast, Bouhuys [83] found that the mean Monday change in FEV 0.75 in 13 cotton workers was +0.01 cc when they were treated with an antihistamine

drug, as compared with -0.32 cc when placebos were administered. Subjective symptoms, however, were little affected. Lemercier and Leledy [84] concluded that byssinosis differed from asthma and that there were strong objections to the histamine theory.

Bouhuys and Nicholls [8] studied the action of aqueous extracts of cotton dust on human volunteers. They found that inhalation of an aerosolized extract of the bracts produced both subjective symptoms of respiratory distress and an increase in pulmonary flow resistance in 3 of 4 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 reproduce the symptoms, but a repetition of the exposure 6-8 days later brought on subjective symptoms similar to those of the first day.

The evidence presented by Bouhuys and his collaborators [8,80-83] that the bract of the cotton plant contains an active material causing byssinosis is impressive. It is also difficult to quarrel with his contention that the effect on humans is more important than the results of experiments with other species, whether in vivo or in vitro. Still, it is difficult to use these findings effectively in the evaluation and control of the problem in textile mills. 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 by Roach and Schilling. [85] Other investigators have reported better correlation of byssinosis with carbohydrate content of dust than with nitrogen content. [86] The active ingredient was suggested to be

a polysaccharide, [87,88] 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. Since clean cotton fibers contain only about 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.

Recent interest in byssinosis has produced reports of three different materials, each of which could be an "active agent" in byssinosis.

Hitchcock et al [89] reported that bracts contain a steam-volatile component which released histamine from chopped human autopsy lungs. This component had physiochemical behavior similar to methyl piperonylate, a material which also released histamine from chopped human lung. The authors concluded that "steam volatile component may contain the principal bronchoconstrictor of bracts, and methyl piperonylate may be this agent."

Taylor et al [90] have reported the extraction of a condensed polyphenol based on leucocyanidin from cotton bracts. This material was shown to react with human sera. Significant differences in reactivity were noted between byssinotics and nonbyssinotics and between controls and cardroom workers. An aerosol of a solution of the material produced symptoms of byssinosis in byssinotic cardroom workers, but not in nonbyssinotics or in controls. The aerosol did not produce changes in FEV 1 or FVC. Since this material is from the bract, any measurement of

airborne bract dust or another component of bract dust would be an indirect measurement of this material.

Investigators at the Industrial Health Foundation [91-93] reported what they considered "a strong relationship between physiologic response and levels of enzyme activity" and suggested that "an enzyme or combination of enzymes found in cotton mill dust" may be "the specific etiologic agent in byssinosis."

The possibility that one or more of these materials are responsible for byssinosis may be related to the findings of Merchant et al [94] which demonstrated that dry heat treatment of cotton increased signs and symptoms of byssinosis, but that either washing or steam treatment considerably reduced the prevalence of symptoms of byssinosis in a group of extraordinarily susceptible workers.

Goscicki et al [95] investigated the level of serum antibodies reacting with antigens isolated from 3 kinds of aerobic spore-forming bacilli in cotton workers. The mean titers of two bacterial antibodies for antigens M3 and C9 were increased in comparison with those of controls, and also by the length of exposure to cotton dust.

Hamilton et al [96] found after studies of byssinotic workers that the active agent in cotton dust is water soluble, filterable at 0.22 μm, nonvolatile at 40 C, and nondialyzable.

Oehling et al, [97] after studying the reaction to cotton dust extracts of seven byssinotics concluded that all the conditions necessary to label the etiopathogenic mechanism as allergic were fulfilled.

The influence of the active agent in cotton dust is not the only environmental factor related to respiratory symptoms among cotton textile

workers. It is well known that particulate and sulfur oxide air pollution in Lancashire, a major textile manufacturing area in England, 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 1960-1961 period ranged from 115-716 μg/cu m. [98] Average sulfur dioxide concentrations in the same period were 90-809 μg/cu m.

The relative freedom of air pollution in the Southeastern United States [99] 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.

The influence of cigarette smoking on chronic bronchitis prevalence has been well documented. [100] Ferris [30] concluded that in his flax-mill population, the influence of smoking far outweighed any possible health hazard of the flax dust. Bouhuys et al [101] concluded that there was no synergism between the effects from smoking and those from hemp dust exposure. In an American cotton textile mill, on the other hand, Merchant et al [62] found that both smoking and work with cotton increased prevalence of chronic bronchitis. Their work did not rule out the possibility of a synergistic effect of cotton dust and cigarette smoking. The prevalence of positive findings in a cotton dust-exposed group of cigarette smokers was significantly greater than in nonexposed cigarette smokers or nonsmoking cotton textile workers.

To summarize, the environmental agent or agents responsible for byssinosis are 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. Although the mechanism by which byssinosis leads to long-term effects such as chronic bronchitis is not known, the assumption is that there must be a connection. The active agent or agents producing acute effects are thus believed to be the source of chronic lung disease. Those who have investigated the problem in detail are of the opinion that workers suffering a greater acute effect are more likely to have eventual irreversible lung function changes. Inasmuch as the reported potential active agents are found in the trash fraction of cotton, a measurement of this fraction of airborne dust would be expected to correlate with prevalence of byssinosis.

Epidemiologic Studies

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. Although presently smaller than in the past, the textile industry in Lancashire still remains one of the world's textile centers. When the state of health of cotton mill workers was investigated by the occupational health unit of the University of Manchester, the strippers and grinders still showed an excess of cardiovascular and respiratory diseases in 1930-1932 and 1947-1948. These workers had the highest dust exposures among all cotton mill workers.

The first studies of Schilling and his co-workers [42,46,55,85,102,103] have been a pattern for those following. From a group of mills, they selected several spinning 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. The 1909 classification by Collis [38] of "coarse", "medium" and "fine" is given in Table XII-3.) Careful examinations of blood pressure were done on all men in the group. [102] The mean systolic and diastolic blood pressures were higher in the experimental card- and blowroom workers than in the control weave-room workers. Observer error, obesity, heredity, and renal disease were considered 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 determined 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% of the workers with byssinosis prompted further studies. [55] In a group of 190 card- and blowroom 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 blowroom workers had byssinosis.

The study of 28 mills was compared with two previous studies of card- and blowroom workers with the number of those affected by byssinosis as shown in Table XII-4 and Table XII-5. [55]

Byssinosis was found in all three geographical areas. The highest prevalence among cardroom workers and blowroom (called picking and opening

in the US) workers as shown in Table XII-5 is consistent with findings back to those of Collis. [38]

The standardized methods of Schilling for classifying byssinosis have been used since 1950 by investigators throughout the world. A number of prevalence studies are summarized in Table XII-6 which is far from all-inclusive. [13-17,38,47-50,55,62,64,85,98,104-106]

In addition to the countries listed in Table XII-6, prevalence studies in one or more mills have also been reported from India, [107] Italy, [47] Israel, [108] Egypt, [109] Uganda, [31] and Yugoslavia, [87] with results in general comparable to those shown in Table XII-6. It is evident that the prevalence has decreased since Collis' lecture in 1915, [70] but prevalence of byssinosis in cardrooms 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 XII-6 and reported in the various studies are not strictly comparable. The studies may include all workers or only the workers in dustier jobs. 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.

One of the first major investigations was the prospective study of Molyneux and Tombleson, [13] in which over 1,500 cotton textile mill workers, in ten occupations were examined. When Schilling's methods were 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, [14,15,48] 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 cardroom. Byssinosis is appearing even in winding. [16,49]

In a study of 18 American plants involving 995 workers, Braun et al [58] came to the conclusion that by the very broadest definition the prevalence of possible chronic effect was 14% in carders and 5.2% in other workers. They found that an additional 23% of carders and 10.3% of non-carders had characteristic findings which might indicate an acute reaction to exposure.

Fox et al [16] surveyed about 35 mills in England between 1966-68 and examined over 2,300 operatives. Between 1968 and 1970 a second survey of 46 mills included 28% of the original group. In all more than 2,500 workers were examined. Symptoms of byssinosis were found in workers in all but the two cotton mills processing fine cotton. Workers who were reexamined showed a 10% greater deterioration in ventilatory function than a local control population.

Imbus and Suh [17] in a study of over 10,000 textile workers found a marked relationship between the incidence of byssinosis and bronchitis and lowered pulmonary function. Cigarette smoking appeared to further increase the incidence of these conditions.

In an evaluation of 846 male textile workers from a cross sectional study Merchant and co-workers [110] "showed that cigarette smoking

interacts with exposure to lint-free cotton dust to increase byssinosis prevalence and severity."

Merchant et al [62] in a study of a modern cotton-synthetic blend mill diagnosed as byssinotic 20% of the workers in preparation areas and 2% of those in yarn processing areas. Among male workers, the byssinotic index increased with smoking and the bronchitis index increased with smoking plus dust exposure. Lemercier and Leledy [84] found that 225 out of 1,500 (17%) cotton mill workers had respiratory difficulties. Among cardroom workers, however, the prevalence was 43%.

Gilson et al [31] 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/cu m of which over half was mineral matter. Khogali [111] found byssinosis in 20% of gin workers in the Sudan. Mean respirable dust concentration was 0.6 mg/cu m as measured by the Hexhlet dust sampler. There were significant changes in FEV 1 in byssinotics during the work shift. El Batawi [109] reported 33% byssinosis in Egyptian gins. Barnes and Simpson [112] studied workers handling recently ginned cotton seed in Wee Waa, New South Wales, Australia. Dust concentrations averaged 20 mg/cu m. Significant changes in ventilatory function were noted. As with the reports from Africa, there is little application of these findings to US conditions, but they do suggest the possibility of health effects in cotton processing even when using modern methods and mechanical handling.

A preliminary study of cotton gin workers in Texas and New Mexico was conducted by NIOSH in 1971. The study showed by questionnaire that a zero prevalence of byssinosis was found among the workers. However, 18.2% of the workers examined were considered to have a sufficiently lowered FEV 1 to suggest that they be removed to a lower dust exposure. From the limited nature of the study no conclusions could be drawn from the results obtained beyond that which could be applied to the group surveyed. [113]

Studies conducted by the Duke University Institute of Environmental Medicine, in cooperation with the North Carolina State Board of Health, the National Institute for Occupational Safety and Health, and Burlington Industries Inc have suggested that steam treatment of cotton may assist in the prevention of byssinosis. [94] It has been found, however, that while steaming improves dust conditions in some preparation areas, higher levels were found in spinning, winding, and twisting areas than with unsteamed cotton. These were accompanied by an increase in byssinosis and bronchitis prevalence in these areas. [114] It was concluded that in the mills studied at least no overall improvement resulted from steaming the cotton before processing.

The data summarized in Table XII-6 indicate a considerable reduction in byssinosis prevalence in modern English mills in comparison with that found by Collis [38] in 1915. Between 1950 and 1973 the mean prevalence among carders appears to have been reduced about 14% (from 41 to 27%). The most recent studies in the United States [15,17,62] indicate prevalences of 20-29% in the same occupational group, only slightly below those found in England. [13,17]

To summarize, the prevalence of byssinosis, Grade 1/2 or greater, among carders has been found to be from 20-40% in the most recent British and American studies. Lower prevalences are usually (but not always) found in spinning and winding.

Animal Toxicity

Experiments exposing animals to cotton dust or its extracts have been designed primarily to determine the nature or identity of the causative agent of byssinosis and the mechanism of the disease.

Cavagna et al [75] administered aerosols of cotton extract and E coli endotoxin to rabbits and produced patterns of bronchitis. Davenport and Paton [115] 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. 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. In some samples 5-hydroxytryptamine was present but not in sufficient amount 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 bronchoconstrictive 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 bronchoconstrictive substance in the tissue 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, [88] in concurrent, independent animal experiments confirmed the findings of Davenport and Paton. [115] 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. 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 dust 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 a histamine-releasing compound, Compound 48/80 (Burrough-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. Nicholls 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 substance is involved in each. Nicholls noted that histamine release might best explain the "Monday symptoms" of cotton workers, but doubted 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 [116] investigated the release of histamine from preparations of animal lung, using aqueous extracts and Compound 48/80. 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. [81] Antweiler [79] confirmed the liberation of histamine in rats and cats, and in the blood of rabbits by aqueous extracts of cotton dust.

Bouhuys and Nicholls [8] failed to detect effects on the respiration of guinea pigs that inhaled extracts of bracts although human subjects were affected.

Lynn et al [117] noted that inhalation of cotton dust extracts (or of many polyphenols) by animals causes in a few hours a marked outpouring of polymorphonuclear (PMN) cells into the lumen of airways. They isolated a steam-volatile fluorescent material of mass 260 (sic) from cotton mill dust and cotton bracts, and found it to be an in vitro chemotaxin of the slow type for peritoneal polymorphonuclear cells in the absence of serum. They concluded that this material appeared to be the major chemotactic agent in cotton bracts, as assayed by their procedure.

Kilburn [118] described how "polyphenol extracts from cotton trash ... administered as aerosols or on dust recruit PMN leucoytes on airways from trachea to terminal broncheoles in hamsters. It promises to model faithfully the time and phases of human responses to cotton trash inhalation or byssinosis."

Correlation of Exposure and Effect

A number of investigators have recorded dust concentrations in mills and work areas where the incidence of byssinosis was also determined. In the early studies only total dust was measured. [85,119] Others using the Hexhlet apparatus with a horizontal elutriator separated the dust into three fractions - coarse, medium, and fine. [11,13,49,56] Some reported only total and fine dust concentrations. [14,120-122] The fine or respirable fraction is considered to have an aerodynamic diameter below 7 μm.

Others reported concentration of fly-free dust obtained by screening out coarse particles by means of a 2-mm wire mesh. [50,58,123] A similar result is obtained by use of a vertical elutriator designed to collect only dust 15 μm aerodynamic diameter [18] or smaller sized fractions. [17] A cyclone separator has also been used to divide the dust sample into fine, middle, and lint fractions. [14,62,124]

In a few surveys no correlation was found between dust concentrations and byssinosis prevalence. Thus Braun et al [58] stated that environmental dust measurements are poor indicators of physiological effects. They concluded that the reason that carders are more frequently

affected than other workers is due to the difference in composition of the dust in the carding operation rather than in its quantity.

The first extensive study of the relationship of dust levels to prevalence of byssinosis was made by Roach and Schilling. [85] They found a prevalence of 20% byssinosis at a total dust concentration of about 2.8 mg/cu m. Virtually no byssinosis was found where the total dust concentration was below 1 mg/cu m. Their classification of the risk from different dust levels is given in Table XII-8. They found almost 60% of the cardroom dust to be coarse, while in spinning rooms 84% of the dust was so classed.

Belin and co-workers [50] in a survey of four mills in Sweden found the lowest prevalence of byssinosis (31% in carders, 25% in others) in the mill with the lowest dust concentration (2.15 mg/cu m total, 1.65 mg/cu m fine). But there was no correlation between dustiness and disease in the other three mills where total dust (mean values) ranged from 2.7-6.7 mg/cu m, and fine dust from 2.3-4.5 mg/cu m. The prevalence of byssinosis in these mills showed considerable variation (60-77% in carders and 44-68% in others). Their method of sampling, patterned after the vertical elutriator, probably classified as fine a greater proportion of the dust than other methods of sampling.

Wood and Roach [11] reported that in a plant where concentrations of total dust had been reduced by ventilation of the cards, that fine and medium dust concentrations were relatively unchanged (each about 0.6 mg/cu m). Nineteen of 33 workers had chest tightness on Mondays.

El Samra et al [119] found concentrations of total dust (as measured with an electrostatic precipitator) ranging from 0.43-1.0 mg/cu m in a

plant which had been in operation for 13 years. Only one of 247 employees, a cardroom worker, had byssinosis.

In contrast Valic and Zuskin [120] reported a 22% prevalence of byssinosis in a cotton mill processing fine cotton where total dust concentrations averaged 1.09 mg/cu m (range 0.16-1.55). Nine years previously no cases of byssinosis were diagnosed at this mill.

Zuskin and others [14] found byssinosis prevalence to be 33% among carders in one mill where the so-called respirable dust average concentration was 0.87 mg/cu m, and 21% in another mill where the concentration was 0.50 mg/cu m. Spinners in the two mills were exposed to approximately equal concentrations of respirable dust and the byssinosis incidence in both plants was about 12%. Total dust concentrations were two to three times higher than those of respirable dust.

Merchant et al [62] reported that total dust samples in a modern cotton-synthetic blend mill gave no indication of the byssinosis risk. Low concentrations (0.2 to 0.3 mg/cu m) of respirable and medium dust were found in carding operations, while somewhat higher levels were detected in spinning (0.62 mg/cu m). Total dust was also higher in the yarn processing area. The prevalence of byssinosis was 20% in preparation areas and 2% in processing areas.

Lammers and co-workers, [98] in a comparison of workers in English and Dutch cotton mills, found higher total dust concentrations in the English cardrooms (2.9 vs 1.9 mg/cu m), but the fine dust concentrations were the same (0.2 mg/cu m). The prevalence of byssinosis was 13.5% and 17%, respectively. In spinning rooms in English mills concentrations were lower (total dust 0.4 vs 2.6, fine dust 0.03 vs 0.1 mg/cu m). Again the

incidence of byssinosis was similar in both countries, about 1.5% and 1.6%, respectively

While the correlation between dust concentration and prevalence of byssinosis is not high in all cases, there is a general pattern of lower prevalence among spinners than among carders [14,62,98] and especially strippers and grinders, [65] even where comparable dust concentrations were found at the various operations.

However Mekky et al [49] found a 20.5% prevalence of byssinosis in cardroom workers where the medium plus fine dust concentration averaged 1.64 mg/cu m. A 6.4% prevalence of byssinosis was observed in the ringroom, where medium and fine dust concentrations were 0.35 mg/cu m. In the winding room where a higher dust levels than in the cardroom (1.92 vs 1.64 mg/cu m) were measured the prevalence of byssinosis was 18.8%. Total dust concentrations were also higher in the winding room than in the cardroom (3.48 vs 2.85 mg/cu m). These results would not indicate a remarkable difference in potency between the cardroom and winding room dusts.

Other investigators have considered correlations between dust concentration (total, fine, or medium plus fine) and the prevalence of byssinosis to be well established. Imbus and Suh [17] report that linear correlations between respirable dustiness and the prevalence of byssinosis were apparent in their study of over 10,000 textile workers, but gave no environmental data in their paper. (Environmental dust levels for that study were provided NIOSH by written communication from HR Imbus in 1972 and are reported below.)

Berry et al [56] found that the Monday fall in FEV 1 was related to the dust concentration. At 0.5 mg/cu m of fine dust (<2mm length) subjects with Grade 0 or 1/2 byssinosis had FEV reductions of about 50 ml; at 1.0 mg/cu m the average fall was 100 ml. The annual decline in FEV was not found to be related to present dust levels.

Molyneux and Berry [125] obtained correlations between dust concentrations and a number of conditions. They reported that the prevalence of byssinosis among 945 workers in five cardroom processes (ring spinners excepted) was best correlated with medium dust. At a concentration of 0.2 mg/cu m the predicted prevalence was about 10%; at 0.5 mg/cu m, over 40%. Among speedframe tenters the incidence at 0.2 mg/cu m was about 15%, at 0.5 mg/cu m 30%. Assuming a linear relationship, there should still be some byssinosis at 0.0 mg/cu m. Simple bronchitis among nonsmokers correlated best with respirable dust (again ring spinners were excluded). At 0.2 mg/cu m a prevalence of about 15% was predicted, and at 0.5 mg/cu m about 35%. Monday morning cough in nonbyssinotic nonsmokers showed a threshold (zero prevalence) at about 0.2 mg/cu m of respirable dust. At 0.5 mg/cu m the predicted prevalence was 8%.

Fox and others [123] determined the prevalence of byssinosis and concentrations of fly-free dust in the cotton preparation areas of 11 mills, making coarse, medium, and fine cotton. Their curve of byssinosis vs dust concentration indicates a prevalence of about 6% at a concentration of 0.5 mg/cu m. When length of exposure was taken into consideration, it was predicted that after 20 mg-years/cu m (eg, 40 years at 0.5 mg/cu m) there would be a 10% prevalence of byssinosis. Table XII-15 summarizes the

correlation between time-weighted exposure and prevalence of byssinosis, as reported by Fox et al. [123]

Merchant and co-workers, [18] using the vertical elutriator sampler, found a strong linear association between prevalence of byssinosis and the concentration of lint-free dust in American mills. In cotton preparation and yarn areas, it appears (see Tables XII-13 and XII-14) that untreated cotton would produce 3% byssinosis (all grades) at 0.05 mg/cu m, 7% at 0.1 mg/cu m, and 13% at 0.2 mg/cu m. At 0.5 mg/cu m of <15 μm dust, 26% byssinosis (all grades) was found. This is in general agreement with the fly-free dust findings of Molyneux and Tombleson. [13] In slashing and weaving areas of the mills, on the other hand, Merchant et al [18] found only 6% byssinosis (all grades) at 0.5 mg/cu m of <15 μm dust. The prevalence for smokers was approximately twice that for nonsmokers.

Imbus in a written communication to NIOSH in 1972 correlated byssinosis prevalence with fine dust (<7μm) as determined with a vertical elutriator using a sampling rate of 1.61 liters/minute. The biologic effects of workers studied was published by Imbus and Suh in 1973. [17] At concentrations below 0.25 mg/cu m, the byssinosis prevalence ranged from 13.5% in preparation areas only to 5.6% in preparation and yarn areas, and 3.5% in yarn areas only. At concentrations between 0.75 and 1.0 mg/cu m the prevalence in preparation areas was 38.5% but only 6.4% in yarn areas. With low grade cotton the prevalence at given dust levels was generally higher than with better grades and in addition higher concentrations of dust were found.

Berry and co-workers [65] included over 1,000 cotton workers in a prospective survey including dust measurements and prevalence data on

byssinosis and bronchitis. Strippers and grinders had the highest prevalence, and ring spinners the lowest, even after making allowance for dust concentration. Nineteen of 36 male workers (53%) exposed at concentrations of fly-free dust between 0.5 and 0.74 mg/cu m had symptoms of byssinosis; 29 of 181 (16%) female workers with similar exposure had byssinosis as did an equal number among 149 (20%) with exposures between 0.25 and 0.49 mg/cu m.

In Table XII-10 the prevalence of byssinosis at different levels of total dust, as determined by various investigators and compiled by the British Occupational Hygiene Society Committee on Hygiene Standards, [126] is summarized. Table XII-11 gives the numbers of workers with Grade II byssinosis (as well as all grades) and the concentrations of total dust to which they were apparently exposed. [126]

To the extent that the content of active agent varies in dusts from cotton of different grades and from different processes, determination of dust concentration, regardless of refinements in particle sizing, is not a precise measure of the risk of byssinosis. [17,58,65,93,125] However, efforts to estimate exposure in terms other than dust concentration have not yet been standardized.

Roach and Schilling [85] determined the protein content of dust in card and spinning rooms. They found 3-8%, 14-21%, and 21-27%, in the coarse, medium, and fine fractions, respectively. At that time they concluded that the best correlation between prevalence of byssinosis and analytical results was with protein. If the concentrations in the various fractions were considered, the best correlation was with the medium

fraction, the least with fine. Later investigations by these authors, however, have apparently not confirmed this finding.

Although other studies (eg, Gilson et al [31]) have linked the protein concentration of dust satisfactorily to its biologic activity, no detailed reports correlating protein concentration with byssinosis have been published.

Braun and co-workers and Tuma et al [92,93] related the percentage of workers showing a 10% decrement in FEV 1 to the concentration of proteolytic enzymes in the air and found a higher correlation than when dust concentrations were used. According to their curve, a concentration of 0.4 milliunits/cu m of chymotrypsin-like enzyme would result in a 10% FEV 1 drop in 14% of the exposed workers.

In summary, a general correlation between dust concentrations and the prevalence of byssinosis has been found by most investigators who made extensive studies of the effects of exposure of workers to cotton dust. Elimination of lint or fly fractions of the dust usually increases the correlation. No definitive conclusion can be drawn as to whether it is better to measure only the respirable (<7μm) fraction, or to determine both medium and fine fractions. The latter procedure (medium plus fine) has the advantage of better analytical accuracy since the weight of dust collected is greater. As a rule, the relationship between prevalence and dust is approximately linear, at least at low concentrations. There is little evidence of a threshold below which zero prevalence is found. The slopes of the prevalence-dustiness curves obtained by different investigators vary considerably. [17,18,65,123, 1972 written communication from HR Imbus]