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OCCUPATIONAL EXPOSURE TO COTTON DUST

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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PREFACE

The Occupational Safety and Health Act of 1970 emphasizes the need for standards to protect the health and safety of workers exposed to an ever-increasing number of potential hazards at their workplace. The National Institute for Occupational Safety and Health has projected a formal system of research, with priorities determined on the basis of specified indices, to provide relevant data from which valid criteria for effective standards can be derived. Recommended standards for occupational exposure, which are the result of this work, are based on the health effects of exposure. The Secretary of Labor will weigh these recommendations along with other considerations such as feasibility and means of implementation in developing regulatory standards.

It is intended to present successive reports as research and epidemiologic studies are completed and sampling and analytical methods are developed. Criteria and standards will be reviewed periodically to ensure continuing protection of the worker.

I am pleased to acknowledge the contributions to this report on cotton dust by members of my staff and the valuable constructive comments by the Review Consultants on Cotton Dust, by Robert B. O'Connor, M.D., NIOSH consultant in occupational medicine, and by William A. Burgess, NIOSH consultant on respiratory protection. In addition, I would like to thank the American Textile Manufacturers Institute, Inc. for their contribution of recommended industrial work practices which has helped significantly in

developing the work practices section of this document. The NIOSH recommendations for standards are not necessarily a consensus of all the consultants that reviewed this criteria document on cotton dust. Lists of the NIOSH Review Committee members and of the Review Consultants appear on the following pages.

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CRITERIA DOCUMENT: RECOMMENDATIONS FOR AN OCCUPATIONAL EXPOSURE STANDARD FOR COTTON DUST

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I. RECOMMENDATIONS FOR A COTTON DUST STANDARD

The National Institute for Occupational Safety and Health (NIOSH) recommends that occupational exposure to cotton dust in the workplace be controlled by compliance with the following sections. Although there are significant gaps in knowledge of the etiology of byssinosis, the standard is designed to compensate for this gap and to provide the greatest feasible degree of health protection for exposed workers over their working lifetime. The significant thrust of the standard for cotton dust is medical management and surveillance, administrative controls, and work practices. Since no definitive environmental level can assure complete health protection, none is recommended in this document. However, to ensure that effective engineering controls are implemented and dust concentrations reduced, an environmental standard should be fixed. The concentration should be set at the lowest level feasible, but in no case at an environmental concentration as high as 0.2 mg lint-free cotton dust/cu m, in order to reduce the prevalence and severity of byssinosis. The criteria and standard will be subject to review and revision as necessary.

"Exposure to cotton dust" includes any work with cotton that results in airborne cotton dust; "cotton dust" is defined as dust generated into the atmosphere as a result of the processing of cotton fibers combined with any naturally occurring materials such as stems, leaves, bracts, and inorganic matter which may have accumulated on the cotton fibers during the growing or harvesting period. Any dust generated from processing of cotton through the weaving of fabric in textile mills and dust generated in other operations or manufacturing processes using new or waste cotton fibers or cotton fiber byproducts from textile mills is considered cotton dust. The recommended standard does not apply to dust generated from the handling or processing of woven materials.

Section 1 - Medical

(a) Medical Examinations

(1) Preplacement: A comprehensive physical examination shall be made available to include as a minimum: medical history, baseline forced vital capacity (FVC), and forced expiratory volume at one second (FEV 1). The history shall include administration of a questionnaire (see Appendix IV) designed to elicit information regarding symptoms of chronic bronchitis, byssinosis, and dyspnea.

If a positive personal history of respiratory allergy, chronic obstructive lung disease, or other diseases of the cardiopulmonary system are elicited, or where there is a positive history of smoking, the applicant shall be counseled on his increased risk from occupational exposure to cotton dust.

At the time of this examination, the advisability of the worker's using negative or positive pressure respirators shall be evaluated.

(2) Each newly employed person shall be retested for ventilatory capacity (FVC and FEV 1) within six weeks of employment. This retest shall be performed on the first day at work after at least 40 hours' absence from exposure to cotton dust and shall be performed before and after at least six hours of exposure on the same day.

(3) Periodic: Each current employee exposed to cotton dust shall be offered a medical examination within six months of the

publication of these regulations and at least yearly thereafter that shall include administration of a questionnaire (see Appendix IV) designed to elicit information regarding symptoms of chronic bronchitis, byssinosis, and dyspnea.

(4) Each current employee exposed to cotton dust shall have measurement of forced vital capacity (FVC) and of forced expiratory volume at one second (FEV 1). These tests of ventilatory function should be performed on the first day at work following at least 40 hours of absence from exposure to cotton dust, and shall be performed before and after at least six hours of exposure on the same day.

(5) Ideally, the judgment of the employee's pulmonary function should be based on preplacement values (values taken before exposure to cotton dust). When preplacement values are not available, then reference to standard pulmonary function value tables may be necessary. Note that these tables may not reflect normal values for different ethnic groups. For example, the average healthy black male may have an approximately 15% lower FVC than a caucasian male of the same body build (see Appendix III). A physician shall consider, in cases of significantly decreased pulmonary function, the impact of further exposure to cotton dust and evaluate the relative merits of a transfer to areas of less exposure or protective measures. A suggested plan (Table XII-12) for the management of cotton workers was proposed as a result of a conference on cotton workers' health.

(6) Medical records, including information on all required medical exminations, shall be maintained for persons employed in work involving exposure to cotton dust. Medical records with pertinent

supporting documents shall be maintained at least 20 years after the individual's termination of employment. These records shall be available to the medical representatives of the Secretary of Health, Education, and Welfare, of the Secretary of Labor, of the employee or former employee, and of the employer.

Section 2 - Posting

(a) The following warning shall be posted to be readily visible at or near entrances or accessways to work areas where there is potential exposure to cotton dust:

WARNING!

COTTON DUST WORK AREA

Unauthorized Persons Keep Out

(b) The following warning shall be posted in readily visible locations in any work area where there is potential exposure to cotton dust:

WARNING!

COTTON DUST WORK AREA

AVOID BREATHING DUST

May Cause Acute or Delayed Lung Injury (Byssinosis)

(c) The posting required under Sections 2(a) and 2(b) shall be printed both in English and in the predominant language of non-Englishspeaking workers, unless they are otherwise trained and informed of the hazardous areas. All illiterate workers shall receive such training.

Section 3 - Personal Protective Equipment

Engineering controls shall be used wherever feasible to maintain cotton dust concentrations below the prescribed limit. Administrative controls can also be used to reduce exposure.

Respirators shall also be provided and used for nonroutine operations (occasional brief exposures above the environmental limit and for emergencies) and shall be considered for use by employees who have symptoms even when exposed to concentrations below the established environmental limit. Appropriate respirators as described in Table I-1 shall be used pursuant only to the following requirements:

(a) For the purpose of determining the type of respirator to be used, the employer shall initially measure the atmospheric concentration of cotton dust in the workplace and thereafter whenever process, worksite, climate, or control changes occur which are likely to alter the cotton dust concentration. This requirement shall not apply when only atmosphere-supplying positive pressure respirators are used. The employer shall ensure that all workers are supplied with respirators appropriate for the concentration of dust to which they are exposed.

(b) A respiratory protective program meeting the requirements of the Occupational Safety and Health Administration Standards, part 1910.134, shall be established and enforced by the employer (29 CFR, Part 1910.134 published in the Federal Register, volume 39, page 23671, dated June 24, 1974).

TABLE I-1
RESPIRATORS FOR USE IN COTTON DUST

Dust Concentration in Multiples of the Standard	Respirator Type
Less than or equal to 10X	(1) Air-purifying dust respirator with replaceable dust filter, quarter or half mask.
	(2) Type C supplied air respirator, demand type (negative pressure) with quarter or half mask.
	(3) Air-purifying, single use dust respirator with quarter or half mask.
Less than or equal to 100X	(1) Air-purifying full facepiece respirator with replaceable dust filter; chin, front, or back mounted filter.
	(2) Type C supplied air respirator, demand (negative pressure) with full facepiece.
	(3) Powered air-purifying respirator with quarter or half mask and replaceable dust filter.
Less than or equal to 200X	Powered air-purifying respirator with full facepiece and replaceable dust filter.
Greater than 200X	Type C supplied air respirator, pressure demand or continuous flow type with quarter or half masks, full facepiece, hood or helmet.

Section 4 - Informing Employees of Hazards from Cotton Dust

(a) Each employee, before being assigned to a cotton work area, shall be apprised of the hazards, relevant symptoms, appropriate emergency procedures, and proper conditions and precautions for safe use or exposure, and shall be instructed as to the availability of relevant information which shall be kept on file and shall be accessible to the worker at each place of employment where cotton is involved in unit processes and operations.

(b) Information as specified in Appendix II, to the extent appropriate to cotton dust, shall be recorded on US Department of Labor Form OSHA-20, "Material Safety Data Sheet," or on a similar form approved by the Occupational Safety and Health Administration, US Department of Labor.

Section 5 - Work Practices

(a) Exhaust Systems and Production Machinery

Local exhaust ventilation and air cleaning systems shall be designed and maintained to prevent the accumulation and recirculation of cotton lint and dust into the workroom. The total system shall be inspected periodically for effective performance. Production machinery shall also be properly maintained and kept at peak operating efficiency to prevent unnecessary dust emissions.

(b) General Housekeeping

(1) Cleaning by blowing with compressed air or dry sweeping shall be avoided and vacuum cleaning substituted wherever possible. Waste material shall be disposed of in closed containers and not

recycled into the process unless the lint-free dust (dust less than 15 μm aerodynamic diameters) has been removed.

(2) When "blow down" is necessary, it shall be conducted only in the absence of personnel not involved in the "blow down" operation, and those involved shall wear approved respirators. Dust shall be allowed to subside or be removed by ventilation before workers without respirators are permitted to reoccupy the workplace.

(3) Good housekeeping practices designed to prevent the resuspension of settled dust shall be developed and shall be followed at all times.

(c) Use of Respirators

Approved respirators shall be worn for those temporary or occasional tasks in which the dust concentration rises above safe levels such as when dry sweeping, "blowing down", removing chokes, manually collecting trash, and performing general cleanup operations (see Section 3).

(d) Specific Work Practices

Specific work practices shall be established and posted for all work positions where cotton dust is present. This includes but is not limited to positions in the waste house, opening, picking, carding, drawing, combing, roving, spinning, winding, twisting, weaving, and knitting areas. Practices such as keeping cotton away from the face, avoiding unnecessary creation of dust by shaking or throwing material, and avoiding localized high dust level areas wherever possible shall also be included. Creation of a positive attitude toward dust control on the part of management and employees is essential. Employees shall be trained in procedures which will limit their exposure and shall be instructed to follow these work practices.

Section 6 - <u>Environmental (Workplace Air)</u>

(a) Concentration

Occupational exposure to lint-free cotton dust (dust less than 15 micrometers (15 μm) aerodynamic diameters) shall be controlled to the lowest feasible limit which shall be less than 0.2 mg lint-free cotton dust/cu m.

(b) Sampling, Collection, and Analysis

Procedures for collection and analysis of environmental samples shall be as provided in Appendix I or by any method shown to be equivalent in accuracy, precision, and sensitivity to the methods specified.

Section 7 - <u>Monitoring and Recordkeeping Requirements</u>

(a) Because personal monitoring for cotton dust is not presently feasible, each operational area shall be monitored in such a manner that individual workers' exposure can be constructed. Samples shall be collected using the vertical elutriator for a sufficient length of time to permit such determinations. Sampling shall be conducted in distinct operational areas (ie, opening, picking, carding, drawing, combining, etc). Each operational area shall have a minimum of 5 sampling locations representative of the area and in proximity to employee activities. For areas greater than 5,000 sq ft, another sampling site should be added for each additional 1,000 sq ft of floor space. Samples in each operational area shall be gathered simultaneously during a typical operating shift.

(b) Within 180 days of the effective date of a cotton dust standard, employers shall identify the locations of all processes or operations where employees may be exposed to cotton dust. Employers shall monitor cotton dust concentrations in these areas at least every 6 months, except as otherwise indicated by the judgment of a professional industrial hygienist. Whenever concentrations exceed the environmental limit, immediate steps shall be taken to reduce the environmental level to or below the limit. If one or more of the samples collected in a work area reveal that the environmental level exceeds the standard, area sampling shall be repeated every month. This increased frequency of monitoring shall be continued for at least 2 months after the last sampling that demonstrated that dust level does not exceed the environmental limit.

(c) Cotton dust concentrations shall be monitored within 30 days after any change of process or operation which could adversely affect the environmental dust level.

(d) Records shall be maintained for all sampling schedules. These records shall include the sampling method, sampler locations, analytical method, type of respiratory protection in use, if any, and the measured dust concentrations in each work area. Each employee shall be able to obtain information on his own environmental exposure.

(e) Medical records and exposure data shall be kept for at least 20 years following an employee's termination of employment.

II. INTRODUCTION

This report presents the criteria and the recommended standard based thereon which were prepared to meet the need for preventing occupational diseases arising from exposure to cotton dust. The criteria document fulfills the responsibility of the Secretary of Health, Education, and Welfare, under Section 20(a)(3) of the Occupational Safety and Health Act of 1970 to "...develop criteria dealing with toxic materials and harmful physical agents and substances ..."

The National Institute for Occupational Safety and Health (NIOSH), after a review of data and consultation with others, formalized a system for the development of criteria upon which standards can be established to protect the health of workers from exposure to hazardous dusts as well as chemical and physical agents. It should be pointed out that any recommended criteria for a standard should enable management and labor to develop better engineering controls resulting in more healthful work practices and should not be used as a final goal.

These criteria and recommended standard for cotton dust are in a continuing series of criteria developed by NIOSH. The proposed standard applies only to the processing, manufacture, and use of cotton as applicable under the Occupational Safety and Health Act of 1970.

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]

IV. ENVIRONMENTAL DATA

Environmental Concentrations

Dust levels measured in cotton manufacturing areas can be influenced by such factors as the type of sampler used for the measurements, the duration of the sampling period, the location of the sampler relative to the dust-producing operations, the type and grade of cotton being processed, the type of operation being carried out on the cotton, the speed at which equipment is operated, air conditioning, location of air inlets, and the dust controls that are in effect for the operation being studied. Because of the number of variables involved, it is hard to arrive at general figures for dustiness which might be representative of the cotton industry as a whole. [127]

It is the usual practice to consider dust levels for the various processing operations separately. Operations usually considered are listed in Table IV-1. As cotton moves down the processing line to the final finished product, each processing operation removes undesirable trash and short fibers from the cotton. All operations may not be found in a single manufacturing plant.

TABLE IV-1

COTTON PROCESSING OPERATIONS

Growing and harvesting
Ginning
Opening, cleaning, and picking
Carding
Drawing and roving
Spinning, winding, and twisting
Spooling, beaming, and slashing
Weaving

from reference 128

Other than esthetics, primary interest in dust levels in cotton production areas relates to the prevalence or prevention of byssinosis. In early studies, the best correlation between the prevalence of the disease and the dust levels was found when the dust level was characterized by the middle-sized particles of relatively high protein content. [85] In more recent studies, the combined levels of middle-sized and fine dust appears to provide an even better correlation with byssinosis incidence. [11,13,129] The prevalence of byssinosis has little relationship to the fiber content of the air although fibers may represent a large percentage of the total mass of airborne material. [85,130] Also, this percentage is variable, depending on cotton type and grade, type of operation, and dust control techniques.

For all of these reasons, until recently there has been little uniformity in methods used to measure dust levels in the mills. Initially the high volume total mass sampler was employed for dust level measurements, [48,124] but more recently, samplers which measure only the smaller sizes of the dust have been used. The vertical elutriator of Lumsden and Lynch [124] in theory excludes all particles having aerodynamic diameters greater than 14.8 μm; the horizontal elutriator of Roach and Schilling [85] segregates the particles into coarse, medium, and fine sized fractions; and a personal sampling method [124,128] collects particles 29 μm and smaller. Although it would seem that the results from these different sampling methods cannot be compared, because of the nature of the cotton dust it is possible to make a rough comparison of results from the various methods. Using a cascade impactor, Lynch [124] measured an aerodynamic mass median diameter for cotton dust (excluding lint) of 4.5 μm with a geometric standard deviation of 3.0. This was the average of four long-term samples. Data reported by Merchant [131] on the size distribution of dust collected by the vertical elutriator of Lumsden and Lynch indicate that more than 80% of the particles have diameters of <3 μm.

Since the dust particles are generally relatively small and the main difference in the theoretical collecting ability of the three size-selective samplers is in the collection of the larger sizes of particles, rough agreement between the results from different investigators using the different sampling methods could be anticipated.

Table IV-2 lists crude average cotton dust levels as reported in the literature for various processing operations. This table is not complete; it makes no attempt to differentiate either between levels measured with or without controls, or between the grades of cotton being processed. It also does not take into account the variability of the individual dust samples as reported by the different investigators.

TABLE IV-2

GROSS AVERAGE COTTON DUST LEVELS REPORTED BY VARIOUS INVESTIGATORS

Operation	Investigator		Dust (mg/cu m)	Dust Excluding Lint (mg/cu m) Fixed Sampler	Personal Sampler
Ginning	El Batawi et al	[109]	15		
	Gilson et al	[31]		6-57 (RS)	
	Khogali	[111]		0.6 (RS)	
	Barnes & Simpson	[112]	20		
Opening	Hammad & Corn	[130]	7.1	3.0 (RS)	
	Hatcher & Lyons	[133]			3.1
	Merchant	[131]		1.6 (L)	
	Anglin	[134]		0.3 (L)	
	Silverman	[135]	17.2		
Picking	Lynch	[124]	6.6	0.7 (L)	2.5
	Hatcher & Lyons	[133]			1.3
	Merchant	[131]		1.7 (L)	
	Hammad & Corn	[130]	1.4	1.1 (RS)	
	Silverman	[135]	3.8		
Carding	Lynch	[124]	5.0	0.3 (L)	3.0
	Hammad & Corn	[130]	1.2	0.6 (RS)	
	Wood & Roach	[11]	1.6	1.0 (RS)	
	Merchant	[131]		1.8 (L)	
	Hatcher & Lyons	[133]			1.9
	Anglin	[134]		0.4 (L)	
	Silverman	[135]	4.1		
Drawing	Hammad & Corn	[130]	3.2	0.7 (RS)	
	Merchant	[131]		0.8 (L)	
	Anglin	[134]		0.4 (L)	
	Lynch	[124]	3	0.3 (L)	2.1
	Silverman	[135]	3.5		
Roving	Merchant	[131]		0.5 (L)	
	Silverman	[135]	4.0		
Spinning	Lynch	[124]	4.0	0.2 (L)	0.7
	Merchant	[131]		0.3 (L)	
	Hammad & Corn	[130]	1.8	0.3 (RS)	
	Silverman	[135]	1.5		

TABLE IV-2 (Continued)

GROSS AVERAGE COTTON DUST LEVELS REPORTED BY VARIOUS INVESTIGATORS

Operation	Investigator		Dust (mg/cu m)	Dust Excluding Lint (mg/cu m) Fixed Sampler	Personal Sampler
Wind & Twist	Lynch	[124]	14.3	0.3 (L)	1.2
	Merchant	[131]		0.3 (L)	
	Silverman	[135]	0.7		
Weaving	Lynch	[124]	1.4	0.4 (L)	0.8
	Merchant	[131]		1.1 (L)	
	Silverman	[135]	3.1		

Note: (L) Refers to vertical elutriator of Lumsden and Lynch. [124]
(RS) Refers to horizontal elutriator of Roach and Schilling. [85]
Measurement includes fine and medium size particles.

The table is useful in indicating the general trend of dustiness in various operations in the processing of cotton. For example, neglecting ginning (since the levels reported are not necessarily representative of the United States operations), it can be seen that the greatest respirable hazard based on dust, excluding lint, is associated with opening, picking, and carding. For these three areas typical respirable dust levels are about 1.5 mg/cu m. As will be discussed in the following section, dust control can appreciably reduce this level. It also appears that the personal sampler consistently measures dust levels higher than those determined using either the vertical or the horizontal elutriators. This observation was also noted in a study by Curtis et al [132] in a mattress factory. When the results of sampling with vertical elutriators are compared with results from personal samplers, the elutriator samples give on the average results which are about 65% of those measured with personal samplers. Although some of this difference could reflect a true difference due to the movement of the workers from one location to another during their work shift, the consistently higher personal sampler results suggest significant differences in the results indicated by the two samplers. This is also borne out by studies on an isolated draw frame reported by Barr et al. [127] A series of five measurements were made using a vertical elutriator, a personal sampler, and an OSHA general area sampler side by side. The results are shown below.

	mean concentration, mg/cu m	std deviation
Vertical elutriator	0.17	0.04
OSHA general area sampler	0.38	0.03
Personal sampler (stationary)	0.36	0.18

In this case the result determined with the vertical elutriator is 44% of that obtained by the personal sampler. However, no epidemiological studies have been completed which report prevalence of byssinosis with dust levels determined by personal sampling.

A series of samples taken at a single location can vary with time as a result of changes in operating conditions, with the presence or absence of local disturbances, and also with unknown or very obscure variables. On the other hand, a series of samples collected in the same work area at the same time will not necessarily give similar results. For example, measurements made in a large cardroom containing 40 cards before and after installation of dust control equipment gave results indicating greatly reduced dust concentrations (from 10-0.86 mg/cu m total dust) at two sampling locations in the room, but a much smaller percent reduction (from 10-2.97 mg/cu m) at a third location. [127] Prior to the test there was no reason to expect pronounced differences in the results for the three locations. It was concluded that the dust level at the high location resulted from the influx of dust from some other source in the mill.

Feasibility of Control

Control of dust levels in cotton-processing operations can be achieved by changing or treating the raw material which is the source of the dust, by changing the process which produces the dust, or by removing the dust from the air once it is generated.

The transition from natural to synthetic fibers in the past decade has resulted in lower byssinosis-producing dust levels in those mills using synthetics or blends. Merchant et al [18] reported a median dust level of 0.485 mg/cu m for 493 samples collected in mills working with pure cotton and a median dust level of 0.163 mg/cu m for 237 samples collected from mills using blends of natural and synthetic fibers. The synthetic fibers are virtually trash free and thus contribute little to the total sample collected. [136] It would be expected that, as the synthetic content of the raw material increased, the dust levels in most work areas would decrease.

A second method of changing the raw material is through the improvement of growing techniques to reduce the trash content of the cotton. Approaches such as developing cotton varieties which shed their bracts prior to maturation and harvest or the development of dwarf determinant cottons with increased fruiting potential compared to the production of vegetative parts [137] offer future potential methods of dust control, but at present these approaches are not feasible. There is little doubt that exposure to cotton dust trash has been greatly augmented by the replacement of handpicking by machines. [138] Studies are in progress to find new chemicals which will more efficiently defoliate cotton and reduce the trash content of the harvested seed cotton. [137]

A third method of changing the raw material is by steaming. Studies of this technique indicated that steaming could reduce the toxic effect of the cotton dust without rendering the cotton unsuitable for processing. [94] Some investigators conclude that the byssinosis-producing dusts are not removed or detoxified, but are just made to adhere more firmly to the cotton fibers; therefore the byssinosis problem is not solved but only moved from the opening, picking, and carding areas to the winding and weaving operations. [139] However, recent studies in a cotton spinning plant do not show an increase in downstream dust levels when processing steamed cotton. [140] Thus, while steaming may not be at this time a feasible alternative to dust control, it may become effective as a supplementary control method after further development. [140] Work is also in progress on improved ginning methods to allow for more efficient trash separation and/or fractionation. [137]

There appears to be little that can be done now to change the process in which cotton fibers are formed into yarn and woven into cloth in order to control dust production. The cotton manufacturing process is essentially one of fiber cleaning and alignment with the desired goal of removing all material in the cotton except the mature fibers. The dust in the cotton is thus an unwanted byproduct which must be dealt with. It is possible that the ginning process could be changed, and work is being actively pursued along these lines [137]; but at present process change does not appear to be a feasible alternative to dust control.

There are also a number of environmental factors which can be adjusted to some extent to control dust levels. As the opening and cotton cleaning machinery more efficiently removes trash and dust from the cotton stock, the release of this material into the work areas diminishes. Thus, dust levels in the picking room, cardroom, and subsequent operations can be reduced by better cleaning of the cotton in the opening and cleaning line. [141]

Decreasing the production machine density in a work area should decrease the dust levels in that area also. Conversely, if the machines are crowded together, higher dust levels would be expected. Dust emission is also increased by higher card speeds. Improperly or poorly maintained production machinery can also lead to higher dust levels. Hocutt [141] reports that cardroom dust levels are lower when the cards are well maintained and properly operated with alert operating personnel using precise machine settings.

Large central air-conditioning systems will tend to even out dust concentrations over the entire mill. [141] Of course, this might create new problems instead of getting rid of one, since it would cause increased dust level in some area while decreasing those in others. However, air-conditioning a textile mill does provide some dust control, but the control is incidental and the increased dust load in the air-conditioning unit will result in increased maintenance costs and impede the performance of the air conditioner. Dust is removed by the washer, a unit which acts as the primary humidifier and heat exchanger in the air-conditioning system. The washer is about 25% efficient for large particles [141] and much less efficient for smaller ones. Reliance on the air conditioner for dust control means that the dust must travel through the work area to reach the air-conditioner inlet, usually located on one wall of the room. Thus, the very nature of the system makes it inefficient for dust reduction or removal.

The capture and removal of dust from the air after it has been generated from the cotton represents the most widespread and efficient method of dust control at the present time. Table IV-3 gives summarized results from a study conducted recently by Barr et al [127] on the effectiveness of dust controls in mills having different degrees of dust control and processing varying grades of cotton. These results serve only to indicate the ranges of concentrations which may be expected for the different operations, with and without dust controls.

It appears that in some instances there may be dust concentrations (<0.5 mg/cu m) near cotton processing operations without dust control devices, but this would be the exception rather than the rule.

TABLE IV-3

RANGE OF TYPICAL LINT AND DUST CONCENTRATIONS

Operation	Total (mg/cu m)	Dust excluding lint (mg/cu m)*
Picking, no control	-	0.6 - 1.6
Picking, control	0.4 - 0.7	0.3 - 0.4
Opening and picking, no control	1.5 - 9.1	0.2 - 1.9
Opening and picking, control	-	0.3 - 0.5
Carding, no control	5.2 - 21.2	0.3 - 5.4
Carding, control	0.5 - 8.4	0.1 - 4.2

*As measured by the vertical elutriator

from reference 127

In a study of four cards, Wood and Roach [11] found dust removal to be less effective than indicated in Table IV-3; total dust levels ranged from 4.2-5.8 mg/cu m without dust extraction to 1.3-4.3 mg/cu m with dust extraction.

Efficient dust removal in cotton processing areas depends on two factors. First, there must be effective dust-capturing devices located at the points where dust could be generated. The captured dust is then transported away from the point of generation to a point where it can either be discharged to the outside atmosphere or removed by some means from the carrier air stream. Direct discharge of the captured dust to the outside atmosphere is not practical for two reasons. The dust is emitted in sufficient quantity to quickly produce its own air pollution problem outside, and some will probably find its way back into the work area negating the effect of the dust capture mechanisms. A second and often more compelling reason for not directly discharging into the atmosphere is the loss of conditioned air which must be replaced by new, heated or cooled makeup air. The quantities of air required for effective dust capture are large enough so that the usual practice is to recycle this air volume within the mill. [127]

Air which receives dust at one point and is cleaned at another point during complete recirculation will with time reach an equilibrium dust concentration. With ideal mixing, this concentration will equal the cleaned air dust concentration plus the ratio of the dust production rate divided by the recirculated air flow rate. [127] With good dust capture (low dust production rate) or a large recirculating air flow rate the concentration of dust in the air which is returned to the workroom will eventually determine the concentration of dust in that space. The isolation of dusty operations, successful in controlling dust exposures in other industries, has not been widely adopted in cotton mills.

In one study, dust concentrations in the return air were reported by Hammad and Corn [130] as 0.21 mg/cu m in the picking areas; 0.20 mg/cu m in the carding, drawing, and roving areas; and 0.13 mg/cu m in the spinning, spooling, and winding areas. Measurements made by Barr et al [127] ranged from 0.10-0.26 mg/cu m, depending on the type of air cleaning equipment in use. All samples were collected with a high volume sampler but the particles penetrating the air cleaners would be primarily in the respirable size range so that these values would most likely approximate measurements made with a vertical elutriator.

These studies [127,130] show that with highly efficient dust collection and removal it is possible to achieve dust levels of about 0.15 mg/cu m to 0.2 mg/cu m in some cotton mills where complete recirculation of the interior air is required. However, individual factors of each mill such as machinery type, condition, location, and isolation (or lack of it) may make achievement of this goal quite difficult in many cases. Also, since there is generally some leakage of air out of the mill as a result of work areas being kept at a positive pressure, [127] dust concentrations in the replacement outside air could become a significant factor when attempting to maintain interior concentrations below 0.2 mg/cu m.

Average suspended particle mass concentrations range from 0.01 mg/cu m in remote, nonurban areas to 0.06 mg/cu m in near-urban locations. In urban areas concentrations range from 0.06 to 0.22 mg/cu m depending on the size of the city and its industrial activity. In heavily polluted areas values up to 2.0 mg/cu m have been reported. [142] In the textile center of Greenville, SC, the median airborne particulate concentration measured in 1966 was 0.084 mg/cu m, and the 90% concentration was 0.15 mg/cu m. [99] High particulate loading in makeup air, whether cotton dust or not, would be measured as cotton dust due to the nonspecificity of dust measurement techniques.

In summary, it would appear from existing data that engineering controls can reduce dust levels in the working environments of opening, picking, carding, drawing, and combing areas below 0.5 mg/cu m as measured by the vertical elutriator. Equipment and systems that will maintain this dust level are commercially available. [127]

Consistently achieving levels of 0.2 mg/cu m would be more difficult particularly in the opening, picking, and carding areas. In general, systems designed to meet this concentration would have to have improved dust capture devices. Also dust collectors highly efficient in the removal of fine particles would be required. Both high-efficiency filtration and electrostatic precipitators are possible techniques to give the high degree of cleaning required, although there is some uncertainty as to whether present filter designs are capable of meeting a 0.2 mg/cu m concentration under all operating conditions. In general, meeting a 0.2 mg/cu m level as measured by the vertical elutriator in the working environments of opening, picking, and carding is now technically feasible but commercially available dust control equipment may not yet be obtainable.

Achieving a dust level of 0.1 mg/cu m would be even more difficult than attaining 0.2 mg/cu m for the same reasons given above. Also since 0.1 mg/cu m is in the range of community air levels for many small cities, makeup air in those areas would have to be meticulously cleaned before being used. The feasibility of achieving a level of 0.1 mg/cu m as measured by the vertical elutriator in the operating areas of opening, picking, carding, drawing and combing is not now evident using commercially available dust removal equipment. [127]

Environmental Sampling

The amount of dust suspended in the air is measured by drawing a known volume of air through a collector, assessing the amount of dust so collected, and expressing the results in terms of the amount of dust per unit volume of air. The concentration is generally reported as mass concentration although it sometimes might be more relevant to express the results in terms of the number or the surface area concentration of the particles. [143] Either by design or through imperfections in instrumentation, particles of different sizes, shapes, or densities are collected with different efficiencies. Therefore, it must be remembered that no two techniques of dust collection will give identical results. Because of their greater simplicity, gravimetric methods are most frequently used for measuring the concentration of cotton dust.

Gravimetric dust measuring techniques can be classified in terms of the size of particles collected (such as total-dust or size-selective sampling) and in terms of instrument location (area samplers and personal samplers). A total-dust sampler is a single stage collector and presumably captures all the particulate matter in a given volume of air. The actual proportion of particles collected, however, depends on both the orientation of the dust sampler inlet and the inlet velocity. In open-faced total-dust samplers an upward facing inlet results in oversampling, and a downward facing inlet results in undersampling. [124,128] The latter orientation also suffers from the danger of losing some of the collected dust when the filter is removed from the sampler. A sampler inlet in the vertical plane will collect a variable proportion of the larger particles depending upon the sampler inlet velocity and the air velocities in the vicinity of the sampler. [128]

Among the total-dust samplers that have been used to sample cotton dust are high volume samplers operating at flow rates of from 40-60 cu ft/min which deposit the collected particles on an 8 in. x 10 in. fiber glass filter. [48,94,124,127] In addition, small battery-powered sampling pumps equipped with polyvinyl chloride membrane filters in three-piece cassettes have been used. These pumps are usually operated at sampling rates of 1.5-2.0 liters/min [48,127,144] or with a critical orifice at 7.4 liters/min. [127,133,144] The cassette filter, when operating at a flow rate of 7.4 liters/min in a fixed location, is known as an OSHA Area Sampler. [144] When operating at a flow rate of 1.5 liters/min, it corresponds to conditions specified by OSHA for personal sampling. [144]

A variety of size-selective instruments have been used for dust sampling in textile plants. The hexhlet samplers used in the British studies [85,125] separate the dust into fine (<7 μm diameter), medium (7 μm to 2 mm), and coarse (>2 mm) size ranges. The instrument normally has a horizontal parallel plate elutriator at the inlet end which passes no dust >7.1 μm aerodynamic diameter. To measure the coarse dust, the horizontal elutriator is removed and replaced by a 2-mm x 2-mm mesh screen made from 0.2 mm diameter wire. Fly and lint collected on the screen are periodically wiped off, weighed, and reported as coarse dust. Medium dust is determined by the difference between the dust passing the screen (fine plus medium) and that passing the horizontal elutriator (fine dust). Some investigators refer to <7μm dust as respirable and <2 mm dust as fine [65] or fly-free. [126]

The first size-selective sampler described by US investigators was a high volume sampler fitted with a cyclone-type size-selector in front of the collecting filter. [124] This sampler had a perforated metal screen surrounding the cyclone entrance, and a small amount of air was drawn off through a filter at the bottom of the cyclone to retain fly. This sampler, which separated the dust into lint, middle, and respirable fractions with an aerodynamic cut-off diameter of 10 μm, [94] was considered to be too bulky for routine use in cotton mills. [124] Another size-selective sampling unit which has been used in American cotton mills is a personal sampler with an attached elutriating section having a size cut-off of about 29 μm aerodynamic diameter. [124]

Perhaps the most feasible sampler is the one developed by Lumsden and Lynch which uses the principle of vertical air elutriation and operates at a higher air volume than is possible with a personal sampler. [124] This sampler is sketched in Figure XII-2. The vertical elutriator cotton dust sampler was developed to have a size cut-off at 15 μm; the cut-off may be changed, however, by using a different air flow through the instrument.

A practical problem with size-selective samplers is that as a smaller size cut-off is used, the amount of dust collected decreases. [128] As weight is proportional to the cube of particle diameter, the mass of dust passing through the size-selector drops off rapidly as cut-off diameter is decreased. Where gravity elutriation is the principle used in size selection, an additional problem arises because the air flow 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 reducing the sampling rate more than 50%. The amount of dust collected in a sampler will, therefore, decrease rapidly as cut-off size is lowered. As the samples become smaller, weighing becomes more difficult. Some comparisons of dust concentrations measured by various samplers have been given in Tables IV-2 and IV-3.

Dust sampling procedures must be designed so that dust concentrations are measured accurately and consistently. Ideally, in order to determine the concentration of dust which is likely to enter the worker's respiratory system, it would be desirable to collect a personal dust sample near his breathing zone. In order for such a measurement to provide a meaningful result, however, the sample collected must correspond closely to that on which the hygiene standards are based. Since all the data obtained for prevalence of byssinosis versus dust concentration have been obtained from area sampling of dusts and most have involved size-selective sampling by instruments not readily adaptable for personal sampling, it is evident that dust concentrations measurements will have to be based on area sampling until adequate means of personal sampling for exposure to cotton dust are developed, and dose-response relationships based on such sampling methods are obtained.

If the fraction of respirable dust in a work area were a constant percentage of the total dust, it might be feasible to determine the respirable/total ratio by making measurements with suitable samplers (vertical elutriator for respirable dust and OSHA area samples for total-dust, for example) and then use this ratio to calculate the respirable dust obtained in a sample collected with a personal sampler. Unfortunately, this fraction varies considerably from area to area [85,124,127,145] and, much more importantly as shown in Table IV-4, it varies within an area even when similar materials are being processed. In textile plants personal samplers also suffer from drafts and air gusts which can either add or remove fly and lint from the face of the sampler.

TABLE IV-4

RESPIRABLE AND TOTAL COTTON DUST LEVELS REPORTED
AT DIFFERENT LOCATIONS WITHIN A CARDROOM
AND WHEN PROCESSING SIMILAR MATERIALS

Material Processed	Dust Concentration (mg/cu m)		Ratio Respirable/ Total (%)
	Respirable	Total	
Middling cotton*	0.44	0.73	60.3
	0.50	0.91	54.9
	0.42	1.49	28.2
	0.50	0.97	51.5
Strict low middling cotton**	1.15	11.89	9.5
	0.62	5.21	11.9
Strict low middling cotton heated at 325 F for 5 min.**	0.61	3.42	17.8
	0.34	2.32	14.7
Strict low middling cotton steamed at 212 F for 30 min.**	0.31	2.87	10.8
	0.51	1.25	40.8
Strict low middling cotton subjected to steaming cycle in bale**	0.23	1.91	12.0
	0.22	1.61	13.7
Strict low middling cotton steamed continuously at 212 F for 5 min.**	0.37	2.47	15.0
	0.20	1.96	10.2
	0.21	3.23	6.5
Strict low middling cotton steamed in production model steamer for 7 min.**	0.23	2.19	10.5
	0.26	2.70	9.6
	0.22	2.03	10.8
Strict low middling cotton steamed in production model steamer for 5 min.**	0.25	1.42	17.6
	0.31	1.62	19.1
	0.32	2.32	13.5
	0.68	7.77	8.8
	0.68	7.69	8.8

*Measurements at different locations within a cardroom [127] (respirable dust measured by vertical elutriator).

**Average measurements when processing similar materials [94] (respirable dust <10 μm measured by cyclone sampler).

These problems associated with the use of personal samplers might be alleviated with the addition of a small elutriator to the sampler. Such a sampler has been described, [124] but it had an aerodynamic cut-off diameter of 29 μm. According to John Lumsden of the North Carolina Department of Human Resources in a 1974 communication to NIOSH, a similar device with a cut-off diameter of 15 μm operating at a flow rate of 0.42 liters/minute is being evaluated. Should this device prove adequate for use as a personal sampler, the data it provides could perhaps replace or supplement data obtained with area samplers.

A modification of a dust sampler [146] in which dust is impacted on Mylar disc between a C14 source and a Geiger-Mueller tube has been described by Neefus. [147] The quantity of dust collected is determined by the reduction in beta ray counts between the beginning and the end of the sampling period. By attaching a vertical elutriator, only <15 μm dust is collected. (Apparently dust below 0.2 μm is also not determined). This device has the advantage of permitting measurement of short-term samples (on the order of 7 min.), as well as avoiding the time-consuming weighing procedure. The author [147] reported excellent agreement between results obtained with this instrument and those obtained with the Lumsden-Lynch unit. [124]

Until suitable personal samplers are available, however, the determination of dust concentrations should be made using the vertical elutriator operating at a flow rate of 7.4 liters/minute. Sampler locations should be selected to provide a representative sample of air to which the workers are exposed.

Sampling should be performed in distinct operating areas of the plant (opening, picking, carding, etc). Samples should be taken in each area at a minimum of five different sites representative of the area. The normalcy of the typical operation at the time of sampling is very critical to results and should be considered as important as frequency of sampling. For large areas (greater than 5000 sq ft), additional sampling sites should be selected with good industrial hygiene judgment. Placement of sampling equipment should be away from machinery and unnatural drafts. Exposure areas should be sampled every 6 months and whenever production techniques or mechanical ventilation changes are made.

If workers are not employed in the same area for most of the shift, a time-weighted average should be used to determine whether their exposure is within recommended limits. The time-weighted average is determined in the usual way, that is by summing the products of each fraction of the working shift by the dust concentration during that fraction of the shift (see Appendix I).

V. DEVELOPMENT OF STANDARD

Basis for Previous Standards

Roach and Schilling [85] in 1960 published byssinosis prevalence vs total-dust concentration data which indicated a negligible prevalence below 1 mg of dust/cubic meter of air. Their recommendation was that a target concentration of 2.5 mg/cu m be adopted. According to their data, the prevalence of byssinosis (Grades 1 and 2) below total dust levels of 2.5 mg/cu m was about 5%, and that of all grades 20%.

In 1964 the Threshold Limits Committee of the American Conference of Governmental Industrial Hygienists (ACGIH), [148] on the basis of Schilling's work, proposed a tentative TLV for cotton dust (raw) of 1.0 mg/cu m. This became a recommended value in 1966. [149] In its 1971 documentation of TLV's, [150] ACGIH noted the work of Bouhuys [151] in American mills who found "17 to 28% byssinosis at cotton dust levels averaging close to the recommended limit of 1 mg/cu m (ie 1.5-1.77 mg/cu m). In view of these findings, a ceiling limit of 1 mg/cu m of raw cotton dust (containing bract) that permits no excursions above this limit would seem more appropriate."

In a report on the Second International Conference on Respiratory Disease in Textile Workers, held in Alicante, Spain, September-October 1968, Bouhuys, Gilson, and Schilling [152] commented: "The standard of 1 mg/cu m for the threshold limit value of cotton dust (i.e. total dust).... may have to be revised downward in the light of recent findings that there are important exceptions to the dose-response relationship on which this proposal was based. Revision of the TLV in terms of respirable dust rather than total dust should also be considered."

This comment probably resulted in part from the report of Molyneux and Berry [125] at the conference, in which they concluded that:

"4. Although the present hygienic standard of 1 mg/cu m is reasonably formulated as a practical means of assessing the cardroom environment, its reference to total dust alone would appear to be unrealistic. The correlations described in this study suggest that respirable and medium fractions have a greater biological significance than was originally anticipated.

"5. The dust produced by the cardroom processes of medium and coarse mills is qualitatively similar but ring frames appear to produce dust which has a lower toxicity per unit mass than that of other processes in the same type of mill. This casts doubt upon the use of one hygienic standard for all mill processes."

Roach [153] noted that a 1.5% prevalence of byssinosis had been reported in workers exposed to concentrations of total dust below 0.5 mg/cu m and 2.8% exposed at between 0.5 and 1.0 mg/cu m. He suggested in 1970 that a concentration of <0.4 mg/cu m of dust excluding fly be considered negligible, and that concentrations between 0.5 and 1.4 mg/cu m be considered low, producing an estimated risk of <2% of causing the least demonstrable permanent effects on the lungs.

The British Occupational Hygiene Society Committee on Hygiene Standards, Sub-committee on Vegetable Textile Dusts, presented its recommendations on cotton dust in 1972. [126] It felt that a reasonable objective would be to reduce dust concentrations to a level where no more than 4% of the workers develop byssinosis Grade II (chest tightness or difficulty in breathing on the first and other days of the working week), and concluded:

"1. The total concentration of dust, less fly, is directly related to the prevalence of byssinosis of all grades and the relationship is similar for processes involving medium and coarse cotton.

"2. Dust levels (less fly) below 0.5 mg/cu m are associated with the occurrence of byssinosis symptoms of less than 20%.... The data from Table 2 [Table XII-11 in this document] suggest that this prevalence should not be associated with one of grade II symptoms higher than about 4%. The reasons for the higher prevalence of grade II symptoms found by Molyneux and Tombleson [ref 13 in this document] have already been discussed .... Since it is unlikely that all workers with grade II symptoms will be permanently affected, a maximum average dust concentration of 0.5 mg/cu m, less fly, should achieve the objective of reducing the risk of permanent effects to a very low level.

"3. Dust levels in excess of 1.0 mg/cu m may produce much higher prevalence of byssinosis and the disease may occur in susceptible individuals within the first 4 years of exposure.

"4. Waste operations should be considered in the high risk category as should spinning operations if they are not physically separated from the cardroom."

The committee noted, however, that Molyneux et al [13,125] found approximately 6% byssinosis (Grade II) at the recommended limit of 0.5 mg/cu m (fly-free). The Committee presented combined data indicating an overall ratio of less than one case of byssinosis (Grade II) per five cases byssinosis (all grades) as shown in Table XII-11.

In 1972 the ACGIH Threshold Limits Committee [154] proposed changing the TLV for raw cotton dust from 1 mg/cu m total dust to 0.2 mg/cu m of lint-free dust, as measured by the vertical elutriator based upon the work of Merchant et al. [18]

The Occupational Safety and Health Administration standard is 1 mg/cu m of cotton dust (raw) based on the ACGIH TLV of 1968 [29 CFR Part 1910.93, published in the Federal Register, volume 39, page 235411, dated June 27, 1974].

Basis for Recommended Environmental Standard

Several problems complicate the selection of a standard for occupational exposure to cotton dust. By far the most important single problem is that identity of the agent responsible for byssinosis and other respiratory ailments of cotton workers is unknown.

It has been shown [85] that the compositions of fine, medium, and coarse dusts in cotton mills vary, with cellulose predominating in the coarse fraction, while organic trash and minerals are concentrated in the medium and fine fractions. Berry and co-workers [65] found marked differences in byssinosis prevalence among different occupations, even when standarized for fine dust concentrations, length of exposure, and smoking habits. Others have failed to find significant correlation between byssinosis prevalence and dust concentration. [14,50,58,62] These findings could be due to the fact that the quantities of active agent in the dusts from different operations and mills may be substantially different. There appears to be no recognition of general differences due to the geographical location of the source of the cotton, although such variation has been reported. [87]

Preferably a limit for a noxious agent in the environment should be based on the concentration of active material. In the case of cotton dust there have been almost as many theories of the identity or nature of the responsible ingredient as investigators of the problem. Byssinosis has been reported as probably being due to a bacteria or fungi, [60] to an endotoxin of bacterial origin, [75] a condensed polyphenol, [90] a polysaccharide, [86,87] methyl piperonylate, [89,143] or to proteolytic enzymes. [92,93]

With the exception of proteolytic enzymes, no serious suggestion has been made that the health standard for cotton dust be based on the content or concentration in the air of the suggested causative agent. Although Tuma et al [93] did not suggest a limit based on the concentration in the air of proteolytic enzymes, their data would indicate a value of 0.2 to 0.4 milliunits per cubic meter (in fine dust) of chymotrypsin-like enzymes.

There is a precedent for basing health standards on airborne enzymes in the case of subtilisin, the enzyme added to some detergents. The proposed TLV for this substance is 60 nanograms per cubic meter of air [155]; in comparison, the TLV's for rhodium (soluble) and beryllium are 1,000 and 2,000 nanograms (1 and 2 μg) per cubic meter of air, respectively. In order to use a standard such as the one for subtilisin, which may require difficult and sophisticated analytical procedures, it is not always necessary to determine the etiologic agent in every air sample. If its concentration in the dust of a given process or area can be shown to be relatively constant, routine monitoring can be carried out by gravimetric determination of dust, appropriately sized.

Such a procedure could be utilized not only for proteolytic enzymes but for any of the other active agents in the dust, provided they could be quantitatively determined in dust samples sized in accordance with the air sampling procedure used.

According to Silverman and Viles, [156] cotton mill dust consists of three main components: cotton, inorganic material, and organic trash. A fourth component, starch, was found in some samples and was attributed to added sizing. The organic trash fraction contained nitrogen and carbohydrates, but appeared to be best characterized by its nitrogen content.

Roach and Schilling [85] made a similar classification in which they recognized cellulose, minerals, and protein as the major components. They found the best correlation between dust concentration and byssinosis to be with protein in medium-sized dust (7 μm to 2 mm). They found cellulose to be concentrated in the coarse fractions (85 - 94% cellulose) while minerals and proteins predominated in the medium and fine fractions.

Noweir [86] however reported that visual inspection of field data indicated a higher correlation of the incidence and severity of byssinosis with the concentration of carbohydrates than with that of protein in the airborne dust, a confirmation of the laboratory findings of Nicholls. [88]

No tabular or graphic presentation or correlations between different concentrations of protein or carbohydrate dust in the air of cotton mills and the prevalence of byssinosis appear to be available.

Using the analytical results of Roach and Schilling [85] it would be possible to recalculate the dustiness-prevalence data, at least for certain operations, in terms of the protein content of the dust. Since only a few investigators have analyzed dust for protein, however, such calculations would be dependent on assumptions as to dust composition and would add little to the data currently available, which are in terms of weight of dust, sized by various procedures.

Since there does seem to be a relationship between the activity of the dust and its trash or bract content, [8] analysis for these materials in airborne dust might seem to promise a better measure of hazard than determination of the weight of the dust. Such a measurement could be made by determination of the nitrogen content [156] or indirectly by measurement of the amount of cellulose and mineral matter. The biological activity of the dust could be assumed to be proportional to the percentage of nonmineral noncellulose matter. Again it would not be necessary to analyze each air sample for these generic components, but only to establish the average composition of dusts, of appropriate particle size, associated with specific operations or areas.

It is apparent that, if a standard for cotton dust exposure is to be established on the basis of available data, there is little alternative to specifying it as weight of dust per unit volume of air excluding as far as possible the fraction which seems to have little biological effect, namely the fly or lint. This fraction can be removed by a fine wire mesh, the usual British practice, or rejected by a suitably designed elutriator, or other appropriate means.

In common with other particulates, especially those whose main effect is on the respiratory system, the size of the particles of cotton dust as well as the number or quantity in the air, is a major consideration in assessing their potential biological effect. Various investigators have measured the total weight of airborne cotton dust in a given volume of air and at the same time have determined the prevalence of byssinosis in the mill or the department where the dust concentration was measured. [11,13,14,18,20,49,50,56,58,85,98,119-121,125] Many of these studies also included determinations of the concentrations of medium and fine (respirable) fractions. A few measured in addition to total dust only the fine fraction. [98,120,121] Others, using fine wire screens or cyclones to remove the coarse particles, determined only the fly-free dust (approximately the medium and fine fractions combined). [14,50,58,123] The vertical elutriator was employed in the investigation of Merchant et al, [18] collecting dust below 15 μm aerodynamic diameter, while Imbus and Suh [17, written communication from Imbus in 1972] used the same principle to collect finer dust (7 μm and smaller).

Although Roach and Schilling [85] found in 1960 a correlation between total dust concentration and byssinosis prevalence, more recent evidence has suggested that fine (respirable) particles, or fly-free dust (medium plus fine fractions), or those below aerodynamic diameter of 15 μm, are more significant. In 1962 McKerrow et al [129] reported: "It is concluded that the fine fraction (under 7 μm) of cotton mill dust produces changes in respiratory function and may be alone responsible." In 1970, however, Roach [153] based his classification of dust exposure on fly-free dust, ie, excluding the portion which would be caught on a 2-mm wire mesh or rejected by an elutriator designed to separate 50% of 15 μm diameter unit density spheres. Thus it seems to be that determination of fly-free dust, as practiced generally in England where the fly is removed by a 2-mm wire screen, [123,153] and dust below 15 μm aerodynamic diameter, as measured by a suitably designed and operated vertical elutriator, are the most practical measures to estimate cotton dust concentrations of hygienic significance. [18,124,157]

Although some authorities [153] consider that these two sampling methods yield very similar results, others [SG Luxon, written communication to NIOSH, 1972] have estimated that the elutriator collects about 40% less dust than the filter preceded by 2-mm wire screen.

In establishing standards for harmful agents in the work environment, the ideal solution is to select a level at which no detectable harmful effect occurs in any individual. This usually poses no problem with substances which are of low toxicity, or have physical and mechanical properties such that their presence in the air in significant quantities is improbable. In fact it is believed that this goal has been achieved in many of the standards in effect or proposed for substances of substantial or even high toxicity.

With materials which characteristically cause serious illness, disability, or death, the level should be set at a point where there is no detectable incidence of the disease (or increase in incidence of a non-specific disease or condition), and where a substantial safety factor would be provided.

On the other hand, if the effects of the agent are relatively mild, and in particular, completely reversible, one might argue that it is acceptable to set a limit at which a small percentage of workers will be affected to some degree, provided there is evidence that no permanent injury will eventually develop.

The effects of cotton dust do not appear to neatly fit any of these categories. There is evidence that in fact a certain percentage of workers affected with this condition may in time suffer permanent impairment of respiratory function, beyond that normally resulting from increased age and inhalation of cigarette smoke and other pollutants. [60] The ratio of prevalence of Grade 1/2 byssinosis to Grade 2 byssinosis is generally given as about 5 to 1. [126]

The British Occupational Hygiene Society (BOHS) [126] considers concentrations of cotton dust, less fly, below 0.5 mg/cu m of air to be acceptable and have established this limit as a standard for cotton dust in England. The fly, or lint, is removed by 2-mm mesh of 0.2-mm diameter wire. Concentrations in this range are reportedly (see Tables XII-10 and XII-11) associated with an occurrence of byssinosis symptoms (all grades) of <20%, and a prevalence of grade 2 symptoms of <4%.

Fox et al, [123] however, concluded that at this concentration (0.5 mg/cu m) only 10% of workers would have symptoms after 40 years' exposure. Their findings are in some disagreement with Berry and associates, [65] whose data predict a byssinosis prevalence of 30-60% for various preparation area workers after 40 years' exposure at 0.5 mg/cu m of fly-free cotton dust. Their results for ring spinners agree well with the findings of Fox and co-workers [123] for all categories of workers.

In contrast, in a 1974 written communication to NIOSH, Imbus maintains that the data published by him and his co-workers, [17] although not adjusted for length of exposure, are in general agreement with the results obtained by Fox et al [123]. Preparation area workers exposed at <0.5 mg/cu m had a prevalence of <10% byssinosis, while for yarn areas a prevalence of about 3% was found in over 1,000 employees exposed at 0.3 mg/cu m or less of <15 μm dust.

Merchant et al [18] however found a prevalence of 7% byssinosis (10% for smokers) in cotton preparation and yarn workers exposed at a concentration of 0.1 mg/cu m, and around 25% at the 0.5 mg/cu m level. If only carding workers had been included, higher prevalences would probably have been observed since it has been noted that ring spinners show a lesser prevalence than those engaged in other yarn preparation processes. [17,125]

Merchant et al [18] recommended that an environmental limit be set at 0.1 mg/cu m, as measured by the vertical elutriator.

Even though the limit of 0.1 mg/cu m recommended by Merchant et al [18] does not provide, according to their own data, complete protection against symptoms of byssinosis, it is so low that its application could involve some problems in interpretation due to possible interference from background dust. The Environmental Protection Agency national primary and secondary standards for particulate matter in ambient air are 75 μg (0.075 mg)/cu m and 60 μg (0.060 mg)/cu m respectively, as published in the Federal Register, volume 36, pages 8186-87, April 30, 1971. This would mean that, in an area where atmospheric pollution was present, even though the limit was not exceeded, the concentration of dust and fume in the outside air could approach the 0.1 mg/cu m suggested limit for dust inside cotton mills.

However, one would expect that a portion of the atmospheric pollution outside the mill would be made up of dust from the mill, thereby reducing the effect any outside particulate matter may have upon air samples taken inside the mill.

There remains the TLV proposed by the ACGIH [155] of 0.2 mg/cu m of dust determined by the vertical elutriator, so designed and operated that half the <15 μm diameter unit density spheres would be separated. [153] The dust so collected is frequently designated as <15 μm or lint-free dust. This limit is twice that recommended by Merchant et al, [18] and two-thirds the BOHS [126] limit, if the estimate [supplied by SG Luxon in a written communication to NIOSH in 1972] that 0.3 mg/cu m of cotton dust collected with the vertical elutriator corresponds to 0.5 mg/cu m by the British sampling method for fly-free dust is correct. Interference from background dust would obviously constitute a less serious problem with 0.2 mg/cu m than with a 0.1 mg/cu m limit.

A compilation of the reported cases of byssinosis, all grades, (see Table XII-6), which have been correlated with measured dust exposure, indicates about 1,980 cases. [11,14,18,49,50,65,85,93,119,120,122, 123,125,126, a 1972 written communication from HR Imbus] The exposure data have been obtained by various sampling procedures, but results are given in terms of total dust; coarse, medium and fine (respirable) dust; fine dust (<7 μm); medium dust (7 μm to 2 mm) meaning it passed through a 2-mm wire mesh but not through a Hexhlet horizontal elutriator; fly-free or lint-free dust; or <15 μm dust. In a few cases cyclones were utilized to separate coarse particles.

In the majority of cases, the coarse dust constituted between 50 and 80% of the total, [11,14,58,62,124,125] although percentages as low as 11% [50] and as high as 85% [58] were reported. Concentrations of fine dust ranged from 3% [124] to 57% [120] of those of total dust. Some investigators [49,56,62,85,124] found two to five times as much medium dust as fine, but others [11,13,125] reported about equal amounts in the medium and fine fractions. In general, dusts from carding processes were finer than those from other operations.

Based on the assumption that, where actual data are not given, the fly constituted 70% of the total dust, and the medium sized and fine fractions were present in equal quantities, it is possible to estimate how many of the 1,980 cases of byssinosis were associated with concentrations of fly free or <15 μm dust below 0.25 mg/cu m. Over 1,880 of the cases occurred in areas or plants where average concentrations were above this level. The majority of these reports [13,14,49,50,58,65,119-121,123,125] did not indicate any definite exposures to concentrations below 0.25 mg/cu m. Of the approximately 85 cases which had exposures below 0.25 mg/cu m, 58 were recorded by Merchant et al. [18] Six are included from the early paper of Roach and Schilling, [85] and 11 from Lammers et al, [98] consisting of spinners in English and Dutch mills where average fine dust concentrations of 0.03 and 0.1 mg/cu m, respectively, were found. None of the 13 cases mentioned by Fox et al [123] exposed at concentrations below 1 mg/cu m (and averaging about 0.5) are used. The 23 cases recorded by Imbus and Suh [17, written communication from HR Imbus, 1974] had exposures below 0.2 mg/cu m.

Of 64 cases associated with dust concentrations below 0.25 mg/cu m reported by two investigators, [18,85] 13, [18] or 20%, were diagnosed as Grade 2 or 3. In comparison 158 (21%) of 749 cases with heavier exposure were classified as Grade 2 or 3.

Under ordinary circumstances, the above data would provide strong justification for a standard of 0.25, or at least 0.2 mg/cu m. The almost unanimous conclusion that there is a linear dose-response relationship, at least in the lower concentrations, [126,157] and the finding by Merchant et al [18] of cases of byssinosis can be associated with dust levels as low as 0.05 mg/cu m, however, cannot be ignored.

If some of the dose-response data are plotted linearly, notably those of Molyneux and Berry [125] and Imbus and Suh, [17, and a 1972 written communication from Imbus] a substantial prevalence up to over 10% is indicated at zero exposure, an unlikely occurrence. If adjusted for this anomaly, the findings of Molyneux and Berry, [125] as plotted by Anderson et al, [157] show an increase in byssinosis prevalence well below 10% at 0.2 mg/cu m, if the presence of fine dust in amounts approaching those of medium dust is assumed. Assuming the concentration of <15 μ dust to be twice that of <7 μm dust, the data of Imbus and Suh, [17, and a 1972 written communication from Imbus] similarly treated, indicate prevalence increases of <3% at 0.2 mg/cu m. Braun et al, [92] although finding a poor correlation between dust concentration and response, reported an average of 20% of subjects with a 10% or more drop in FEV 1 at a concentration of fine (fly-free) dust of about 1 mg/cu m, compared to a 45% byssinosis prevalence reported by Merchant et al. [18] Mekky et al [49] found 20.5% byssinosis prevalence in cardrooms where the concentration of fine plus medium dust averaged 1.64 mg/cu m. Valic and Zuskin [122] reported 21% byssinosis among nonsmoking female cotton workers with about 9 years' exposure, where an average of 0.55 mg/cu m of respirable dust (presumably at least 1.1 mg/cu m of <15 μm dust) was found.

In a summation of earlier data, Roach [153] concluded that the prevalence of all grades of byssinosis at concentrations below 1 mg/cu m of total dust (0.2 to 0.3 mg/cu m of <15 μm dust) would be 4% or less.

Studies with steamed cotton [94,114] have indicated a decrease in the biologic activity of the dust produced in subsequent processing operations. Other investigators have reported a lower prevalence of byssinosis in certain occupations (eg, ring spinning, [65,125] or yarn areas, [17] and slashing and weaving [18]) at given dust levels, with the implication that higher limits might be applicable in such situations. Data [139,140] at this time do not justify a separate standard for steamed cotton.

While the correlation between incidence of byssinosis and levels of airborne cotton dust is not consistent between investigators, the data show a gradual decrease in disease prevalence with decreasing dust levels. But even at levels of 0.1 or 0.2 mg/cu m there has been a definite incidence of byssinosis. (In fact, a linear extrapolation of the data suggests a finite incidence of disease in the complete absence of cotton dust, ie at 0 mg/cu m, an unlikely result.) At levels below 0.1 mg/cu m (and perhaps even near 0.1 mg/cu m) background dust levels, indistinguishable from cotton dust by available sampling methods, would further confuse any attempt to establish a limit in this range.

For these reasons, NIOSH cannot recommend an environmental limit of cotton dust that will prevent all adverse effects on workers' health. However it is evident that lower cotton dust levels result in a decrease in the prevalence of byssinosis. It is recommended that any permanent standard also incorporate a program of medical monitoring and management, work practices, and administrative controls, as well as the lowest feasible environmental limit which has been indicated to be less than 0.2 mg lint-free cotton dust/cu m of air. [127]

In support of this recommendation, it should be noted that there is considerable evidence, both epidemiologic and experimental, suggesting that cotton dust per se is not the cause of byssinosis, but that some biologically active material, perhaps a proteolytic enzyme or a foreign protein, is carried by cotton dust into the lungs of workers and causes the disease. Research on this point as well as on other aspects of cotton dust disease should be vigorously pursued with the eventual goal of developing scientific data that will enable development of a better occupational health standard for cotton dust. Pending acquisition of more information, it is recommended that available knowledge be used to limit adverse effects in workers to the maximal feasible extent.

VI. WORK PRACTICES

(a) Operating Procedures

To reduce workers' exposure to cotton dust, management must actively seek and implement engineering controls and should maintain all engineering, dust capture, ventilation, and physical control systems in efficient working order at all times.

For those processes and areas in which engineering controls are not practicable or completely effective in reducing dust levels to the required standards, administrative controls and medical surveillance programs should be used to assure that the exposure of workers identified as reactors to cotton dust is below the recommended environmental limit (see Section I).

The operator in turn must realize that specific work practices and actions can reduce individual exposure to cotton dust. In order to insure that the employee understands that much of the effectiveness of operating procedures will be a direct result of individual actions, the following programs should be initiated in all areas were exposure may occur:

(1) Employees must be informed by supervisory and/or medical personnel of the potential health hazards of an environment where exposure to cotton dust may occur. This should include information as to the clinical symptoms of byssinosis with emphasis on such symptoms as chest tightness, their frequency and progression.

(2) Each employee shall be instructed in approved work practices to insure his understanding of the importance of specific operating procedures designed to reduce exposure to harmful levels of cotton dust and to prevent the resuspension of settled dust. Such work practices shall be posted in the workplace.

(3) Specific work practices should be established and posted for all work positions. The following example of such a work practice for an Opening Room Operator has been recommended by the American Textile Manufacturers Institute [158]:

Position: Opening Operator

Location: Opening Room

Classification of Area: High Risk Area

General Duties: The operator feeds cotton to the opening hoppers in small layers from the bales and places into hoppers. The operator also stacks baling material and performs cleaning operations around the hoppers, feed table, condenser, and general work area.

Specific Work Habits:

(A) All operators should be instructed to keep cotton as far away from his face as possible when feeding hoppers. This can be accomplished by only feeding hoppers with layers of cotton which should not exceed approximately three inches.

(B) When stacking and sorting baling material, the operator should not shake or throw material into piles. Baling material should be stacked as it is removed from the bale and should not be left to pile up.

(C) Specific locations should be designated for baling material pending removal.

(D) When performing preshift and shift cleaning operations, approved respirators must be worn regardless of the risk classification of the area.

(E) During preshift cleaning operations, all waste from under the hoppers, feed table, and condenser should be removed with the equipment provided. Waste should not be gathered up in the operator's arms to be piled.

(F) Shift cleaning shall be performed with only that equipment designed for cleaning operations.

(G) When removing chokes from hoppers and the table shafts, respirators shall be worn.

Similar work practices should be developed by management for all positions in the waste house, opening, picking, carding, drawing, combing, roving, spinning, winding, twisting, weaving, knitting, and for other locations where cotton is processed. A positive attitude on the part of plant management toward dust control is essential to an effective work practices program. Employees must be frequently reminded and encouraged to follow practices which minimize dust exposure.

(b) Personal Protective Equipment and Respiratory Protection

The most desirable means of controlling cotton dust exposure is through appropriate process design and engineering control techniques. However, individual respiratory protection devices become necessary in certain nonroutine operations not amenable to dust reduction by engineering control methods. For example, some maintenance operations must be performed inside air washers or on machinery when dust control systems are temporarily disconnected; many preshift and shift cleaning operations generate high dust concentrations and require individual respiratory protection. Respirators should only be considered for use during such operations which are performed for short periods--no longer than 1/2 hour/day. Respirators should not be used as a primary control measures in lieu of appropriate environmental controls during routine, on-going operations.

A number of different types of respirators are available for use in protecting against harmful dusts. These range from half-mask, single-use type respirators approved for use at lower dust levels to the full facepiece, air-powered regulators for protection against very high concentrations of most toxic materials. An exploratory investigation of the performance of half-mask, single-use dust respirators in a textile plant environment has demonstrated that these respirators, when properly used, can be effective in reducing cotton dust inhalation. [159] Approved single-use respirators had filtering efficiencies ranging from 93-99% and were reported to be generally convenient from the standpoint of being lightweight, offering low resistance to breathing, and requiring little or no maintenance. Higher degrees of protection are provided by half-mask and full-facepiece type regulators with replaceable filter elements.

In addition to a proper respirator, an effective respirator program should include appropriate operating procedures and employee training in respirator use. All operations and locations where respirators are required should be clearly specified and so designated in the workplace. Adequate instructions should be given to employees on respirator fit, adjustment, inspection, and any necessary maintenance or replacement. Frequent random inspections should be conducted by the plant safety engineer, nurse, industrial hygienist or physician. A maintenance program should be established to ensure that respirator filters and disposable respirators are changed according to practices outlined in American National Standard Practices for Respiratory Protection, Z88.2. [160] Employees experiencing any breathing difficulty while using respirators should be referred to a physician for evaluation.

Where respirators are furnished for use by workers, they shall be those approved by the National Institute for Occupational Safety and Health and/or the Bureau of Mines for pneumoconiosis-producing dusts. Whenever respirators are used, a respirator program conforming to the requirements of the Occupational Safety and Health Standards, part 1910.134 shall be followed. (29 CFR Part 1910.134 published in the Federal Register, volume 39, page 23671, dated June 24, 1974)

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VIII. APPENDIX I

AIR SAMPLING AND ANALYTICAL PROCEDURES FOR DETERMINING CONCENTRATIONS OF COTTON DUST

As discussed in Chapter IV, Environmental Sampling, the preferred index of cotton dust exposure is the concentration of dust in mg/cu m collected by the Lumsden-Lynch vertical elutriator cotton dust sampler, shown in Figure XII-2, operating at the prescribed flow rate. Any instrument shown to be equivalent in precision and accuracy to the method specified shall be acceptable.

Sampling Locations

The sampling procedure must be designed so that samples of the actual dust concentrations are collected accurately and consistently and reflect the concentrations of dust at the place and time of sampling. In order to collect an ideal sample representative of airborne dust which is likely to enter the worker's respiratory system, it is necessary to position a collection apparatus near the nose and mouth (breathing zone) of the worker. As discussed earlier, suitable instrumentation is not yet available which will permit reliable samples of lint-free dust to be collected with personal samplers. At least five 6-hour area samples in each distinct operational area of the plant should be collected at locations which provide representative samples of air to which the worker is exposed. Samples in each operating area should be gathered simultaneously during a normal operating period. The daily time-weighted average (TWA) exposure of each worker can then be determined by using the following formula:

$$\text{TWA} = \frac{\text{Summation of hours spent in each location times the dust concentration in that location}}{\text{Total hours exposed}}$$

A time-weighted average concentration shall be computed for each worker and properly logged and maintained on file for review.

Sampling Equipment

(a) Sampler

The vertical elutriator (Figure XII-2) cotton dust sampler works on the principle of producing a slow laminar up-flow of air that equals the falling speed of dust particles at the upper end of the respiratory range. Particles with falling speed greater than this, such as cotton fly and lint fibers, and dust particles larger than 15 μm aerodynamic diameter and unit density will not be carried to the filter and thus will not be sampled. The sample collected will include all fine dust except lint and will approximate the sum of alveolar and bronchotracheal deposition. The flow rate is controlled at 7.4 ± 0.2 liters/minute by a critical orifice which requires that the vacuum be maintained above 14 inches of mercury.

In order to insure proper dust measurement, pumps have to be monitored and vacuums checked during sampling. It is important that the samplers be cleaned prior to sampling.

(b) Filter Holder

A three-piece cassette constructed of polystyrene designed to hold a 37-mm diameter filter such as that shown in Figure XII-3 shall be used. To insure that an adequate seal exists between elements of the cassette, an opaque cellulose shrink band shall be placed over the joint between the center and bottom parts of the cassette. Polystyrene is recommended as a construction material because polyvinyl chloride filters increase in weight when stored in cassettes made from cellulose acetate-butyrate, which are commonly used in cotton dust sampling. [161] It is thought that plasticizers and possibly butyric acid from the hydrolysis of ester linkages in this latter material are readily absorbed by the filter to alter its weight.

(c) Filters and Support Pads

The membrane filters used shall be polyvinyl chloride with a 5-μm pore size and 37-mm diameter. A support pad, commonly called a backup pad, must be used under the filter membrane in the field monitor cassette.

(d) Balance

A balance sensitive to 0.01 milligram should be used.

Instrument Calibration Procedure

The accuracy of an analysis can be no greater than the accuracy of the volume of air which is sampled. Therefore, accurate calibration of the sampler is essential. The frequency of calibration is dependent on the use, care, and handling to which the instrument is subjected. Samplers should be calibrated when first received from the factory, after repair, and after receiving any abuse. Ordinarily the samplers should be calibrated in the laboratory both before they are used in the field and after receiving any abuse or after extensive use. The accuracy of calibration is dependent upon the type of instrument used as a reference. For laboratory testing, primary standards such as a spirometer or a wet test meter are recommended, although other standard calibrating instruments such as a large bubble meter or dry gas meter can be used. The setup will be the same for all instruments. Instructions for calibration with the wet test meter follow. If another calibration device is selected, equivalent procedures should be used.

The calibration setup for the limiting orifices with the sampling train system is shown in Figure XII-4. The procedure is as follows:

(a) Level wet test meter. Check the water level which should just touch the calibration point at the left side of the meter. If water level is low, add water 1-2 F warmer than room temperature to fill point. Run the meter for 30 minutes before calibration.

(b) Place the polyvinyl chloride membrane filter in the filter cassette.

(c) Assemble the calibration sampling train as shown in Figure XII-4.

(d) Connect the wet test meter to the train. The pointer on the meter should run clockwise and a pressure drop of not more than 1.0 inch of water indicated. If the pressure drop is greater than 1.0 disconnect and check the system.

(e) Operate the system for ten minutes before starting the calibration.

(f) Check the vacuum gauge on the pump to insure that the pressure drop across the orifice exceeds 14 inches of mercury.

(g) Record the following on calibration data sheets:

(1) Wet test meter reading, start and finish

(2) Elapsed time, start and finish (at least two minutes)

(3) Pressure drop at manometer

(4) Air temperature

(5) Barometric pressure

(6) Limiting orifice number

(h) Calculate the flow rate and compare against recommended flow of 7.4 ± 0.2 liters/minute. If flow is between these limits perform calibration again, average results, and record orifice number and flow rate. If flow is not within these limits discard or modify orifice and repeat procedure.

(i) Record the name of the person performing the calibration, the date, serial number of the wet test meter, and the number of the critical orifices being calibrated.

Sampling Procedure

(a) Sampling data sheets shall include a log of:

(1) The date of the sample collection

(2) The time of sampling

(3) The location of the sampler

(4) The sampler serial number

(5) The cassette number

(6) The time of starting and stopping the sampling and the duration of sampling

(7) The weight of the filter before and after sampling

(8) The weight of dust collected (corrected for controls)

(9) The dust concentration measured

(10) Other pertinent information

(11) Name of person taking sample

(b) Assembly of Filter Cassette (see Figure XII-3)

(1) Loosely assemble 3-piece cassette

(2) Number cassette, top and bottom

(3) Place absorbant pad in cassette

(4) Weigh filter to an accuracy of 0.01 mg

Although it has been common practice to desiccate the filters prior to weighing for periods up to 24 hours, [127,158,161] it has been demonstrated that when the specified highly hydrophobic polyvinyl chloride filters are used, less than 1/2% of the total weight could be attributed to the absorption of water by the dust or by the filter. [132] In another study, the highest observed variation between desiccated and nondesiccated dust weights was 2%. [161] When samples having a high rate of moisture regain are weighed directly after removing them from a desiccator, the elapsed time after removal becomes a significant factor. Under these conditions the best way to accurately weigh such samples could be in a conditioned atmosphere. [161] Because of these findings, desiccating prior to weighing the filters is not required.

(5) Place filter in cassette

(6) Record weight of filter in log, using cassette number for identification

(7) Fully assemble cassette, using pressure to force parts tightly together

(8) Install plugs top and bottom

(9) Put shrink band on cassette, covering joint between center and bottom parts of cassette

(10) Set cassette aside until shrink band dries thoroughly

(c) Sampling Collection

(1) Clean lint out of the motor and elutriator and clean the relief valve screen

(2) Install vertical elutriator in sampling locations specified above with inlet 4 1/2 to 5 1/2 feet from floor (breathing zone height)

(3) Remove top section of cassette

(4) Install cassette in ferrule of elutriator

(5) Tape cassette to ferrule with 1 in. wide masking tape or similar material for air-tight seal

(6) Remove bottom plug of cassette and attach hose containing critical orifice

(7) Start elutriator pump and check to see if gauge reads above 14 in. of Hg vacuum.

(8) Record starting time, cassette number, and sampler number

(9) At end of sampling period (a approximately 6 hours) stop pump and record time

(10) Controls

With each batch of samples collected, two additional filter cassettes should be subjected to exactly the same handling as the samples except that they are not opened. These control filters are weighed the same as the sample filters. Any difference in weight in the control filters would indicate that the procedure for handling sample filters may not be adequate and should be evaluated to ascertain the cause of the difference, the necessary corrections made, and additional samples collected.

(c) Shipping

The cassette with samples are collected, along with the appropriate number of blanks, and shipped to the analytical laboratory in a suitable container to prevent damage in transit.

(d) Weighing Sample

(1) Remove shrink band

(2) Remove top section of cassette and bottom plug

(3) Remove filter from cassette and weigh to an accuracy of 0.01 mg

(4) Record weight in log against original weight

(e) Calculation of Volume of Air Sampled

(1) From starting and stopping times of sampling period, determine length of time in minutes of sampling period

(2) Multiply sampling time in minutes by flow rate of critical orifice in liters per minute and divide by 1000 to find air quantity in cubic meters

(f) Calculation of Dust Concentration

(1) Subtract weight of clean filter from dirty filter and apply control correction to find actual weight of sample. Record this weight (in mg) in log

(2) Divide mass of sample in mg by air volume in cubic meters to find dust concentration in mg/cu m. Record in log.

IX. APPENDIX II

MATERIAL SAFETY DATA SHEET

The following items of information which are applicable to the processing of cotton shall be provided in the appropriate section of the Material Safety Data Sheet or other approved form. If a specific item of information is inapplicable (eg, flash point), the initials "na" (not applicable) should be inserted.

(a) Section I. Source and Nomenclature.

(1) The name, address, and telephone number of the manufacturer or supplier of the product.

(2) The trade name and synonyms for a mixture of chemicals, a basic structural material, or for a process material; and the trade name and synonyms, chemical name and synonyms, chemical family, and formula for a single chemical.

(b) Section II. Hazardous Ingredients.

(1) Chemical or widely recognized common name of all hazardous ingredients.

(2) The approximate percentage by weight or volume (indicate basis) which each hazardous ingredient of the mixture bears to the whole mixture. This may be indicated as a range or maximum amount, eg, 10-20% V; 10% max. W.

(3) Basis for toxicity for each hazardous material such as an established standard, in appropriate units.

(c) Section III. Physical Data.

Physical properties of the total product including boiling point and melting point in degrees Fahrenheit; vapor pressure, in millimeters of mercury, vapor density of gas or vapor (air = 1), solubility in water in parts per hundred parts of water by weight; specific gravity (water = 1); percent volatile, indicate if by weight or volume, at 70 Fahrenheit; evaporation rate for liquids (indicate whether butyl acetate or ether = 1); and appearance and odor.

(d) Section IV. Fire and Explosion Hazard Data.

Fire and explosion hazard data about a single chemical or a mixture of chemicals, including flash point, in degrees Fahrenheit; flammable limits, in percent by volume in air; suitable extinguishing media or agents; special fire fighting procedures; and unusual fire and explosion hazard information.

(e) Section V. Health Hazard Data.

Toxic level for total compound or mixture, effects of exposure, and emergency and first aid procedures.

(f) Section VI. Reactivity Data.

Chemical stability, incompatibility, hazardous decomposition products, and hazardous polymerization.

(g) Section VII. Spill or Leak Procedures.

Detailed procedures to be followed with emphasis on precautions to be taken in cleaning up and safe disposal of materials leaked or spilled. This includes proper labeling and disposal of containers containing residues, contaminated absorbants, etc.

(h) Section VIII. Special Protection Information.

Requirements for personal protective equipment, such as respirators, eye protection, and protective clothing, and ventilation such as local exhaust (at site of product use or application), general, or other special types.

(i) Section IX. Special Precautions.

Any other general precautionary information.

U.S. DEPARTMENT OF LABOR
Occupational Safety and Health Administration

Form Approved
OMB No. 44-R1387

MATERIAL SAFETY DATA SHEET

Required under USDL Safety and Health Regulations for Ship Repairing, Shipbuilding, and Shipbreaking (29 CFR 1915, 1916, 1917)

SECTION I

MANUFACTURER'S NAME	EMERGENCY TELEPHONE NO.
ADDRESS *(Number, Street, City, State, and ZIP Code)*	
CHEMICAL NAME AND SYNONYMS	TRADE NAME AND SYNONYMS
CHEMICAL FAMILY	FORMULA

SECTION II - HAZARDOUS INGREDIENTS

PAINTS, PRESERVATIVES, & SOLVENTS	%	TLV (Units)	ALLOYS AND METALLIC COATINGS	%	TLV (Units)
PIGMENTS			BASE METAL		
CATALYST			ALLOYS		
VEHICLE			METALLIC COATINGS		
SOLVENTS			FILLER METAL PLUS COATING OR CORE FLUX		
ADDITIVES			OTHERS		
OTHERS					

HAZARDOUS MIXTURES OF OTHER LIQUIDS, SOLIDS, OR GASES	%	TLV (Units)

SECTION III - PHYSICAL DATA

BOILING POINT (°F.)		SPECIFIC GRAVITY (H_2O=1)	
VAPOR PRESSURE (mm Hg.)		PERCENT, VOLATILE BY VOLUME (%)	
VAPOR DENSITY (AIR=1)		EVAPORATION RATE (________ =1)	
SOLUBILITY IN WATER			
APPEARANCE AND ODOR			

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (Method used)	FLAMMABLE LIMITS	Lel	Uel
EXTINGUISHING MEDIA			
SPECIAL FIRE FIGHTING PROCEDURES			
UNUSUAL FIRE AND EXPLOSION HAZARDS			

SECTION V - HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE
EFFECTS OF OVEREXPOSURE
EMERGENCY AND FIRST AID PROCEDURES

SECTION VI - REACTIVITY DATA

STABILITY	UNSTABLE		CONDITIONS TO AVOID
	STABLE		
INCOMPATIBILITY *(Materials to avoid)*			
HAZARDOUS DECOMPOSITION PRODUCTS			
HAZARDOUS POLYMERIZATION	MAY OCCUR		CONDITIONS TO AVOID
	WILL NOT OCCUR		

SECTION VII - SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED
WASTE DISPOSAL METHOD

SECTION VIII - SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION *(Specify type)*		
VENTILATION	LOCAL EXHAUST	SPECIAL
	MECHANICAL *(General)*	OTHER
PROTECTIVE GLOVES	EYE PROTECTION	
OTHER PROTECTIVE EQUIPMENT		

SECTION IX - SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING
OTHER PRECAUTIONS

MEMORANDUM

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
CENTER FOR DISEASE CONTROL
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

TO : Assistant Institute Director
for Research and Standards Development

DATE: April 27, 1973

FROM : Special Assistant for Medical Criteria

SUBJECT: NIOSH Ad Hoc Committee on Pulmonary Function Evaluation

The following members participated:

Harold Imbus, M.D., Medical Director, Burlington Industries, Greensboro, N.C.

Arend Bouhuys, M.D., Professor of Medicine and Epidemiology Yale University, School of Medicine, New Haven, Conn.

Roscoe C. Young, Jr., M.D., Assoc. Professor of Medicine, Howard University Medical School, Washington, D.C.

K. Albert Harden, M.D., Emeritus Dean, Professor of Medicine Howard University, Washington, D.C.

Thomas G. Shelton, M.D., Chief Pulmonary Disease Service, Veteran's Hospital, Tuskegee, Ala.

Robert B. O'Connor, M.D., Consultant in Occupational Health to NIOSH

William S. Lainhart, M.D., NIOSH, Cincinnati, Ohio

Keith C. Morgan, M.D., NIOSH, ALFORD, Morgantown, W.Va.

N. Leroy Lapp, M.D., NIOSH, ALFORD, Morgantown, W.Va.

The above committee was selected to advise NIOSH on how best to inform physicians practicing industrial medicine of the differences in lung volumes between black and white workers. Allowances should be made in pre-employment examinations for such ethnic differences.

Because of suspected ethnic differences in simple tests of lung function used in preplacement of employees entering the textile industry, the ad-hoc committee convened on March 14, 1973 to determine the significance of this difference, and to discuss methods of eliminating it, so as to exercise proper precautions in prevention of byssinosis on one hand, and not be discriminating in hiring practices on the other.

The committee agreed that there is a difference in pulmonary vital capacity between various ethnic groups which in turn may be affected by other variables, e.g., geographical location, altitude, the underlying physiological cause for the difference is not known.

Several comparative studies on the vital capacity of black and white workers were discussed. The committee agreed that review of these studies showed the pulmonary vital capacity of black workers to be in general, about 15% less than that of white workers, for persons of equal height and age.

Dr. Imbus described his experience in pre-employment examinations of cotton workers. He found 20 workers in one group with a pulmonary vital capacity less than 75% of the predicted normal based on the accepted VA-U.S. Army Prediction Table Kory et al: American Journal Medicine 30: 243-58, 1961. Eighty percent of these 20 workers (18-30 years old) were black, whereas only 35% of the group examined were black.

Dr. Imbus reviewed the medical records of the rejected blacks, found them to be young healthy males with negative medical histories and of whom on re-evaluation he found a large number fully qualified to work.

The committee agreed:

1. That criteria documents which recommend pulmonary function evaluations should point out that there is an ethnic difference in vital capacity, which persists if age, height, and sex are taken into account. (1) Smillie WG, Augustine DL: JAMA, 87, 2055, 1926
(2) Abramowitz et al: Amer. Review Respir Disease 92: 287-92 1965
(3) Damon Albert: Human Biology 38: 380-93 1966.

2. The committee agreed that the names and institutional affiliations of the committee members be listed in support of its recommendations (1).

3. That the following equations be recommended in the criteria documents as guidelines for use in pre-placement pulmonary function evaluations, using as a model the clinical experience of Dr. Imbus in pre-employment pulmonary function evaluations of cotton workers.

   a. In white persons the FVC should not be less than 75% of the value predicted for age, sex and height, from the VA-U.S. Army study equations.

b. In black persons, the FVC as predicted according to a should first be multiplied by 0.85 to adjust for the 15% lower FVC in blacks, before applying the 75% rule described in a.

c. Irrespective of ethnic origin, the ratio FEV 1.0/FVC should equal 70% or more.

Denis J. McGrath, M.D.

APPENDIX IV
RESPIRATORY QUESTIONNAIRE

A. IDENTIFICATION DATA

PLANT ______________________ SOCIAL SECURITY NO. ______________________
DAY MONTH (figures) YEAR (last 2 digits)

NAME ______________________ DATE OF INTERVIEW ______________________
(Surname)

______________________ DATE OF BIRTH ______________________
(First Names) M F

ADDRESS ______________________ AGE ________ (8,9) SEX ______________________ (10)

______________________ RACE [W] [N] [IND.] [OTHER] (11)

INTERVIEWER: 1 2 3 4 5 6 7 8 (12)

WORK SHIFT: 1st ________ 2nd ________ 3rd ________ (13) STANDING HEIGHT ________ (14,15)

PRESENT WORK AREA WEIGHT ________ (16,18)

If working in more than one specified work area, X area where most of the work shift is spent. If "other," but spending 25% of the work shift in one of the specified work areas, classify in that work area. If carding department employee, check area within that department where most of the work shift is spent (if in doubt, check "throughout"). For work areas such as spinning and weaving where many work rooms may be involved, be sure to check the specific work room to which the employee is assigned — if he works in more than one work room within a department classify as 7 (all) for that department.

	Workroom Number	(19) Open	(20) Pick	Area	(21) Card #1	(22) #2	(23) Spin	(24) Wind	(25) Twist	(26) Spool	(27) Warp	(28) Slash	(29) Weave	(30) Other
AT RISK (cotton & cotton blend)	1			Cards										
	2			Draw										
	3			Comb										
	4			Rove										
	5			Thru Out										
	6													
	7 (all)													
Control (synthetic & wool)	8													
Ex-Worker (cotton)	9													

Adapted from reference (158)

Use actual wording of each question. Put X in appropriate square after each question. When in doubt record 'No'.
When no square, circle appropriate answer.

B. COUGH

(on getting up)†
Do you usually cough first thing in the morning?______________ Yes____No______(31)
(Count a cough with first smoke or on "first going out of doors."
Exclude clearing throat or a single cough.)

Do you usually cough during the day or at night?______________ Yes____No______(32)
(Ignore an occasional cough.)

If 'Yes' to either question (31-32):

Do you cough like this on most days for as much as three months a year?______________ Yes____No______(33)

Do you cough on any particular day of the week? Yes____No______(34)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	
If 'Yes': Which day?	Mon.	Tues.	Wed.	Thur.	Fri.	Sat	Sun.	(35)

C. PHLEGM or alternative word to suit local custom.

(on getting up)†
Do you usually bring up any phlegm from your chest first thing in the morning? (Count phlegm with the first smoke or on "first going out of doors." Exclude phlegm from the nose. Count swallowed phlegm.)______________ Yes____No______(36)

Do you usually bring up any phlegm from your chest during the day or at night? (Accept twice or more.)______________ Yes____No______(37)

If 'Yes' to either question (36) or (37):

Do you bring up phlegm like this on most days for as much as three months each year?______________ Yes____No______(38)

If 'Yes' to question (33) or (38):

(cough)
How long have you had this phlegm?
(Write in number of years

(1) ☐ 2 years or less (39)

(2) ☐ More than 2 years-9 years

(3) ☐ 10-19 years

(4) ☐ 20+ years

†These words are for subjects who work at night

D. CHEST ILLNESSES

In the past three years, have you had a period of (increased) †cough and phlegm lasting for 3 weeks or more?______________

(1) ☐ No (40)

(2) ☐ Yes, only one period

(3) ☐ Yes, two or more periods

†For subjects who usually have phlegm

During the past 3 years have you had any chest illness which has kept you off work, indoors at home or in bed? (For as long as one week, flu?) Yes____No______(41)

If 'Yes' to (41): Did you bring up (more) phlegm than usual in any of these illnesses? Yes____No______(42)

If 'Yes' to (42): During the past three years have you had:
Only one such illness with increased phlegm? (1) ☐ (43)

More than one such illness: (2) ☐ (44)

Br. Grade______________

E. TIGHTNESS

Does your chest ever feel tight or your breathing become difficult?__________Yes______ No_____(45)

Is your chest tight or your breathing difficult on any particular day of the week? (after a week or 10 days away from the mill)__________Yes______No_____(46)

		(3)	(4)	(5)	(6)	(7)	(8)	
If 'Yes': Which day?	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Sun.	(47)
	(1) Sometimes	(2) Always						

If 'Yes' Monday: At what time on Monday does your chest feel tight or your breathing difficult?

1 ☐ Before entering the mill (48)

2 ☐ After entering the mill

(Ask only if NO to Question (45)

In the past, has your chest ever been tight or your breathing difficult on any particular day of the week?__________Yes ______No_____(49)

		(3)	(4)	(5)	(6)	(7)	(8)	
If 'Yes': Which day?	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Sun.	(50)
	(1) Sometimes	(2) Always						

F. BREATHLESSNESS

If disabled from walking by any condition other than heart or lung disease put "X" here and leave questions (52-60) unasked. ☐ (51)

Are you ever troubled by shortness of breath, when hurrying on the level or walking up a slight hill?__________Yes______No_____(52)

If 'No', grade is 1. If Yes', proceed to next question

Do you get short of breath walking with other people at an ordinary pace on the level?__________Yes______No_____(53)

If 'No', grade is 2. If 'Yes', proceed to next question

Do you have to stop for breath when walking at your own pace on the level?__________Yes______No_____(54)

If 'No', grade is 3. If 'Yes', proceed to next question

Are you short of breath on washing or dressing?__________Yes______No_____(55)

If 'No', grade is 4. If 'Yes', grade is 5.

Dyspnea Grd. __________(56)

ON MONDAYS:

Are you ever troubled by shortness of breath, when hurrying on the level or walking up a slight hill?__________Yes ______No_____(57)

If 'No', grade is 1. If 'Yes', proceed to next question

Do you get short of breath walking with other people at an ordinary pace on the level?__________Yes ______No_____(58)

If 'No', grade is 2. If 'Yes', proceed to next question

Do you have to stop for breath when walking at your own pace on the level?__________Yes______No_____(59)

If 'No', grade is 3. If 'Yes', proceed to next question

Are you short of breath on washing or dressing?__________Yes______ No_____(60)

If 'No', grade is 4. If 'Yes', grade is 5

B. Grd. __________(61)

G. OTHER ILLNESSES AND ALLERGY HISTORY

Do you have a heart condition for which you are under a doctor's care?________Yes________No______(62)

Have you ever had asthma? Yes No (63)

If 'Yes', did it begin: (1) ☐ Before age 30

(2) ☐ After age 30

If 'Yes' before 30: did you have asthma before ever going to work in a textile mill?________Yes________No______(64)

Have you ever had hay fever or other allergies (other than above)?________Yes________No______(65)

H. TOBACCO SMOKING*

Do you smoke?

Record 'Yes' if regular smoker up to one month ago. (Cigarettes, cigar or pipe)________Yes________No______(66)

If 'No' to (63).

Have you ever smoked? (Cigarettes, cigars, pipe. Record 'No' if subject has never smoked as much as one cigarette a day, or 1 oz. of tobacco a month, for as long as one year.)________Yes________No______(67)

If 'Yes' to (63) or (64); what have you smoked and for how many years? (Write in specific number of years in the appropriate square)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	
Years	(<5)	(5-9)	(10-14)	(15-19)	(20-24)	(25-29)	(30-34)	(35-39)	(>40)	
Cigarettes										(68)
Pipe										(69)
Cigars										(70)

If cigarettes, how many packs per day? (Write in number of cigarettes)

(1) ☐ less than 1/2 pack (71)
(2) ☐ 1/2 pack, but less than 1 pack
(3) ☐ 1 pack, but less than 1-1/2 packs
(4) ☐ 1-1/2 packs or more

Number of pack years: ________________(72,73)

If an ex-smoker (cigarettes, cigar or pipe), how long since you stopped? (Write in number of years) ________________(74)

(1) ☐ 0-1 year
(2) ☐ 1-4 years
(3) ☐ 5-9 years
(4) ☐ 10+ years

*Have you changed your smoking habits since last interview? If yes, specify what changes.

I. OCCUPATIONAL HISTORY**

Have you ever worked in: A foundry? (As long as one year)________Yes________No______(75)

Stone or mineral mining, quarrying or processing? (As long as one year)________Yes________No______(76)

Asbestos milling or processing? (Ever)________Yes________No______(77)

Cotton or cotton blend mill? (For controls only)______Yes________No______(78)

Other dusts, fumes or smoke? If yes, specify:________Yes________No______(79)

Type of exposure ________________________________

Length of exposure ________________________________

**Ask only on first interview.

At what age did you first go to work in a textile mill? (Write in specific age in appropriate square).

(1)	(2)	(3)	(4)	(5)	(6)
<20	20-24	25-29	30-34	35-39	40+

(80)

When you first worked in a textile mill, did you work with (1) ☐ Cotton or cotton blend (81)

(2) ☐ Synthetic or wool

Within the first few days you first worked in a textile mill, do you remember becoming sick with fever, chills, cough or sickness of the stomach? (Accept any of the above signs or symptoms)______Yes______No______(82)

If "no" to (75): Have you ever had such an illness after returning to the mill after a few days away from the mill?______Yes______No______(83)

How many years have you worked in a textile mill? (Write in total number of years in appropriate square)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	
Processing:	<1	1-4	5-9	10-14	15-19	20-24	25-30	30+	
Cotton or Cotton Blend									(84)
All Synthetic or Wool									(85)

If cotton, how many years did you spend in each area? (Write in years in each area)

	(86)	(87)	(88)	(89)	(90)	(91)	(92)	(93)	(94)	(95)	(96)	
	Open	Pick	Card	Spin	Wind	Twist	Spool	Warp	Slash	Weave	Other	
<1												(1)
1-4												(2)
5-9												(3)
10-14												(4)
15-19												(5)
20-24												(6)
25-29												(7)
30+												(8)

For those working in more than one area:

Did you move from a dusty work area to one that was not as dusty?______Yes______No______(97)

If yes, did you move because the dust bothered your breathing?______Yes______No______(98)

XII. TABLES AND FIGURES

TABLE XII-1

WASTE ANALYSIS OF 950 BALES OF COTTON*

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. [9]

From Graham [5]

TABLE XII-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 [5]

TABLE XII-3

SIZE OF COTTON YARN PRODUCED AND EFFECT ON WORKERS

No. of mills visited	Average count* of cotton yarn	No. of Strippers & Grinders: Sound	Slightly affected	Markedly affected	Total examined	Total affected No.	%
6	Below 30 (coarse)	2	8	13	23	21	91.3
17	Between 30 and 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 [38]

TABLE XII-4

RELATIVE PREVALENCE OF BYSSINOSIS
IN MALE COTTON MILL WORKERS AGED 40-50

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 [55]

TABLE XII-5

PREVALENCE OF BYSSINOSIS IN CARDROOM WORKERS AND SPINNERS AGED 40-59 IN SIX MILLS

Operation Group	Sex	No.	Age Mean	Exposure Mean Yrs.	Normal	Byssinosis I	II	Total (%)
Card- and blowroom 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 [55]

TABLE XII-6

PREVALENCE OF BYSSINOSIS IN COTTON WORKERS

Country	Year Reported	Opening and Picking	Carding	Stripping and Grinding	Spinning	Other	Reference	Remarks
		-----------	-----------	%	-----------	-----------		
England	1915			91			[38]	Coarse
England	1915			72			[38]	Medium
England	1915			62			[38]	Fine
England	1950			43			[104]	
England	1955	66	43	65		42	[55]	
England	1956		39		7		[64]	
England	1960		51		2		[85]	Coarse
England	1960		6				[85]	Fine
Belgium	1961		8				[105]	
W. Germany	1963		62				[47]	
England	1964		14		2		[98]	
Netherlands	1964		18		2		[98]	
Sweden	1964		62			52	[50]	Other cardroom

TABLE XII-6 (continued)

PREVALENCE OF BYSSINOSIS IN COTTON WORKERS

Country	Year Reported	Opening and Picking	Carding	Stripping and Grinding	Spinning	Other	Reference	Remarks
		---------	---------	%	---------	---------		
England	1966		30				[106]	
England	1966		62				[106]	
England	1967					18	[49]	Winding
U.S.	1969		26		29		[48]	
U.S.	1969		25		12		[14]	
England	1970	24	24	49	25*	4	[13]	Medium (10-50)
England	1970	14	32	48	29*	9	[13]	Coarse (1-24)
U.S.	1970	15	29		10	7	[15]	
U.S.	1972		20			2	[62]	Modern Mill
U.S.	1973		23		4	13	[17]	Winding
England	1973		26		4	2	[16]	Slashing, Weaving

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

TABLE XII-7

COTTON DUST: SIZE AND DEPOSITION SITE

Constituent	Aerodynamic diameter (μm)	Remarks
Lint and fuzz fibers	>20	Essentially no deposition in respiratory tract
Vegetable trash	>15	Do
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	Do
Air pollution	<8	Do

From Ayer [128]

TABLE XII-8

CLASSIFICATION OF WORK AREA
BY TOTAL DUST CONCENTRATION

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

From Roach and Schilling [85]

TABLE XII-9

CATEGORIZATION OF WORK AREAS BY 8-HOUR, FLY-FREE COTTON DUST CONCENTRATION

Dust Category	Concentration, Less Fly Averaged over 8 hours (mg/cu m)
Low	0.5 or less
Moderate	more than 0.5 and less than 1.0
High	1.0 or more

From British Occupational Hygiene Society Committee on Hygiene Standards [126]

Note: The concentration, less fly, is the weight of dust in milligrams per cubic meter of air excluding particles which would be caught by a 2-mm wire mesh gauze, or which would not pass through a vertical elutriator designed to accept 50% of unit density spheres 30 microns in diameter. The recommended maximum average concentrations is therefore 0.5 mg/cu m, less fly.

TABLE XII-10

PREVALENCE OF BYSSINOSIS
COMPARED TO KNOWN DUST EXPOSURES

Total Dust Exposure mg/cu m	Prevalence*	No. of People Examined
0 - 0.5	1.5%	212
0.5 - 1.0	2.8%	108
1.0 - 2.0	9.9%	1,259
2.0 - 3.0	8.5%	1,226
3.0 - 4.0	34.0%	465
4.0 - 5.0	55.0%	245
5.0 - (34.0)	27.5%	92
	Total	3,607

*Byssinosis all grades.

From British Occupational Hygiene Society Committee on Hygiene Standards [126]

TABLE XII-11

NUMBER OF BYSSINOTIC WORKERS WITH GRADE II SYMPTOMS
AT VARIOUS LEVELS OF DUST CONCENTRATION

Total Dust mg/cu m	No. of Workers with Byssinosis		Reference
	All Grades	Grade II	
1.5	9	0	[85]
1.6	8	1	[49]
1.7	13	3	[85]
1.7	27	7	[14]
2.8	23	2	[49]
2.8	6	0	[49]
3.5	22	5	[49]
4.0	142	29	[85]
6.0	5	0	[49]
Total	255	47 (18.5%)	

From British Occupational Hygiene Society Committee on Hygiene Standards [126]

TABLE XII-12

RECOMMENDATIONS FOR CLASSIFICATION AND MANAGEMENT OF WORKERS EXPOSED TO COTTON DUST

Functional severity	FEV 1* (% of predicted)	FEV 1** (%)	Interpretation of FEV 1	Recommendations for Employment
F0	>80 (No evidence of chronic ventilatory impairment)	(a) -4 to 0; or more	(a) Minimal or no acute effect of dust on ventilatory capacity	No change; annual FEV 1, and questionnaire
		(b) -9 to -5 or more	(b) Moderate acute effect of dust on ventilatory capacity	No change; 6 mo. FEV 1, and questionnaire
		(c) -10 or more	(c) Definite and marked acute effect of dust on ventilatory capacity	Move to lower risk area; 6 mo. FEV 1, and questionnaire
F1	60-79 (Evidence of slight to moderate irreversible impairment of ventilatory capacity)	(a) -4 to 0; or more	As (a) above	No change; 6 mo. FEV 1, and questionnaire
		b) -5 or more	As (b) above	Move to lower risk area; 6 mo. FEV 1, and questionnaire
F2	<60 (Evidence of moderate to severe irreversible impairment of ventilatory capacity)	---	---	Work requiring no cotton dust exposure, detailed pulmonary examination, and questionnaire

*FEV 1 in absence of dust exposure (2 days or longer).

**Difference between FEV 1 before and after 6+ hours of cotton dust exposure on a first working day.

Derived from Organizing Committee of National Conference on Cotton Dust and Health, [162] Bouhuys et al, [152] and reference 158

TABLE XII-13

PREDICTED DUST LEVELS TO PRODUCE VARIOUS PREVALENCES OF BYSSINOSIS

Byssinosis	Milligrams per Cubic Meter of <15 (u)m Dust					
Prevalence	All Grades		Grades 1 + 2		Grade 2	
(Per Cent)	Level	95% Limits	Level	95% Limits	Level	95% Limits
1	0.021	0.012 0.033	.060	0.034 0.086	0.082	0.042 0.12
2	0.036	0.021 0.051	.097	0.063 0.130	0.14	0.086 0.19
3	0.050	0.032 0.068	0.13	0.091 0.17	0.20	0.13 0.26
4	0.063	0.043 0.084	0.16	0.12 0.21	0.25	0.18 0.33
5	0.07	0.054 0.10	0.20	0.15 0.25	0.31	0.24 0.41
10	0.15	0.12 0.18	0.38	0.31 0.46	0.64	0.49 0.93
25	0.48	0.40 0.59	1.10	0.84 1.6	2.1	1.4 4.6
50	1.70	1.2 2.7	3.63	2.3 7.4	8.0	3.9 28.5

From data of Merchant et al, [18]

TABLE XII-14

PREDICTED PREVALENCE OF BYSSINOSIS
by <15 μm Dust Level

Cotton Preparation and Yarn Area Workers
North Carolina 1970-1971

<15 μm Dust Level mg/cu m	Percent Byssinosis					
	All Grades		Grades I + II		Grade II	
	Percent	95% Limits	Percent	95% Limits	Percent	95% Limits
0.1	6.5	5.0 8.5	2.1	1.3 3.3	1.3	0.7 2.3
0.2	12.7	10.8 14.9	5.0	3.8 6.6	3.0	2.1 4.3
0.5	25.8	22.5 29.3	13.1	10.7 15.8	8.0	6.1 10.2

From Merchant et al [18]

TABLE XII-15

PREVALENCE OF BYSSINOSIS IN TIME-WEIGHTED DUST EXPOSURE GROUPS

Time-weighted dust group (mg years/cu m)	No. of subjects examined	Mean time-weighted dust measurements (mg years/cu m)	%Prevalence of byssinosis (Grade 1/2 and over)
0.0-10.0 ..	330	5.75	3.63
10.1-20.0 ..	257	15.34	9.73
20.1-30.0 ..	206	24.06	12.31
30.0 ..	347	48.50	22.19

After Fox et al [123]

TABLE XII-16

BYSSINOSIS CASES AND DUST CONCENTRATIONS

A. Exposed to over 0.25 mg/cu m fly-free dust

Investigator	Ref.	Year	Number of Cases	Dust Concentration- mg/cu m Total(t) or respirable(r)	Fly-free or <15 μm
Roach	[85]	1960	155	1.5-5+ (t)	(0.3-1.5+)
Wood	[11]	1964	52		0.7-1.2
Lammers	[98]	1964	106	0.2 (r)	0.4
Belin	[50]	1965	67		1.65-4.54
Mekky	[49]	1967	63		0.35-1.92
Molyneux	[125]	1968	365	0.9-5.4 (t)	(0.28-1.65)
Zuskin	[14]	1969	27		0.43-1.07
El Samra	[119]	1972	1	1.0 (t)	(0.3)
Valic	[120]	1972	6	1.07 (r)	(2.1)
Valic	[122]	1972	29	0.55 (r)	(1.1)
Merchant	[18]	1973	197		0.35-1.7
Tuma	[93]	1973	211		0.25+
Fox	[123]	1973	157		0.55-3.74
Berry	[65]	1974	289		0.25-2.38
Imbus	*	1974	158		0.2-2.0
Total			1883		

B. Exposed to less than 0.25 mg/cu m fly-free dust

Investigator	Ref.	Year	Number of Cases	Dust Concentration- mg/cu m Total(t) or respirable(r)	Fly-free or <15 μm
Roach	[85]	1960	6	1.0- (t)	(0.3-)
Lammers	[98]	1964	11	0.03-0.1 (r)	(0.06-0.2)
Merchant	[18]	1973	58		0.05-0.23
Imbus	*	1974	23		0.2-
Total			98		

*Written communication from HR Imbus, 1974

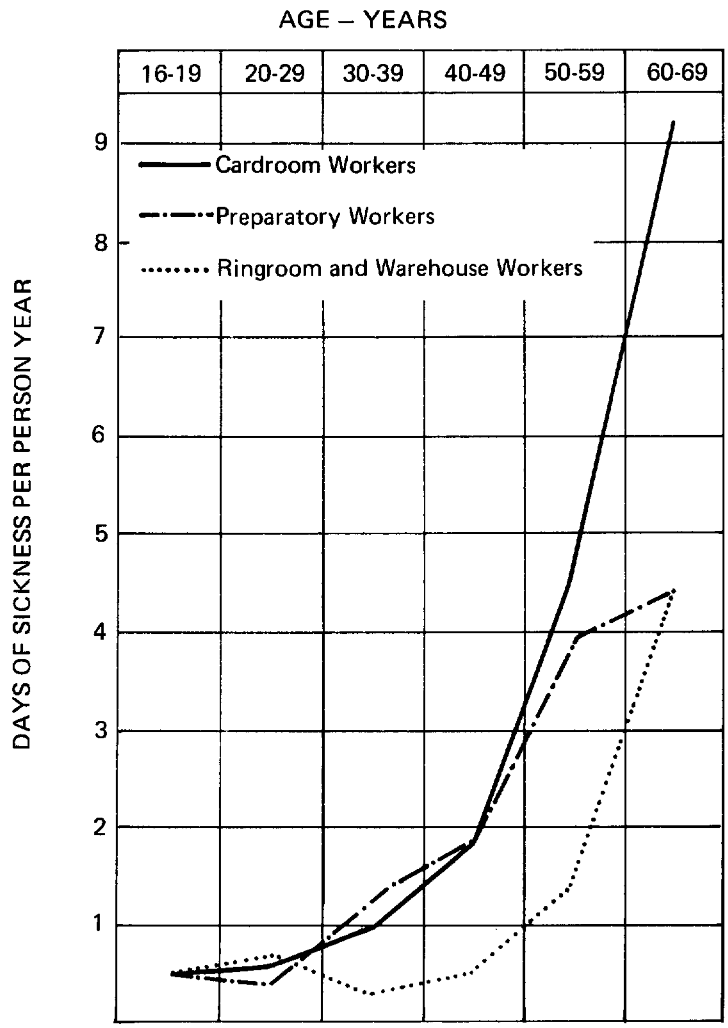

FIGURE XII-1
DAYS OF SICKNESS VS AGE
MALE COTTON OPERATIVES
LANCASHIRE, ENGLAND, 1923-1927

From Hill (40) and Prausnitz (41)

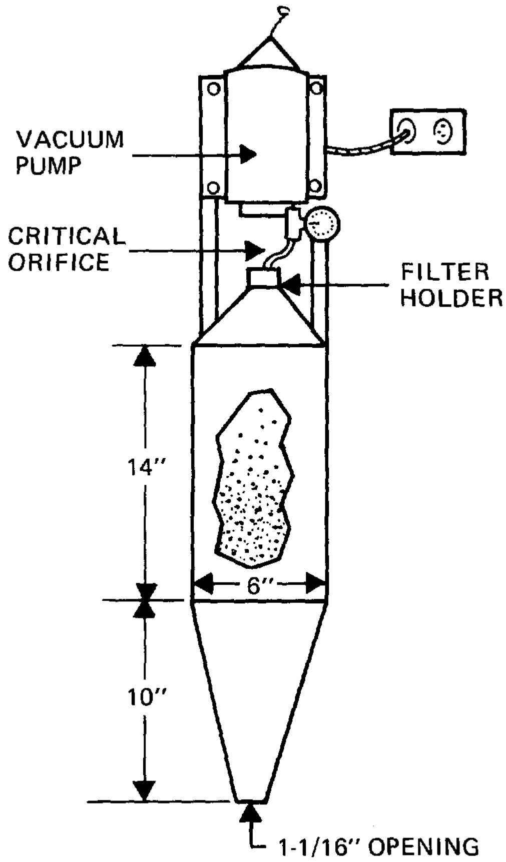

FIGURE XII-2
VERTICAL ELUTRIATOR COTTON DUST SAMPLER

From Lynch (124)

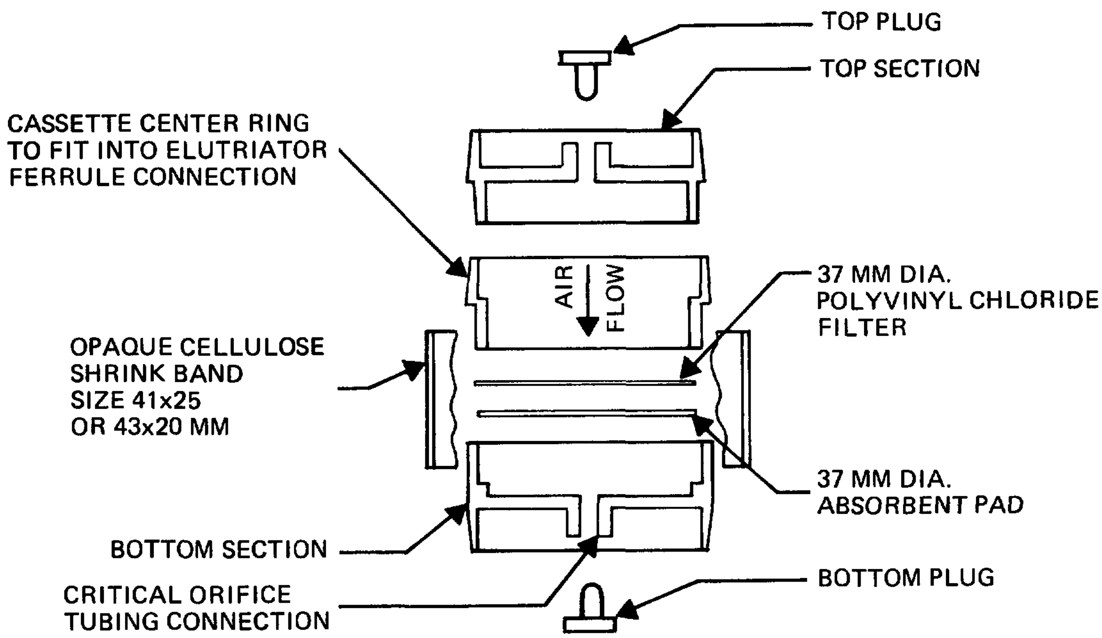

FIGURE XII-3
FILTER CASSETTE ASSEMBLY

From Barr et al (127)

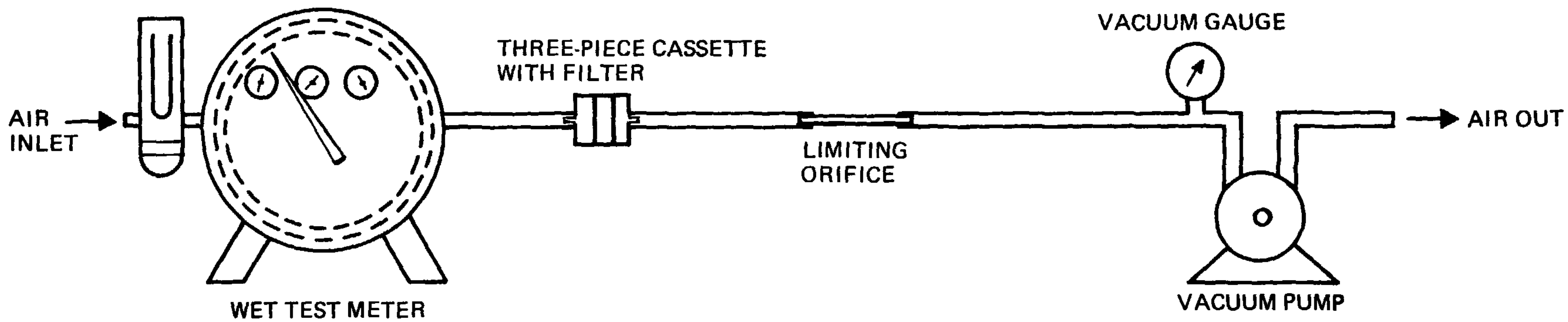

FIGURE XII-4
CALIBRATION SAMPLING TRAIN FOR CASSETTE
WITH FILTER AND LIMITING ORIFICE

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