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Five hundred fifty-one cotton gin workers and 1,218 workers in non-dusty comparison plants were studied in a cross-sectional industrial hygiene and respiratory disease prevalence survey of 37 gins throughout the cotton belt in the United States. After deletion for previous dust exposures, the data on 375 cotton gin workers and 1,023 comparison plant workers were analyzed. The industrial hygiene study consisted of determination of ambient respirable cotton dust levels with vertical elutriators and characterization of particle size distribution.

NIOSH concludes that this study demonstrates that exposure to cotton dust in gins produces adverse health effects. That 86% of the elutriated samples were below .500 mg/M^3 (geometri mean) indicates that this level of dust control is technically feasible, and NIOSH recommen that this level be set as a dust exposure standard.

NIOSH recommends specific dust control strategies, as well as a medical surveillance progra which would detect early adverse health effects. NIOSH further recommends that the medical surveillance data should be actively collected by OSHA and NIOSH for a prospective study of the effects of dust exposure in this industry.

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RESPIRATORY DISORDERS AND DUST EXPOSURE IN SECTORS OF THE COTTON INDUSTRY OF THE UNITED STATES

Part 1: Cotton Gins

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FOREWORD

This industry-wide medical and industrial hygiene study of the United States cotton gin industry is a part of an overall effort by NIOSH to describe the health and environmental conditions of the "non-textile" or "secondary" cotton industry. The "non-textile" cotton industry is that part of the cotton industry in which the spinning of cotton yarn or the weaving of cotton cloth does not occur. By using a sampling technique of sectors of the whole "non-textile" cotton industry we place a scientific foundation under standards that we recommend for this industry.

J. Donald Millar, M.D.
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PREFACE

Workers in the "non-textile" cotton industry breathe a dust which is similar to the dust in the cotton spinning and weaving industry. This exposure prompts the question of byssinosis prevalence and other respiratory disease in the non-textile cotton industry. However, since cotton dust is of biologic origin and therefore of variable composition, one cannot assume that the byssinosis prevalence per unit of respirable cotton dust is the same in the non-textile cotton industry as it is in cotton mills. This observation motivated a study of cotton dust exposure, the respiratory health status of workers, and any relationship between exposure and respiratory health status which occurs in the non-textile cotton industry.

ABSTRACT

Five hundred fifty-one cotton gin workers and 1218 workers in non-dusty comparison plants were studied in a cross sectional industrial hygiene and respiratory disease prevalence survey of 37 gins throughout the cotton belt in the United States. After deletion for previous dust exposures, the data on 375 cotton gin workers and 1023 comparison plant workers were analyzed. The industrial hygiene study consisted of determination of ambient respirable cotton dust levels with vertical elutriators and characterization of particle size distribution.

The geometric mean dust concentrations in each facility ranged from 0.03 mg/M^3 to 1.03 mg/M^3, with 86% (30/35) of the gins having geometric means of less than 0.5 mg/M^3. Particle sizes (Mass Median Diameter) were also variable but tended to be larger than that found in textile mills. Factors in the ginning process that affected dust levels were condition of seed cotton, layout of the gin, and management practices.

Medical tests included standardized questionnaire and pre- and post-shift spirometry. Matched-pair analysis revealed no excess prevalence of byssinosis in gin workers compared to controls. Among persons who never smoked there were significantly greater prevalences of bronchitis and "respiratory disorders arising from exposure to textile vegetable dusts" (WHO definition) in gin workers. Among ex-smokers and present smokers there were significantly lower mean pre-shift FEV_1 values. Among cotton workers there was a significant dose-response relationship between decline in $FEF_{50\%}$ and peak flow over the shift and dust exposure. Finally, probit analysis revealed an increasing prevalence of bronchitis in never-smokers as dust level increased, and an increasing prevalence of "respiratory disorders arising from exposure to textile vegetable dusts" as dust level-years of exposure increases. This latter prevalence more than doubles from a very smaller dust-year factor (.302) to a high one (20.3), the latter of which can represent exposure at .500 mg/M^3 for 40 years of working life.

NIOSH concludes that this study demonstrates that exposure to cotton dust in gins produces adverse health effects. That 86% of the elutriated samples were below .500 mg/M^3 (geometric mean) indicates that this level of dust control is technically feasible, and NIOSH recommends that this level be set as a dust exposure standard.

NIOSH recommends specific dust control strategies, as well as a medical surveillance program, which would detect early adverse health effects. NIOSH further recommends that the medical surveillance data should be actively collected by OSHA and NIOSH for a prospective study of the effects of dust exposure in this industry.

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ACKNOWLEDGEMENTS

In the 1960s Arend Bouhuys, James Merchant and others described the health and environmental conditions of the cotton spinning and weaving industry. Their data formed a part of the scientific support for a standard in this industry. When Dr. Merchant came to NIOSH in 1975 he began an effort to look at respiratory effects in other portions of the cotton industry. Dr. Michael Shasby, Dr. Richard Piccirillo, Mr. John Zey, Mr. Martin Petersen, Dr. John Hankinson, Dr. Robert Castellan, Dr. Alan Engelberg, and Dr. Brian Boehlecke contributed to the original design and did the early field work on the project. Later Dr. Alan Palmer at SRI International performed the epidemiologic work on the Texas and California portions of the cotton gin and cotton compress warehouse segments of the study. The last half of the entire study has been under the direction of Dr. Mark Carlson and Mr. Greg Piacitelli. Valuable industrial hygiene and statistical support has been provided by Mr. Greg Kullman, Mr. Wayne Sanderson, Mr. William Jones, Mr. Rick Ferguson, Mr. Frank Hearl, Mr. Jerry Clere, Mr. Byron Burchell, Ms. Rochelle Althouse and Mr. John Hancock. Mr. Greg Spransy directed the coordination of the field team. The bulk of the industrial hygiene and medical data collection and organization was done by a group whose hours of labor far exceed that done by the above named individuals.

For the overall "non-textile" cotton study we examined about 3700 individuals at 150 plants in 11 states. For the cotton gin study the collection of the data took place during the 1978 and 1979 ginning seasons. We obtained information on comparison plant workers during the 1978, 1979 and 1980 cotton seasons.

This study has also been called "A cross-sectional epidemiologic study for byssinosis in the non-textile industry."

INTRODUCTION

A 22 year old man complained of chest tightness after working a shift in the mote press area of a Tennessee cotton gin. He had not worked long enough to develop any chronic problems from his exposure and had no acute changes in his pulmonary function that day. Does this young man have byssinosis? Does he have significant respiratory disease? If he has either of these two conditions, what is the association with his work in a cotton gin? Let us consider some of the origins of these questions.

For 280 years those interested in occupational health have described, in workers in the textile trades, a respiratory condition now known as byssinosis. In a book published in 1713, Bernardino Ramazzini described the respiratory disease of flax and hemp workers in the Po Valley of Italy. Ramazzini described these workers as: "always covered with dust from the hemp, pasty-faced, coughing, asthmatic..."(1)

In the nineteenth century, British factory physicians heard a similar complaint from cotton textile workers. Substantial numbers of these workers started feeling chest tightness or oppresssion. At first the affected workers only felt this tightness on Mondays but as they spent more years in the cotton textile mills they also felt tight in the chest on other days of the week. Cough and phlegm many times accompanied the other symptoms. Jesse Leach presented evidence that the condition was due only to Surat cotton. However, 100 years later, epidemiologic studies done on textile workers in the United States showed that workers exposed to American cotton also experienced the "Monday feeling."

Two studies of cotton gin workers in the United States have appeared. The rest of the studies are from foreign countries. The results of those studies appear in Table 1.

It is difficult to compare the U.S. experience with studies from other countries. However, the two studies done in the United States provide some indication of the status of byssinosis in the ginning industry. Of note in the Palmer study is the absence of the symptoms of byssinosis in the Lower Southwest Region workers even though those workers had significant pulmonary function abnomalities. In the Larson study 100 of 633 gin and control workers were excluded from analysis because of poor performance on the pulmonary function test. With that many exclusions we cannot assume as the authors did that the 100 excluded workers had no significant respiratory disease or agree with the authors' conclusion of "negative results." To evaluate this problem a sample of gins and workers in the entire U.S. cotton industry was studied.

Starting in 1977, NIOSH-DRDS medical officers and industrial hygienists planned a cross-sectional medical and industrial hygiene study of the cotton industry. They were interested in the part of the cotton industry that is peripheral to the mills that spin cotton yarn and weave that yarn into cloth. Since the cotton spinning and weaving industry has been of prime importance in the studies of byssinosis, the industry represented by cotton ginning, warehousing, etc., has been termed "secondary" or "non-textile." The terms are not specifically descriptive but are used since no better term has appeared. An assessment of the non-textile cotton industry and the defined subsets of that industry (Table 2) was completed in 1981.

Table 1. Summary of results from published reports of epidemiologic surveys for byssinosis or other respiratory disorders in cotton gins.

Author	Year	Country	Dust mg/M3	Spirometry Acute Change	Chronic Change	Byssinosis Prevalence	Ref.
Gilson	1962	Uganda	3.0-11.0	none	none	not detd.	(2)
				yes	none	not detd.	
El Batawi	1962	Egypt	not detd.	not detd.	not detd.	38 %	(3)
El Batawi	1964	Egypt	15.0-34.0	yes	probable	33 %	(4)
		follow-up		yes	probable	50 %	
Kondakis	1965	Greece	not detd.	not detd.	yes	0%	(5)
Khogali	1969	Sudan	0.5-3.0	yes	yes	20 %	(6)
				yes	yes	49 %	
Khogali	1976	Sudan	1.0-2.0	not detd.	no	18 %	(7)
				not detd.	yes	48 %	
Palmer	1978	Texas Rio Grande	0.9	yes	no	0 %	(8)
Larson	1981	California	gin 0.7	yes	no	13 %	(9)
			control 0	yes	no	10 %	

Note: Ginning processes, dust sampling methods, and epidemiologic methodology used in the surveys listed varied significantly; therefore, there is no attempt to directly compare the results.

Table 2. Subsets of the non-textile cotton industry.

cotton gins*
cotton compress warehouses*
cotton shipping and receiving warehouses
cottonseed oil mills*
cotton classification offices*
cotton waste utilization plants*
cotton gin mote recyclers†
cotton garnetting plants†
cottonseed delinting plants (crop preparation)
cotton farms
cotton merchants sample rooms
cotton sample rooms (textile mills)
cotton research facilities
cotton mop factories
cotton salvage operations
cotton cellulose users

*Segments off the industry studied by NIOSH in the "secondary" or "non-textile" cotton study.

†This segment was scheduled for study in the original study design but was dropped because of budget and travel restrictions.

MATERIALS AND METHODS

I. Background of Study Design

NIOSH determined the total number of workers in each of the subsets and calculated the minimum sample size necessary to represent the total population of those industries. Criteria were established for the measurement of pulmonary function (10), respiratory symptoms, important demographic co-variables and exposure to cotton dust (11, 12, 13).

The sample size chosen was calculated to be necessary for us to be 90% sure of claiming an association between delta FEV_1 and respirable dust if in reality the difference in mean delta FEV_1 between the high and low dust groups was 45 ml, while at the same time allowing us to be 95% sure that an association was not claimed when, in fact, no association existed. The estimated sample size was 450 subjects.

The analysis employed a linear model and the 45 ml difference translated into a slope of -3.049 $L/(mg/M^3)$. Using only subjects with pulmonary function and dust measurements, and adjusting for variables associated with pulmonary function, resulted in the equivalent of 207 subjects. This resulted in an estimated power of .89.

The supervising industrial hygienist defined these work areas: gin stand, bale press, suction/cotton unload, yard, storage, office, other, and background and set up the protocol for placement of vertical elutriators.

Control or "comparison plants" to determine the background symptom and abnormal lung function prevalence were also studied. These comparison plants were to include workers who were basically from the same racial, sex, and socioeconomic status as the cotton gin workers but these workers were to have no exposure to harmful respirable dust. The food and kindred products industry provided most of the comparison workers for this study.

A contractor to NIOSH (SRI International) carried out the statistical sampling which set the stage for the field work. The contractor described the cotton gins in terms of age, production and geographical area and targeted the cotton gins and comparison plants for study. Both NIOSH-DRDS researchers and the contractor did the field work according to the protocol described below. The contractor studied the cotton gins in California and Texas. NIOSH-DRDS studied, in-house, the cotton gins in North Carolina, Georgia, Arkansas, and Tennessee (Figure 1).

Walkthrough surveys of each study facility were made by an industrial hygienist and/or a medical officer prior to each prospective field study. These visits allowed a detailed explanation of the study purpose as well as coordination of proposed study dates with cotton gin and comparison plant management.

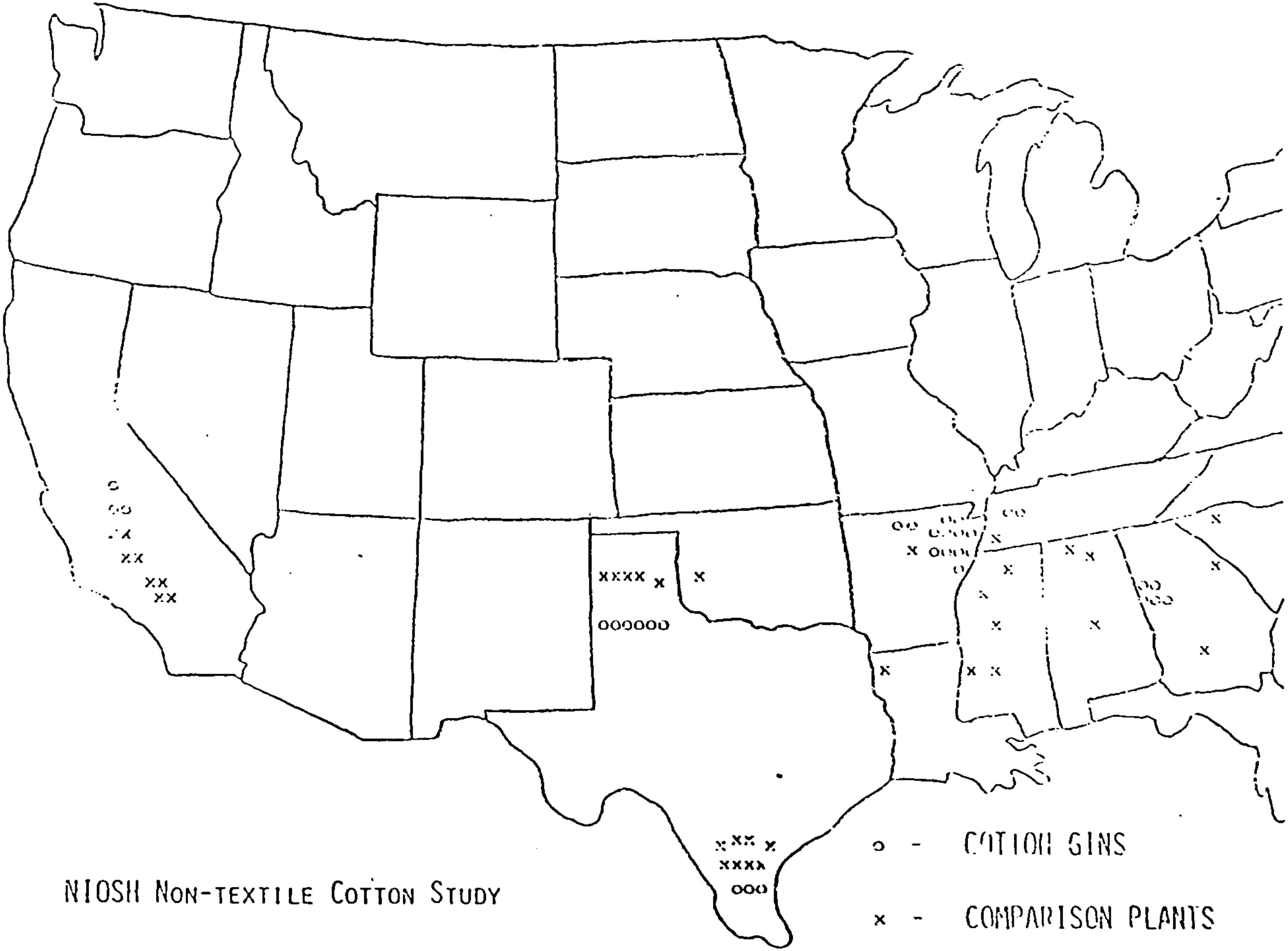


Figure 1. NIOSH or its contractor studied workers and conditions in cotton gins and comparison plants located at the sites shown above.

II. Description of the Cotton Ginning Industry

A. Background

Cotton is a natural fiber crop derived from a herbaceous plant of the Malvaceae family. The fibers (lint) are attached to and grow from the surface of the seeds which are located inside the capsule (boll). When mature, the capsules open exposing the fiber and seed. Seed cotton is then harvested by machine from fields which may have been treated by harvest-aids such as defoliants and desiccants. The first mechanical process for the seed cotton following harvesting is ginning, the primary aim of which is to separate the fiber from the seed.

B. Geographical Distribution of Cotton Gins

Cotton gins are strategically located throughout the 18 cotton producing states, generally in the immediate production area.

The ginning industry in the United States can be divided into five geographic regions. The regions include all or portions of the following states:

1. West Region: California, New Mexico, Arizona, Nevada, and the El Paso region of Texas
2. Upper Southwest Region: Texas High Plains area, Central Texas, and Oklahoma
3. Lower Southwest Region: Rio Grande Valley area of South Texas
4. South Central Region: Louisiana, Arkansas, Mississippi, Missouri, Kentucky, and Tennessee
5. Southeast Region: Georgia, Alabama, Florida, South and North Carolina, and Virginia

Cotton ginning is seasonal. It begins with the maturing of the cotton crop, which varies with geographical distribution, and ends shortly after the cotton harvest ends. In the United States, the cotton growing seasons are such that each year cotton ginning starts in the Lower Southwest Region in mid-summer, continues through the South Central and other geographical regions in late summer and early autumn, and ends on the Upper Southwest Region in late autumn and early winter. Approximately 900-1000 hours of actual ginning time would constitute a normal ginning season as defined by the USDA. (14) Actually, the bulk of the crop in each geographical region is ginned in 6-8 weeks. During the remainder of the year, the gin is idle.

C. Regional Differences

The selection and proper use of ginning machinery and equipment are determined by the types of cotton processed, the harvesting method, and the moisture content of the lint. Since these factors differ geographically throughout the Cotton Belt, they necessitate regional practices in conditioning, ginning, and packaging the lint cotton.

1. Types of Cotton

There are two types of cotton produced in the U.S.: Upland cotton (Gossypium hirsutum), which accounts for 99% of the cotton harvested; and American Pima (Gossypium barbadense), which accounts for the remaining 1%. (15) The major difference in the two species is the staple length, American Pima having a longer staple. The differences in staple length require different ginning processes--most evident by the type of gin-stand used. American Pima can only be ginned on a roller-type or McCarthy gin, while Upland cotton can be ginned using either a roller-type or saw-type gin. There are approximately 20-30 roller-type gins in the U.S. (15) The majority of gins is the saw-type, of which there are greater than 2500.

2. Harvesting Methods

Ginning machinery and equipment vary throughout the Cotton Belt primarily because of the regional differences in the crop itself, harvest-aid practices, and methods of harvesting. The harvesting method generally determines the amount of trash in the cotton, hence the type and amount of equipment required at a gin.

There are five methods of harvesting cotton: machine picking, machine stripping, machine scrapping, hand picking and hand snapping. Hand picking and snapping, formerly common practices, produced the cleanest seed cotton. However, they have declined to the point that their impact on processing is no longer of importance in determining gin specifications. Machine scrapping, a method of harvest in which very large amounts of plant trash and soil are incorporated into harvested seed cotton, is also of minor importance to the ginning industry.

The methods of harvest which are most prevalent in the American ginning industry are machine stripping and machine picking. Machine picked cotton accounts normally for 60-70% of the total cotton harvested, while machine stripped cotton normally accounts for 30-40% of the total acreage. Machine stripping, which is predominant in the Upper Southwest Region, differs from machine picking mainly in the method by which the seed cotton is removed from the plant.

The mechanical picker selectively separates the exposed seed cotton from the open capsules while the mechanical stripper incorporates the entire capsule with lint plus bract, leaf, and stem components in the harvested material. The higher ratio of trash to lint resulting from machine stripped operations requires gins to have additional equipment for cleaning and trash extraction.

3. Moisture Content of Seed Cotton

The moisture content of the seed cotton is critical in the storage and ginning of cotton. Ideally, cotton should be harvested when the moisture content of the lint is less than 10%. For ginning purposes, the moisture content of the lint should be from 6.5 to 8%. The moisture content of the cotton depends largely on the climatic conditions during the harvest and storage conditions prior to gin processing, and these vary on a regional basis.

D. Process Description

Today's modern cotton gin must be equipped to perform many additional functions than Eli Whitney's initial gin. At the time, Whitney's gin met a great economic need because it: (A) removed cotton fibers much faster than hand methods and (B) removed cotton fibers at much less cost than existing hand methods. However, it did not necessarily remove the fibers more gently than hand methods. The elimination of hand picking has required gins to install additional extracting and cleaning machines in order to maintain quality and grade levels demanded by their mill customers. The modern gin is equipped with many accessories employing several different physical principles that: dry the seed cotton; remove green bolls; separate soil, stick and capsule components (burs) from seed cotton; remove lint from seed; humidify if necessary; remove plant and soil trash from ginned lint· align and smooth the fibers; and package the fiber into a bale for transport and storage.

The modern cotton ginning system is fully automated. Seed cotton is normally conveyed from the mechanical harvester to storage trailers or modules. These are delivered to the gin by the producer and the cotton is pneumatically removed and fed into most ginning systems. Some gins, however, are equipped with a modular feeding system that feeds seed cotton through seed conveyors into the plant. Once it enters the process flow, the seed cotton is conveyed pneumatically through all subsequent process operations.

Initially, the seed cotton moves through a drying system consisting of a series of fans and a source of heated air which serve the two-fold purpose of adjusting the moisture content to 6.5 to 8% and conveying it through the dryer. Dryers condition the seed cotton for smoother efficient ginning; dried cotton gives up more of its foreign matter, and the ginned lint is smoother. Subsequently, the cotton moves into a series of cleaners, including stick machines, air-line cleaners and inclined cleaners. These seed cotton cleaners serve the dual purpose of opening the cotton or breaking up large wads, and removing foreign matter such as stems, leaf fragments, capsule components (burs), sand and dust from the seed cotton. These foreign materials have become incorporated in the cotton primarily during mechanical harvesting operations. Ginning facilities processing machine-stripped cotton usually utilize more cleaning equipment since this cotton contains more non-lint material than machine-picked cotton when it is received at the gin.

Next, the seed cotton is conveyed to the gin stand feeder where it is distributed at a steady uniform flow into gin stands. In the gin stands, seeds are separated from the lint. The size and capacity of the gin plant are determined by the number of gin stands it houses. Ginning facilities usually contain from one to five stands, with three or four being most common. Seeds are conveyed mechanically and pneumatically to a storage house and subsequently to another industry sector (cottonseed oil mills) for further processing. The lint is conveyed by air through lint cleaners for a final cleaning and combing action before baling.

Most gins use a double-press box for packaging the cotton into bales. The lint drops into one press box and fills it while a bale is being pressed and strapped in the other box. Approximately 480 pounds (217 kg) of cotton is pressed into a bale before it is wrapped with a cover, and strapped. One-half of all the U.S. gins operate at a rate of 8 bales per hour or less, and only about 8% are rated at 19 bales per hour or more. Cotton bales produced in most gins are not compact enough to meet shipping requirements; thus, they must be sent to a compress-warehouse for further compressing. Some modern gins are presently equipped with higher-tonnage bale presses that produce the more compact "universal sized" cotton bales and are also equipped with cotton sampling instruments therefore bypassing the compress-warehouse route. The finished cotton bale is transported to the textile mill for processing into yarn.

E. The Ginning Work Force

The plant labor in the ginning operations can be divided into three specific crew functions: receiving; conditioning and ginning; and bale packaging.

Each gin crew has somewhat different operational characteristics. The size of the operation and capabilities of the individuals all influence the makeup of the gin crew. Typically, it was found during this study, the crew of a three to four-stand gin having a capacity of 10 or more bales per hour had a plant manager (usually the owner), a gin superintendent, a gin stand operator, a lint cleaner operator, a press operator and two to four helpers, a sucker pipe operator, and one or two yard men who also alternate as sucker pipe operators. Machine-stripped cotton requires additional crew members for the receiving and ginning. conditioning functions because of the greater volume of material that is handled and the additional machinery and equipment. The duties involved with each job include the following descriptions:

manager: - employs personnel and assigns duties
- periodically checks entire gin plant operation
- responsible for gin maintenance and for general and seasonal repairs

superintendent: assistant manager
- directly responsible for minor gin maintenance and repair during shifts
- has direct supervision of personnel
- directly responsible for proper operation of plant
- assists gin stand operator as needed

gin stand operator: head ginner
- keeps stands operating at designed optimal capacity
- checks moisture content of seed cotton

lint cleaner operator: assistant ginner
- maintains lint cleaners at operating capacity
- assists gin stand operator

press crew:

a) press operator: - supervises and operates the press
- marks and tags the bales

b) assistants: - keep press supplies available
- assist in "dressing press" and "tying out" bales
- perform general housekeeping

sucker pipe operator: feeds seed cotton at as uniform rate as possible

yard man: - keeps trailers of seed cotton supplied to sucker pipes
- moves empty trailers away from gin plant

office workers:

a) scale man: weighs trailers before and after cotton unloaded

b) gin clerk: performs clerical duties

The typical gin facility operates continuously during the work shift except for occasional machine repairs, choke clearing, or other similar problems unexpectedly encountered. Most facilities shut down process operations at mid-shift for a meal break and during the last 30 minutes of each shift during which cleaning and maintenance activities are performed.

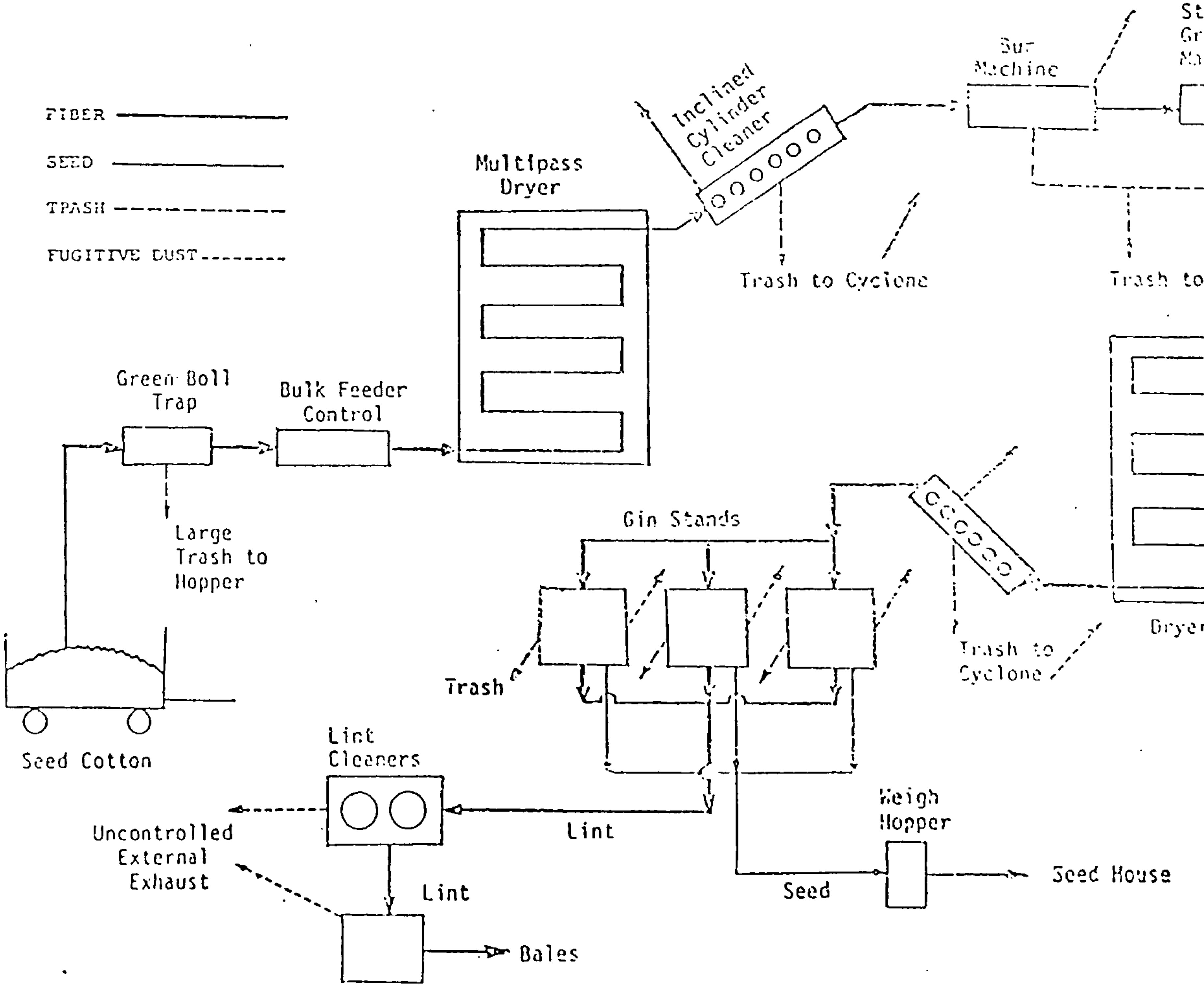


FIGURE 2. PROCESS FLOW IN A GINNING FACILITY

III. Sampling Procedure

The primary objective of determining levels of dust concentration in the ginning work environment was to provide data for correlation with the results of the medical surveillance tests. In early studies, one group of investigators (16) was unable to adequately correlate byssinosis symptoms with levels of airborne cotton dust until they used a size-selective sampling device to measure the dust levels.

Cotton dust has been considered a complex dust because it contains a respirable portion and a non-respirable portion which includes fibrous material. (17) The non-respirable dusts which are in the air of a cotton gin are of some importance from the standpoint of fire and general housekeeping. They have little known health significance. Not only is the cellulose of the fibers biologically inert but also the fibers are generally too large to be inspired, and all are too large to penetrate any distance into the human respiratory tract. If the cotton fibers were in a constant ratio to the dust of biologic significance, then it would make little difference whether they were included or excluded from the dust sample. If, however, the concentration of cotton fibers can vary by an order of magnitude for a given concentration of biologically significant dust, then the cotton fiber must be excluded from the sample. (18)

Therefore, the industrial hygienist must try to exclude both the fibrous materials as well as the medium size dust which could not reach the trachea, bronchi and lower regions of the lung. The aerodynamic diameter (AED) cut-off for dust entering the trachea and bronchi is believed to be 15 microns. (19) The cut-off size chosen for the instrument to sample for biologically significant cotton dust, therefore, should approximate 15 microns, to most accurately collect that fraction similar to that deposited in the trachea and lower regions of the pulmonary tract.

Vertical elutriation utilizes gravity for particle separation. As previously described (20), the basic equation is:

$$Q = VA$$

where,

- Q = flow rate pulling dust in filter
- V = velocity at which particles of the selected size or larger fall according to their aerodynamic diameter
- A = cross sectional area of the elutriation chamber

Using the above equation, a practical vertical elutriator was described in 1970. (21) The use of the vertical elutriator for measuring human exposure to cotton dust produced data which correlated well with indications of biological response. (16) Therefore, for the purpose of determining the concentration of biologically significant cotton dust in the work environment as addressed in this study, the Lumsden-Lynch vertical elutriator (VE) was used. This 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 microns aerodynamic diameter, 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 broncho-tracheal deposition.

The main components of the vertical elutriator are the separation chamber, the filter, the critical orifice and the vacuum source.

The separation chamber, made of aluminum, has a length of 14 inches and an inside diameter of 6 inches. The conical entry section is 10 inches and has an opening of 1-1/16 inch diameter which purposely undersamples the large lint particles. (22) The length of the central chamber results in adequate separation of particles at the designed 15 micron AED cutoff. (21)

A 37 mm diameter polyvinyl chloride filter with a pore size of 5 micrometers was used with a standard 37 mm, 3-piece polystyrene sampling cassette.

The actual flow rate through each filter was controlled by a critical orifice located between the filter and the vacuum pump. A critical orifice made of delrin plastic and calibrated at 7.40 $\pm$ 0.20 liters per minute flow at 406 mm (16") of Hg was used. A wet test meter was used for the calibration of orifices as described in the NIOSH Criteria Document: Recommendations for an Occupational Exposure Standard for Cotton Dust. Orifices were cleaned ultrasonically after every 6-8 field surveys and recalibrated.

A metal lure adapter was used between the cassette and orifice-rubing assembly attached to the vacuum source to insure a positive connection.

The vacuum source used with the vertical elutriator was an oil-less vacuum pump capable of 7.40 liters per minute continuous operation at 406 mm (16") of Hg.

Inertial classifiers such as cascade impactors can theoretically give an accurate measurement of the size distribution of particles over the range of interest for occupational exposures. Size characteristics of gin generated dusts were measured by mass characterization using an eight-stage Andersen cascade impactor, operating with four VE's connected in parallel. The Andersen sampler was designed to sample at 28.4 liters per minute, which is roughly four times greater than the sampling rate of a vertical elutriator (7.4 $\pm$ 0.2 liters per minute). Therefore, four vertical elutriators were arranged to be used as preseparators to the cascade impactor. Theoretically, if the sampling flow in the four vertical elutriators was equally distributed, dust entering the Andersen sampler would have the same size characteristics as that collected by a vertical elutriator. This sampling arrangement operates as a two-stage sampler and serves to characterize the size distribution of the dust fraction penetrating the four VE's. (23) The VE section aerodynamicaly excludes large (greater than or equal to 15 μm aerodynamic diameter) particles, and the impactor section collects and characterizes the smaller, "respirable" fraction of the elutriated dust.

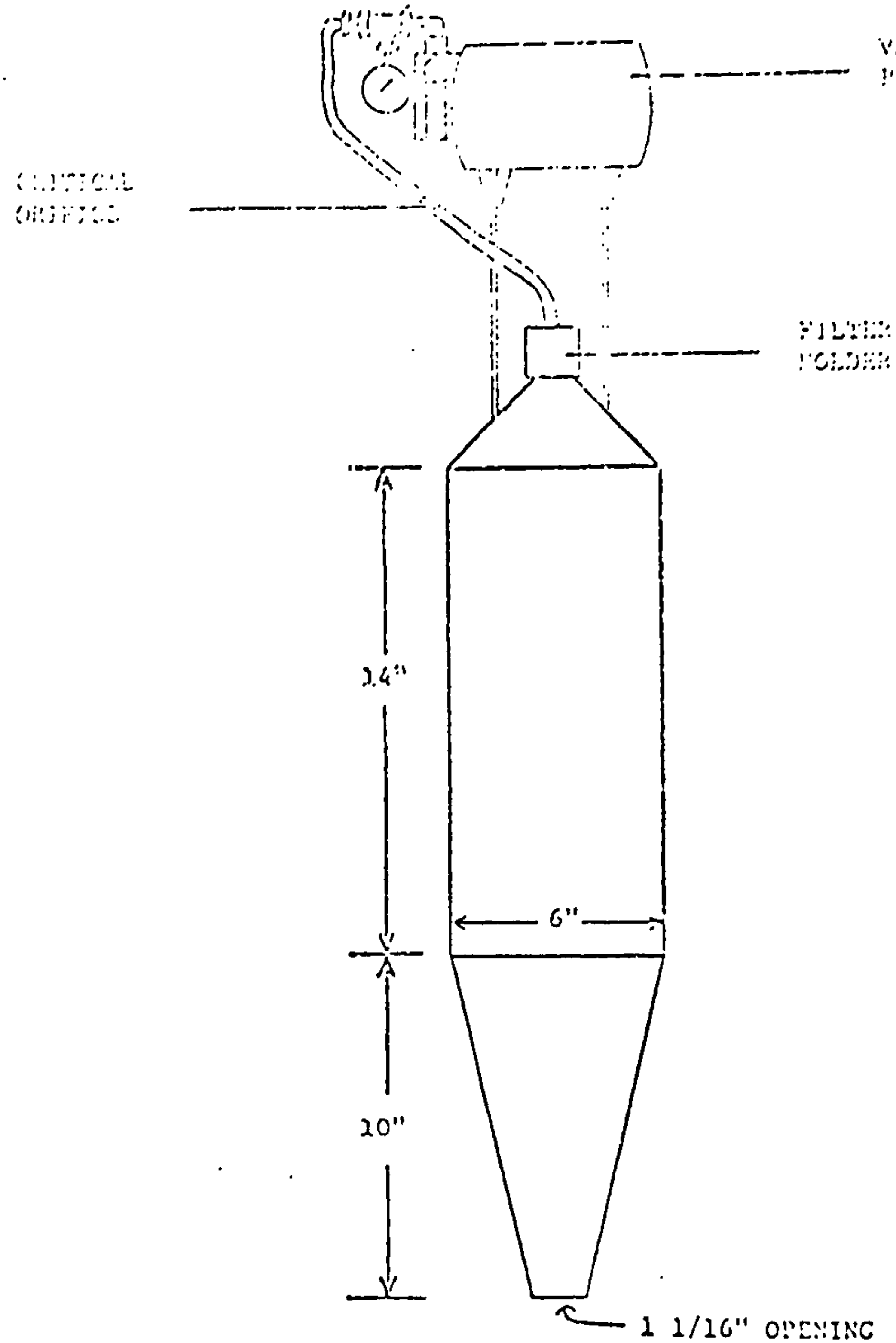


FIGURE 3. Vertical elutriator cotton dust sampler.

A short-term sample for cotton dust can be made with a portable inertial dust monitor using a properly designed vertical elutriator to separate lint and medium size dust from the dust fraction with less than 15 micron aerodynamic diameter. The instrument used in our surveys was the GCA Respirable Dust Monitor, Model RDM 101, which has been described by its developers. (24) The operation of the RDM-101 is based on the principle of beta-absorption which yields a measurement of mass concentration independent of the particle characteristics. Consequently, its performance is not significantly affected by variations in particle composition, optical characteristics, particle size or other physical and chemical variables of the collected sample. The Respirable Dust Monitor was used to complement the data to be generated from vertical elutriator samples and to help evaluate instantaneous ambient dust concentrations which would be used to determine filter loading rates and changing requirements. (25)

IV. Survey Procedure

The primary objective of determining levels of dust concentration in the work environment was to provide data for correlation with the results of the medical survey tests. The secondary objective was to assess the impact of variables in operations, facilities, equipment, and processes on dust levels.

In order to provide correlation with the data from the medical evaluations, the exposure measurements must provide a representative assessment of the dust levels encountered by the employees examined. Because the medical examinations were given prior to exposure to cotton dust following at least 36 hours without exposure, and repeated during (or immediately after) the end of the work shift, dust samples were collected during each "medical trial exposure" period on that first day of the medical-environmental survey. First day sampling commenced when pre-shift pulmonary function testing was initiated and was stopped after post-shift medical tests were completed.

Stationary vertical elutriators were the primary sampler used in collecting respirable dust samples to be correlated with employee exposures. Because gin workers only intermittently work at the equipment and move about within their respective work areas (primarily around the gin stands or the bale press), several strategically located samplers were used to collect adequate samples to reflect worker exposure during the work shift. The placement of the vertical elutriators would obviously have an effect on the amount of dust collected; therefore, they were placed in a position that would yield consistent results representative of actual employee exposure.

A minimum of two vertical elutriators were positioned in each distinct operational area of the plant where workers, included in the medical survey, normally work. Additionally, it was necessary to use at least one vertical elutriator for each distinct area that the subject workers enter for significant periods (providing that the concentration profiles indicate different concentration levels.. Designated areas from which employees would be medically tested included the following:

1. gin stand
2. bale press
3. suction/seed unload
4. storage
5. yard
6. office

The industrial hygienist relied on professional judgment and comments made by plant personnel in positioning samplers as close to the normal work stations as was reasonably possible. Optimum sampling locations included the following considerations:

- areas where workers spend significant amounts of time

- areas away from interfering disturbances such as aisles, windows, fans, etc.

- areas where the laminar flow characteristics of the vertical elutriator would not be influenced. In cases where cross-drafts or updrafts were suspected and the site could not be relocated, the inlet of the separation chamber was protected with a funnel, previously described (17), to minimize laminar flow disturbances.

- areas where the instruments could be mounted without interfering with process operations and without disturbance from equipment or workers.

Depending on the location where it was used, the vertical elutriator was supported on a tripod base or hung on a wall, structure beam or a piece of equipment to insure the chamber opening located at a proper breathing zone height of 60 $\pm$ 1 inches (1.5 meters) above floor surface.

Dust sampling was initiated only if the gin was operating. If there was a breakdown or temporary shutdown resulting in no cotton being ginned, yet the work crew remained at the gin, sampling was continued. Normally, the workers would engage in repair and clean-up activities; consequently, activities performed during shutdown periods may have resulted in higher dust concentrations than did activities performed during normal operations. If the gin was shut down and the gin crew left the facility, samplers were turned off, filters removed, and samplers were restarted with new filters only when the gin resumed operations.

In order to collect an ideal sample respresentative of airborne dust which is likely to enter the worker's respiratory system, the sampling procedure was designed so that samples of the actual dust concentrations were collected accurately and consistently and reflected the concentrations of dust at the time and place of sampling. To associate the dust levels in the workplace and the employee's exposure to cotton dust during the respective medical trial period, it was necessary to determine where in the facility they had worked and what portion of time was spent in each of these areas. The work patterns and movements of all medical test participants were, therefore, observed and recorded by the industrial hygiene personnel for varying intervals (usually from 15 to 60 minutes) of the survey period. Each employee was subsequently assigned the average dust concentation as measured by the vertical elutriators located in that area of the plant where the employee had spent each interval. The interval exposures were then cumulated for the entire survey period and a time-weighted average (TWA) exposure of each worker determined by using the following formula:

$$TWA = \frac{\text{summation of time spent in each location times the average dust concentration in that location}}{\text{total time exposed}}$$

The time-weighted-average exposure evolved as a method of calculating daily average concentrations by exposure time. It is the equivalent of integrating the concentration values over the total time base of the TWA. The TWA exposure was the most accurate description of each employee's actual exposure to cotton dust during the medical trial period.

In addition to the first day work shifts, samples were collected during a minimum six-hour period on the day following the medical trial if sampling proved feasible.

Information collected during each sampling period also included comments on operational and environmental variables. Specific data collected at each gin facility included:

1. Production rate (bales per hour, bales per shift).
2. Type of cotton processed (machine-picked or machine-stripped).
3. Environmental conditions (temperature, relative humidity, precipitation, winds, fog).
4. Atypical conditions encountered during sampling (choke-up, fire, mechanical breakdown).

Background/ambient dust levels were collected at selected facilities which were not fully enclosed and/or which were subject to potentially high ambient dust levels in the judgment of the industrial hygienist. The purpose of determining background dust levels was to evaluate the potential for ambient dust to significantly affect dust levels as measured in the employees' work areas. In general, no attempt was made to use the background dust measurements a priori as a correction factor in determining workplace dust concentrations.

Gravimetric Determinations

The vertical elutriators were used to determine dust levels on a weight basis; therefore, accurate methods and procedures were developed to weigh the filters before and after obtaining dust samples.

The Cahn microbalance (model 4700 electrobalance, sensitivity = 0.01 mg) with digital readout was selected for weighing. Tests have shown that the moisture adsorption capability of polyvinyl chloride filters is negligible (less than one percent by weight when exposed to a relative humidity of 90 percent). (26) For this reason, the PVC filters were used to collect samples in the ginning facilities.

The accuracy of the balance manipulation was evaluated periodically by checking a known weight that was about equal to that of the filter. Control filters (one out of each lot of ten "or a minimum of ten control filters per facility") were handled in the same manner as the sample filters, except for exposure to dust, to insure that differences in weight due to factors other than dust collection are properly corrected.

Before weighing the filters, the balance was zeroed and calibrated in the proper range. As a calibration check, a 20-mg calibrating weight was weighed and, if the balance did not read 20 mg, the zeroing and calibrating procedures were repeated. During filter weighing, the balance was checked periodically against the 20-mg calibrating weight.

The filter packages were opened and allowed to stand in the conditioned atmosphere of the laboratory for at least one hour prior to weighing. A filter was then removed from its package by carefully grasping the edge of the filter with unserrated metal forceps and then placing the filter over an ionizing unit to eliminate static electricity. The filter was then centered on the balance pan and weighed to the nearest 0.01 mg. The filter was removed from the balance pan and placed on the numbered cellulose support pad of a filter holder cassette. A filter-retaining ring was applied with sufficient pressure to insure a tight seal and covered with a filter cassette top. A plug was inserted in the orifice of both the top and bottom parts of the filter cassette. To insure that an adequate seal existed between the bottom and middle sections of the cassette, an opaque cellulose shrink band was placed over this joint.

The filters were then stored in the equipment van and transported to the respective gin facility. Immediately prior to exposure, the top section of the cassette and the plug in the bottom part were removed. The cassette was then placed with the exposed filter face down in the ferrule of the separation chamber of the vertical elutriator. The cassette-ferrule joint was sealed by placing a one-inch wide rubber band over the joint.

The lure adapter of the rubber hosing containing the critical orifice (and attached to the inlet of the vacuum pump) was attached to the outlet orifice of the cassette bottom section.

The vertical elutriator pump was started and vacuum pressure maintained at 16 inches of Hg during the period of sampling. Filter loading and proper operation of the samplers were monitored during sampling. At the end of the sampling period, the pump was stopped, rubber hosing detached from cassette, cassette removed from ferrule and top part of cassette and plugs replaced.

The exposed filters and controls were then hand-carried to the weighing laboratory. The small plug in the cassette top was removed from all cassettes, including controls, and the filters were allowed to stand in the conditioned atmosphere for at least one hour prior to weighing. The dust sample filters, including controls, were carefully removed (making sure not to disturb dust on the filter) with forceps from the cassettes and reweighed using the same procedure as in pre-weighing.

Vertical elutriated dust concentrations were calculated from the total weight of dust collected and the measured volume of air sampled.

Impactor samples were collected on 81-mm diameter Gelman glass fiber filters placed over each impaction stage. The mass of material collected on each stage was determined by weighing the filter before and after sampling. The impactor-collected cumulative masses provided aerodynamic size characterization and mass concentration data for the sampled dusts. The particle size·distribution, assumed to be lognormal was determined by plotting the cumulative mass associated with particles smaller than the ECD for successive stages on log-probability paper. The mass median aerodynamic diameter (MMAD) was then determined from the 50% mass intercept and the geometric standard deviation from the slope. (23) Mass concentration was determined by summing the masses collected on each impaction stage and calculating the sample volume.

V. Medical Survey Methods

Standard pulmonary function testing and respiratory questionnaires were used to assess lung function, work history, smoking history and respiratory symptoms. Spirometry was performed utilizing standard NIOSH equipment and procedures (See Table 3 and Appendices A and B for details) before shift work began and after six hours of exposure. An attempt was made to conduct spirometry on a Monday following a weekend or at least 36 hours of exposure out of dust, but this was not always possible.

Both English and Spanish translation of English respiratory questionnaires were used. These questionnaires utilized by both the SRI contractor and NIOSH were based on the Schilling modification to the Medical Research Council questionnaire for byssinosis. Questionnaires were administered by trained interviewers fluent in the language of the questionnaire. Copies of the questionnaires utilized together with questionnaire instructions may be found in Appendices C and D. Key definitions are found in Tables 4, 5, and 7. Co-variables measured from questionnaire data are found in Table 8.

Results of individual pulmonary function results were provided to each employee by mail. Copies were also provided to the employee's physician, if a physician was identified. See Appendix F for a copy of the notification form.

The set-up of equipment required during each field survey was arranged and completed by industrial hygiene and medical personnel on the day prior to the scheduled medical-environmental survey. Following is a brief outline of the daily activities performed by the field team during a typical survey:

A. Pre-Shift:

1. Calibrates spirometry instrumentation.
2. Obtains listing of employees' names from plant management.
3. Informs workers of purpose of study and risks involved with cooperation.
4. Acquires informed consent from each employee participating in medical tests.
5. Registers and identifies all medical test participants.
6. Performs pre-shift medical survey:
   a. measurement of employee's height and weight.
   b. five forced expiratory maneuvers performed by each employee into spirometer.
   c. employee interview using standardized questionnaire (demography, respiratory symptoms, work history, smoking history).

B. During Shift:

1. Interviewers check completeness and accuracy of responses on respiratory symptoms and co-variables reported.

C. Post-shift:

1. Interviews employee to ascertain activities and physical condition during shift.
2. Repeats five forced expiratory maneuvers of employees.

VI. Data Processing

Collected dust samples and control filters were hand-carried to the NIOSH-DRDS laboratory for gravimetric analysis. Sampling information and filter data were computer coded, processed and cross-linked with the information tapes defining individual employee work areas and frequency of exposure. The employee exposure information had been key-punched from field data recorded by industrial hygienists.

Completed questionnaires and spirometry data tapes were hand carried to either the contractor's or NIOSH-DRDS data analysis centers. NIOSH and contractor technicians digitized acceptable PFT curves from the analog spirometry tapes and questionnaires were computer coded and key-punched into a computer system. A printout of all computer entered information was checked for coding errors and incongruous data listings were corrected. The criteria used for evaluating spirometry, questionnaire and industrial hygiene data are shown in Tables 4-9. The project officer subsequently used reduced information from the questionnaire and spirometry tapes to analyze for and to assess the presence and severity of byssinosis or other respiratory diseases (using the WHO classification of respiratory disorders due to exposure to textile vegetable dusts). Dose-response curves were calculated from merged computer tapes of respiratory effect information and dust exposure data.

These curves are the result of measuring the quantity of cotton dust that is present (dose) along with the observed percentage change in lung function (response).

VII. Statistical Methods

Data were analyzed on an IMB 370/168 computer via a copyrighted software package, the Statistical Analysis System (SAS). (27) Dose-response curves were developed for acute exposures to elutriated cotton dust versus shift changes in FEV_1, $FEF_{50\%}$, $FEF_{75\%}$ and peak flow by employing the General Linear Models Procedure (GLM) of SAS. Predicted values for comparison of gin workers' pulmonary function results were derived from the data from the comparison plant workers who were examined in this study. The matched pair analyses that were used throughout the study were based upon McNemar's test (28) and the Chi-square distribution. (29)

Table 3. Definitions of technically acceptable pulmonary function measurements.

The criteria for technical acceptability of pulmonary function data are according to American Thoracic Society:

1. The workers blew into the spirometer until the pulmonary function technician, in the field, observed five visually acceptable forced expiratory maneuvers per session (pre-shift or post-shift) We deemed the data from the session acceptable if the computer technician back at the laboratory determined that at least two maneuvers met the ATS criteria of acceptability.

2. The analog tapes of these maneuvers were digitized by sampling at each 10 millisecond intervals and the curve was saved, if and only if the duration of the curve was greater than 1.1 seconds.

3. The computer technician excluded from the analysis any curve which demonstrated any coughing, early termination, or extra breaths.

4. We accepted for analysis only the highest FVC if and only if the second highest FVC was 95% of the highest FVC recorded during a pulmonary function testing session.

5. In addition to the ATS criteria, we added another criterion, which is that we accepted for analysis the highest FEV_1 if and only if the second FEV_1 was 92.5% of the highest FEV_1 recorded during a pulmonary function testing session.

Source: Standardization of Spirometry, Am Rev Resp Dis 119(5):2-11, May 1979

Table 4. Definitions of respiratory symptom data.[†]

bronchitis:	phlegm production on most days for at least 3 months in at least one year
cough:	cough on most mornings for as much as 3 months in one year
dyspnea:	shortness of breath on return to work after some days off when walking with other people of the same age at an ordinary pace on the level

†Protocol for translating questionnaire into these definitions is found in Appendix E.

Table 5. Definitions of technically acceptable personal dust exposure levels.

1. The worker must have been under observation for at least 6 hours.

2. Required that the worker have no exposure to the dusty processes in the work environment for 7 hours before the pre-shift spirometry.

3. Calculated the dose-response only on those workers who did not wear a respirator or who wore a respirator improperly.

4. In the comparison plants we excluded, from analysis of acute pulmonary function change, any worker who had exposure to known pulmonary irritants, or, who left the plant for more than an hour during the working shift.

Table 6. Study registrants and exclusion criteria for data analysis.

Total number of cotton gin workers registered: 551
Total number of comparison plant workers registered: 1218

Cotton gin workers were excluded from any type of analysis if they had previous exposure to cotton dust outside the cotton gin industry or worked in any type of a mine or foundry or had exposure to flax, hemp, jute, or asbestos.

Comparison plant workers were excluded from any analysis if they met any of the conditions above or worked in a cotton gin.

The pulmonary function results from any worker were not analyzed if the forced expirogram did not meet standards as stated in Table 3.

All missing questionnaire data were classified as such.

If the gin worker did not work more than 5.5 hours or wore a respirator properly, the dose-response for shift change spirometry excluded that worker.

Table 7. Definitions for respiratory disorders arising from exposure to textile vegetable dusts.†

Category	Symptoms
0	None
1/2 A	Non-classic byssinotic chest tightness or cough
1/2 B††	Monday* cough or occasional Monday chest tightness
1	Chest tightness on every Monday*
2	Chest tightness on every Monday* and consecutive days thereafter
3	Bronchitis

† Protocol for translating questionnaire into these definitions is found in Appendix E.

†† Grades 1/2 B, 1, and 2 constitute Schilling's definition of Byssinosis.

* or first day back to work

Source: WHO Report OCH/81.1

Table 8. Co-variables measured.

1. age in years

2. race
   - American Indian
   - Asian
   - Black, not of Hispanic origin
   - Hispanic
   - White
   - Other

3. sex
   - male
   - female

4. smoking
   - never smoker
   - ex-smoker
   - present smoker

5. residence
   - West Region
   - Lower Southwest Region
   - South Central Region
   - Southeast Region
   - Upper Southwest Region

6. height in centimeters

7. ponderal index in kilograms of body weight per meter in stature: expressed as kilograms/meter:
   - less than 0.5 kilograms/meter
   - 0.5 kilograms/meter or more

8. asthma beginning before the age of 26
   - "yes"
   - "no"

9. pack years: Cigarettes smoked per day currently times years smoked

10. change in spirometer temperature over the shift

11. plant

Table 9. Description of cells used in matched pair analysis.

1. age in years: expressed in intervals of 5 years each from ages 15 years to 69 years and then an interval of 70 years old and greater

2. race
   - American Indian
   - Asian
   - Black, not of Hispanic origin
   - Hispanic
   - White
   - Other

3. sex
   - male
   - female

4. smoking
   - never smoker
   - ex-smoker
   - present smoker

5. residence
   - West Region
   - Lower Southwest Region
   - South Central Region
   - Southeast Region
   - Upper Southwest Region

6. language
   - Spanish
   - English

7. questionnaire
   - Original
   - Revised

RESULTS AND DISCUSSION

Environmental

Throughout the cotton gin process, dust particles escape into the environment from leaks and openings in the pneumatic conveying systems from the cleaners and dryers, from the open fronts of the gin stands, and from the overflow bin, the lint chute and the bale press. Trash material accumulated around the plant or on process equipment may also be a source of airborne dust. All these dust sources affect the dust concentrations measured.

There are a few things that should be kept in mind when reading the results from these surveys. Concentrations measured by the vertical elutriator were influenced by variable operational parameters such as air flow patterns, condition of pneumatic conveyance and local exhaust systems, and typical and atypical ginning work practices. Additionally, placement of the samplers can affect concentrations measured, a decision based on the judgment of the industrial hygienists. These factors should be considered as limitations when observing differences between regions, gins, and areas which were sampled. Nevertheless, it is our professional opinion that these results do accurately represent the range of exposure levels which can be expected to exist in cotton gins. To insure a representative sampling, we sought to measure conditions within a range of variables. We observed a number of low and high capacity gins, gins processing machine-stripped or machine-picked seed cotton, facilities using old and new equipment and gins operating under differing climatic conditions.

Hypothesis testing on environmental measurements using Statistical Analysis Systems (SAS) general linear model (GLM) procedures was used to study relationships among variables. For this analysis, a lognormal model is assumed and for samples below the limit of detection, that limit was taken to be the observed concentration (for manipulations requiring logarithmic values). (NOTE: The limit of detection was established to be 30 micrograms per cubic meter as determined by the propagation of errors inherent in the sampling and analytical procedures.) The impact of this necessary manipulation is twofold: First, the inferred mean cotton dust exposure level moved slightly upward; and secondly, the frequency distribution of the data is slightly skewed because the distribution of exposure levels below 30 micrograms is censored.

In the tables presented, <u>SAMPLES</u> refer to the total number of samples comprising an individual data set. <u>MEAN</u> or "arithmetic mean" is the average of the values in the respective data set. <u>STD</u> or "standard deviation" is a measure of the variability of the data. <u>GM</u> or "geometric mean" is a measure of central tendency for a lognormal distribution. <u>GSD</u> or "geometric standard deviation" is a measure of relative variability of a lognormal distribution using all values in each data set. <u>MIN</u> or "minimum" and <u>MAX</u> or "maximum" represent the range of values comprising each data set. Because dust data tended to follow a lognormal distribution, the geometric mean was chosen as the measure of central tendency.

Generally, dust concentrations in the surveyed ginning facilities were low. The geometric mean dust concentrations in each facility (as calculated using all vertical elutriated dust samples collected at that facility) ranged from 0.03 to [illegible] mg/M^3. Eighty-six percent (30 of 35) of the gins had a geometric mean dust level measuring less than 0.5 mg/M^3.

Elutriated dust data indicated that dust levels in and between gins were variable. The mean elutriated dust concentrations measured with vertical elutriators inside the cotton gins are summarized in Tables 10 and 11 and Figures 4-6. A variation in dust concentrations was found in gins within each geographic area. These differences in dust concentrations in the different geographical areas can be attributed to several factors:

A. Different varieties of cotton are planted in these areas, necessitating different harvesting methods. For example, the varieties of cotton grown in the West, Lower Southwest, South Central, and Southeast Regions have a tall plant which mature long before the first killing frost and are, therefore, most efficiently harvested with a spindle harvester, which is designed to pull the seed cotton from the capsule. A shorter plant variety of cotton grows in the Upper Southwest Region and is harvested with a stripper harvester. A stripper harvester is designed to pull the entire capsule off the plant and this process also picks up leaves, stems, and weed materials as well. The amount of trash collected with the stripper-picked cotton is thus greater than with the spindle-picked cotton (e.g., 409 kg trash for stripper; 98 kg trash for picker-harvested cotton) per bale (15) and, subsequently, may result in higher dust levels during the ginning of the harvested seed cotton. It has been previously shown that raw cottons from locations where the crop is machine-stripped generate a much greater quantity of vertical elutriated particulate during carding than does cotton from locations where harvest is by machine-picking. (30)

B. Environmental phenomena such as freezing and precipitation, etc. encountered during or immediately prior to harvesting may affect plant part friability and therefore dust levels measured at the gin. (31) Also, raw cotton originating from the humid eastern U.S. produces less dust during carding for a given grade division than cottons from the arid west. (32)

C. Most of the ginning facilities surveyed in the Upper Southwest Region were older than those in other areas, and generally, poor housekeeping practices were followed. The accumulated trash inside the plant was inevitably a secondary source of airborne dust. Additionally, ventilation systems in these older facilities were in poor condition (often inoperable) and less efficient than those methods used in more modern gins.

D. Finally, the survey periods, which coincided with the peak ginning season, were July-August in the Lower Southwest Region, October-November the South Central, Southeast and West Regions, and December-January in the Upper

Southwest Region. Freezing and subfreezing temperatures encountered during December and January forced gin workers to keep doors and windows closed as much as possible, thus limiting the amount of air entering the plant. On the other hand, gins in the Southeast, South Central, and Lower Southwest Regions operated during warm, sunny days and generally kept windows and doors open allowing a steady flow of relatively cleaner outside air to circulate through the gin building, therefore, diluting ambient dust levels. The West Region gins operated between these two extremes and most had partially closed work areas. (25)

Geometric mean dust levels were broken down into gin stand (0.37 mg/M^3), bale press (0.27 mg/M^3), suction/unload (0.13 mg/M^3), yard (0.13 mg/M^3), and "other" (0.32 mg/M^3) areas (Table 11). The "other" listings included samples collected in the lint cleaning, bale storage, cotton drying, and shipping areas. The dust concentrations measured in these respective areas reflect the amount of dust released during the process operation and activity level inherent to each defined area. Air movement and machinery layout seemed to have a significant effect on the dust levels measured in various areas of the gin facilities. For example, in most ginning facilities surveyed, gin stands were typically placed alongside of the building, often leaving a narrow aisle between the stands and the wall. The bale press was located at one end of the building, usually near a door. This type of arrangement tended to create localized air pockets, which results in different concentrations in different areas. Also, exhaust fumes from diesel or gasoline tractors, left to idle in the unload (suction) area of some gins, may have contributed to the airborne dust measured in this area. (This situation was indicated by the brownish-gray color of samples sometimes collected in this area.) However, since the samples were not analyzed chemically, the amount of collected particulate resulting from engine exhaust is unknown, but is thought to be negligible.

Particle Size Determinations

Andersen samplers were used to collect at least one set of dust samples or particle size analysis from most ginning facilities surveyed. For some samples, low dust concentrations and insufficient sampling time resulted in inadequate dust collections for accurate weight analysis. In these instances, no size distributions could be determined.

Additionally, for some of those samples suitable for weight analysis, it was found that fibrous material caused the orifices for the collection stages to become plugged. Any bridging over the small orifices on the impaction plates could yield a high deposition on the early stages with corresponding low deposition on the lower stages of the sampler. The result would be a biased particle distribution due to collection of all but very fine particles. These samples were discarded and the MMD and GSD were not determined.

Data presented below summarize the mass median diameter of those samples collected by the cascade impactor which were suitable for weight analysis and for the determination of particle size distributions. Each set of values (MMD and GSD) listed for the following facilities were calculated from samples collected during a minimum 6-hour sampling period in the bale press area.

Facility	Mass Median Diameter (MMD in microns)	Geometric Standard Deviation (GSD)
401	5.6	2.6
402	8.5	2.4
403	4.0	4.0
405	8.5	3.4
406	2.7	4.1
412	6.8	3.3
413	4.7	3.2
414	3.5	5.1
419	3.7	3.4

MMD Range = 2.7-8.5
MMD Mean = 5.30

In comparison, the median size of elutriated particles collected in textile mills has been reported to range from 1.82-3.40 microns. (33) Similar studies performed by other investigators (23) on cotton gin dust indicate an average MMD of 4.7 microns with a standard deviction of 1.8 for the dust fraction penetrating the vertical elutriator. The large range of values reported in this study of ginning facilities indicates variations from gin to gin. In all cases, only a single sample was collected from each gin and, therefore, strong inferences should not be attempted. That the average MMD of elutriated dust collected in gins is somewhat greater than that collected in textile mills is not surprising considering the different technical processes in each industry. Mechanical processing operations in other non-textile cotton industries are thought to be mild in comparison to opening, picking, and carding in a textile mill. (34) In gins, a larger MMD particle size might also be anticipated because of the mild processing operations. Also, cotton dust in gins might be expected to have a larger amount of sand and silt particulate versus that in a textile mill.

The general conclusion based on these field results is that the Andersen multi-stage cascade impactor is of limited value in cotton dust sampling because of problems with sample loss and fiber bridging over the stage orifices in high dust areas. Adequate sampling periods may, therefore, vary from a few hours to several shifts, depending upon the dust concentrations and the sensitivity of the analytical procedure.

Direct Reading Measurements

The use of the GCA RDM-101 proved to be of limited value. Of the measurements taken alongside a vertical elutriator, the Dust Monitor could only produce an occasional correlation when the elutriated dust concentrations were lower than

0.7 mg/M^3 as was found previously by Neefus. (17) In most instances, readings from the Dust Monitor were lower than those concentrations measured with a vertical elutriator, but no clear pattern was observed.

In summary, environmental studies were conducted in a cross-sectional sampling of the U.S. cotton ginning industry. The purpose of these studies was to accurately assess employees' occupational exposure to airborne cotton dust in the ginning environment. Dust samples were collected by NIOSH sampling methods, with vertical elutriators and time-weighted-average concentrations of employee exposure determined. Generally, dust concentrations in the surveyed ginning facilities were low. The geometric mean dust concentrations in each facility as calculated using all vertical elutriated dust samples collected at that facility ranged from 0.03 to 1.83 mg/M^3. Eighty-six per cent, 30 of 35, of the gins had a geometric mean dust level measuring less than 0.5 mg/M^3. Data indicated that dust levels in and between gins were variable. Aerodynamic particle size was also variable between gins, but tended to be larger than that found in textile mills. Data also indicated that the dust levels in the gins were dependent on ginning processes. Ginning variables that affect vertical elutriated dust concentrations were: 1) input material, including condition and contamination of seed cotton; 2) layout of gin, including type and quantity of machinery used; and 3) management practices, including machinery maintenance, housekeeping practices and air-treatment.

Epidemiological

Demographic, smoking, and geographic characteristics of the cotton gin and comparison plant workers are given in Tables 12, 13, 14, and 15. A slightly higher proportion of male gin workers, a higher proportion of Hispanic gin workers, but lower proportion of black gin workers relative to comparison plant workers, were studied. Smoking proportions also varied somewhat. A higher proportion of gin workers is current smokers (53% to 46%) and more comparison plant workers had never smoked (42% to 34%). Ages, heights, and geographic distribution of gin and comparison plant workers were similar.

Because of differences in smoking, sex, and ethnic proportion of study subjects and to eliminate the possible effect of these and other co-variables, gin and comparison plant workers were matched for sex, race, age, height, weight, smoking status and region. Therefore, differences in respiratory symptoms or lung function between groups are likely to be attributable to differences in environmental exposure. Tables 16, 17, and 18 summarize respiratory symptoms, while Table 19 summarizes differences in lung function between exposed and non-exposed matched groups. Cotton gin workers tended to have more dyspnea and bronchitis than controls, but this was significant ($p<.01$) only for bronchitis among gin workers who had never smoked (Table 16). Although non-smoking gin workers reported bronchitis over five times as frequently as controls, there was only a modest and non-significant increase in bronchitis among current smokers. Similar trends were seen using the WHO criteria to assess respiratory symptoms from exposure to textile vegetable dusts (Table 17). Although gin workers had more symptoms in all smoking categories, only non-smokers were significantly different, with gin workers reporting over four times the prevalence of symptoms by these criteria. Using Schilling's definition of byssinosis (Table 18), no over-all difference in byssinosis prevalence was found. Matched analysis of lung function (Table 19) revealed slight but insigificant increases in the proportion of gin workers who had a greater than 10% fall in FEV_1 over a work shift. Although this criterion is more strict than others used in the past, it is consistent with current WHO guidelines. However, when gin and comparison matched pairs were compared for the proportions having a pre-shift FEV_1 less than 80% predicted (using predicted values based upon the comparison workers) cotton gin workers had a consistently higher prevalence of abnormality in all smoking categories. Only among current smokers was this difference significant ($p<.01$). Similarly, gin workers consistently had greater mean shift decrements in FEV_1 for all smoking categories and consistently smaller mean pre-shift FEV_1. These were significantly smaller for ex-smokers and present smokers (Table 19).

Dose response relationships in gin workers were calculated by plotting exposure to elutriated cotton dust in mg/M^3 against percent changes in FEV_1, $FEF_{50\%}$, $FEF_{75\%}$ and peak flow over a work shift while adjusting for co-variables of age, height, weight, race, plant, pack-years, smoking status and sex (Figures 7 and 8). In all gin workers, trends toward decrease in lung function were observed and were significant in some instances (peak flow and $FEF_{50\%}$). When similar regressions were done on comparison plant workers, no relationships were found. This is not surprising because the workers were exposed to low concentrations of biologically inert dust.

Because of the clear trend toward lower pre-shift lung function among cotton gin workers, a model was created based on regression analysis utilizing a number of measures of lung function by elutriated dust level (mg/M^3) and months of cotton dust exposure while adjusting for other important co-variables (age, height, weight, race, plant, peak years, smoking status, and sex--see Table 20). Little effect was seen in the FVC. However, the indices of flow (FEV_1, $FEF_{50\%}$, $FEF_{75\%}$) showed trends toward decreases in pulmonary function with increasing dust level and months in cotton gin work.

The prevalence of bronchitis and cough (based on Probit Analysis) by four elutriated dust levels among never smokers (previously found to have significantly more bronchitis than comparison plant workers) is shown in Table 21. A slight trend with increasing dust level is noted. The prevalence of byssinosis, as defined by Schilling, was too low to perform an analysis on that indicator. However, utilizing the WHO index of respiratory disorder against cumulative cotton dust exposure expressed as years-mg/M^3, both never smokers and current smokers were analyzed (Table 22). A clearer trend of increasing prevalence, with over doubling in symptom prevalence with 20 dust-years, is observed among those who never smoked. A less clear trend is seen among current smokers, with the lowest prevalence seen at the lowest dust-year level and higher (but not highest) at the highest dust-year level. Therefore, both these analyses of respiratory symptoms among never smokers suggest some increase in respiratory symptoms with increasing dust and years.

Results of this industry-wide study of cotton ginning are in many ways consistent with previous studies of cotton gins (reviewed in Table 1). There are, however, some differences which should be noted. The relatively high byssinosis prevalence noted by El Batawi and Khogali was generally associated with much dustier conditions than we observed in U.S. gins. There may also have been slight differences in disease definition and study methods which could account for some of these differences. Palmer in an earlier NIOSH study of cotton gins found no byssinosis. Although a low percentage of subjects in both the exposure and comparison groups had questionnaire responses consistent with byssinosis, byssinosis per se does not appear to be significantly increased among cotton gin workers. This is probably largely attributable to the relatively low dose and larger particle size observed in U.S. gins, but is also probably related to the short ginning season and the highly variable work week.

Although byssinosis (as defined by Schilling) does not appear to be increased, there is a good deal of evidence that cotton dust exposure is having an adverse effect on respiratory health among U.S. cotton gin workers. Respiratory symptoms, especially bronchitis among non-smokers, were clearly increased. The data suggests that there was a dust and duration influence on this increase in bronchitis and respiratory disorders (as defined by WHO). Similarly, evidence of a decrease in lung function over the work shift with increasing respirable dust level was observed. This is consistent with Palmer's previous findings and tends to provide validation to the increase in symptoms observed by questionnaires. Finally, the level of lung function prior to acute dust exposure was decreased among gin workers, and significantly among smokers. This finding is similar to the findings of Merchant et al. (16) and Beck et al. (35) among cotton textile workers in that smokers were found to have the lowest lung function suggesting both a smoking and cotton dust effect. Whether these changes in lung function among cotton gin workers are persistent beyond the end of the ginning season is unknown. It does, however, appear that lung function is depressed among U.S. cotton gin workers, especially among smokers. All of these observations were consistent with findings made previously on cotton dust exposure among cotton textile workers.

In summary, a large cross-sectional study designed to survey a representative sample of the U.S. cotton ginning industry has been completed. Environmental assessment relied principally on the vertical elutriator and a cascade impactor to assess airborne concentration and particle size, respectively. Direct reading instruments proved to be of limited value. Generally dust levels in U.S. gins were relatively low with most gins having geometric mean dust levels below 0.500 mg/M^3. The gin stand was the work area with the highest dust level, but dust level was found to vary greatly from work area to work area and gin to gin. Epidemiological assessment revealed no more byssinosis among gin workers than comparison plant workers, but showed an increase in bronchitis and "respiratory disease arising from exposure to textile vegetable dusts" among non-smoking gin workers. Evidence of a dose-response relationship was found between dust exposure and decline in peak flow and $FEF_{50\%}$ lung function over the work shift. Finally, a higher proportion of smoking gin workers was found to have depressed pre-shift lung function.

RECOMMENDATIONS FOR AN ENVIRONMENTAL STANDARD

In an earlier study in the U.S. ginning industry, Palmer, et al. (8) found evidence of pulmonary function abnormalities. Certain results of this present study corroborated their findings and in addition found evidence of excessive symptoms as well as the increased prevalence of bronchitis and "respiratory disorders arising from exposure to textile vegetable dusts" in cotton gin workers who have never smoked; increased prevalence of below-normal pre-shift FEV_1 in smokers; and lower mean pre-shift FEV_1 in ex-smokers and present smokers. When combined with dust level data, the medical data show trends toward smaller pre-shift pulmonary flow indices (FEV_1, $FEF_{50\%}$, $FEF_{75\%}$) in a statistical model based on dust levels and duration of exposure and significant dose-response curves for cotton workers' peak flow and $FEF_{50\%}$. Probit analysis shows an increasing prevalence of bronchitis in never-smokers with increasing dust level, and increasing prevalence of "respiratory disorders" with increasing dust-years. The latter analysis shows that bronchitis prevalence more than doubles when the factor of dust-years is 20.3. The environmental data indicate that 86% of the geometric mean dust levels for the gins in this cross-sectional survey were below .500 mg/M^3. Therefore, given these effects of dust on health, and the technical feasibility of attaining a geometric mean level of .500 mg/M^3, NIOSH recommends that a level of .500 mg/M^3 geometric mean be set as a standard for the cotton ginning industry.

RECOMMENDATIONS FOR CONTROLLING EMPLOYEE EXPOSURE TO COTTON DUST

A. Control Technology for the Non-Textile Industry

The most effective means of controlling employee exposures to cotton dust is to reduce emissions at their source through the use of mechanical methods combined with work practices. NIOSH contends that the achievement of the recommended environmental limits in the non-textile industry is technologically feasible by utilization of appropriate control technology. While it is recognized that development and application of control technology have not advanced to the stage demonstrated for the textile industry, modification and adaptation of existing dust control systems should bring most of the non-textile cotton workplaces within the proposed standards. As demonstrated by the data, compliance has and can be achieved without the need for advanced engineering controls.

In preventing adverse health effects from exposure to raw cotton dust, the primary engineering objective is to prevent the air from becoming contaminated. This is accomplished as far as possible by improved process design and feasible engineering control methods. Control of cotton dust levels relies primarily upon general principles of dust control. There are three general methods of control that should allow most non-textile workplaces to maintain exposure levels below the recommended limits.

(a) Ventilation. The primary method for reducing exposure to cotton dust is installation of either general or location ventilation systems. In facilities utilizing central air conditioning, proper adjustment of the system could constitute an effective dust control system. With the installation of efficient supplementary filtration and air-washing built into the system, air conditioning can become an integral part of the cotton dust control strategy.

The capture and removal of dust from the air at its point of generation represent the most widespread and efficient method of dust control at present. Many times, installing a hood over a piece of machinery discharging dust throughout the workplace, or strategically collecting trash being discharged from operating machinery may be sufficient to reduce levels to the same extent provided by elaborate general ventilation schemes.

Local exhaust ventilation (LEV) is a control technique employing the following principles: capture of the contaminant as closely as possible to the point of generation; application of sufficient air volumes for capture and transport of the contaminant; and collection of the contaminant with efficient filtration devices. Quantities of air required for ventilation would not be expected to depend on the concentration of dust in the air being removed, but rather on the dynamic properties of these particles in the air. After the dust is collected by the appropriate capture devices, it is transported to the filter media. It is recommended that fine dust filters which are most efficient for capture of particulate sizes of 15 microns or less must be used.

Representatives of Research Triangle Institute and Pneumafil Corporation have testified (36) that by employing adequate dust capture devices, sufficient air volumes, and efficient single-stage filtration, dust levels in the range of 100 $\mu g/M^3$ can generally be achieved; with two-stage filtration (and air washing), levels not exceeding 500 $\mu g/M^3$ can be expected; if efficient third-stage filtration is added, workroom dust levels will generally not exceed 200 $\mu g/M^3$ for an eight-hour time-weighted average. The success achieved by the textile industry in reducing dust concentrations through the appropriate use of ventilation systems suggests similar reductions are feasible in the non-textile industries in which similar dust generation mechanisms are recognized.

(b) Modification or isolation of a process. Isolation consists of providing enclosures for equipment or complete separation of one work area from another. Total isolation of dusty operations such as bale press areas and even isolation or separation of filtration systems are recommended as a practical approach to reducing dust exposure levels in the workplace.

Recommended modification of production equipment consists of designing automated feed systems, automation of bale strapping systems, and converting from manual to mechanical handling of cotton in all practical situations. In facilities where automation has been utilized to a great extent, reduced dust levels have resulted. (37)

(c) Work practices. Significant reductions of cotton dust levels could be achieved by simply maximizing the effectiveness of the existing control devices. Maintenance of local exhaust hoods, ductwork, dust collection equipment, and fans in optimum working condition; programs of total maintenance; and good work practices should be instituted to be efficient and effective in reducing exposure levels.

A written program of work practices to include procedures which will minimize cotton dust exposure for each specific job is recommended. The protocol utilized by the American Textile Manufacturers Institute, Inc. in developing work practices for specific jobs consists of making a detailed analysis of the sequence of actions practiced by an individual worker or work team at a work station and developing a specific work practice program from this information. (38)

Often by simply altering a ritual or unnecessary routine or correcting sloppy practices, significant reductions can be achieved in dust levels to which employees are exposed. For example, the ritual use of compressed air cleaning in "blow down" operations results in elevated dust concentrations and should, therefore, be limited strictly to maintenance uses such as removal of dust and lint from machinery. Thus, common practices such as cleaning of clothes or floors with compressed air should be avoided. (When blow down operations are necessary, NIOSH recommends that workers performing these operations wear respiratory protection and those not involved in the process leave the area.)

Other specific work habits should include the following:

- all employees should be instructed to keep cotton as far away from the face as possible when feeding hoppers, cleaning equipment, or gathering waste cotton. Waste piles should not be gathered up in the employee's arms.

- shift cleaning should be performed with only that equipment designed for cleaning operations. Dry sweeping should be avoided and efficient vacuum cleaning with appropriate filter devices substituted wherever possible.

- when removing chokes from machinery, approved respiratory protection should be worn.

Housekeeping and maintenance activities cannot be totally effective unless they are systematically and regularly done. Therefore, a written plan should be adopted for implementing such operations. It is important to continue good work practices once significant reductions in dust levels have been achieved so that lower exposures to cotton dust are maintained.

B. Specific Control Technology for the Ginning Process

Following are examples of specific control technology which should result in major reductions in cotton dust levels in a wide range of processes. Employment of this technology and continued experience in applying general control principles to specific problems will bring most of the facilities in this non-textile segment within the limit of the recommended standard.

In a control technology assessment of raw cotton processing operations conducted by Enviro Control, Inc. and sponsored by NIOSH (39), it was reported that observed gins did not utilize cotton dust controls to a large degree. The major controls observed included local exhaust ventilation, process modification, liquid overspray and gin design. For the most part, the application of these control techniques did indicate significant reductions. For example, the use of a local exhaust hood over a lint slide reduced the cotton dust level by 68 percent (1295 ug/M^3 to 413 ug/M^3). The most dramatic observation was the reduction of cotton dust levels through gin design. The design approach included isolation of process, orientation of building, exhaust air discharge so as to prevent re-entrainment of dust laden air, and automation of processes.

Although much of the handling of cotton in many gins, especially the modern ones, is accomplished by automatic or enclosed systems, there are some gins where the operations are performed manually; for example, where seed cotton is sucked out of a trailer. It is recommended that the workers utilize approved respiratory protection in such situations.

The need for and importance of housekeeping and maintenance in reducing dust levels in gins are emphasized since effective engineering control measures are generally not as practical or feasible in this industry as in others. Therefore, basic housekeeping provisions to maintain surfaces as free as practicable of accumulated dust are strongly recommended. All gin engineering equipment and ventilation systems including power sources, duct works, joints and filtration units should be regularly inspected, cleaned, and/or repaired as necessary.

C. Respiratory Protection

NIOSH recommends that feasible engineering and work practice controls should be used as the primary means of reducing employee exposure to cotton dust. In situations where feasible control measures and work practices are insufficient to reduce exposure to the recommended limits, the controls should be implemented to reduce exposures to the lowest achievable level and then be supplemented by the use of respiratory protection. While respirators are not the preferred means of controlling employee exposure, respiratory protection must be utilized to reduce exposure during the time required for installation or implementation of feasible engineering controls and work practices, where such measures have been implemented and the recommended environmental limit has not been achieved, and where engineering controls are inappropriate, such as during some repair and maintenance activities or non-routine work practices. Respiratory protection should also be provided whenever an employee requests a respirator to provide protection for those employees who are sensitive when exposed to concentrations below the recommended environmental limit. In requiring respiratory protection as a supplementary means of reducing exposure levels in only limited situations, the burden of reducing employee exposure levels remains upon the employer rather than through reliance on the variability of human behavior so critical to the successful use of respirators.

In those circumstances which necessitate the use of respiratory protection, the employee should be provided with an appropriate respirator and adequate training in its proper use. Respirators should be selected from those tested and approved by NIOSH/MSHA for penumoconiosis and fibrosis-producing dusts under 30 CFR Part II which will afford the employee the proper degree of protection. A number of different types of respirators are available for use in protecting against cotton dusts. These range from a single-use type respirator approved for use at low dust levels to the full facepiece, air-powered breathing apparatus for protection against very high concentrations. An investigation of the performance of single-use dust masks in a textile plant environment has demonstrated that these respirators, when properly used, can be effective in reducing cotton dust inhalation. (40) Approved single-use respirators had fitting efficiencies ranging from 93-99% and were reported to be generally convenient from the standpoint of being lightweight, sanitary, economical, offering low resistance to breathing, requiring little maintenance, and receiving wide acceptance among workers.

Appropriate respirators for use in varying dust concentrations are described below:

Exposure not greater than :	Required Respirator:
(a) 5 times the applicable limit	1. Any dust respirator, including single use.
(b) 10 times the applicable limit	1. Any dust respirator, except single use or quartermask; or

	2. Any supplied air respirator; or 3. Any self-contained breathing apparatus.
(c) 50 times the applicable limit	1. High efficiency particulate filter respirator with a full facepiece; or 2. Any supplied air respirator with full-facepiece, helmet or hood; or 3. Any self-contained breathing apparatus with full-facepiece
(d) greater than 50 times the applicable limit	1. A powered air-purifying respirator with high efficiency particulate filter; or 2. A self-contained breathing apparatus with a full-facepiece operated in pressure demand or other positive pressure mode; or 3. A type "C" supplied air respirator operated in pressure mode; or 4. A combination respirator type which includes a type C supplied-air respirator with a full-facepiece operated in pressure or continuous-flow mode and an auxillary self-contained breathing apparatus operated in pressure demand or other positive pressure mode.

The employer should institute and enforce a respiratory protection program in accordance with OSHA Standards, Part 190.34. In addition to selection, cleaning and maintenance of respirators, an effective respirator program should include appropriate operating procedures and employee training in respirator use. The employee must be properly trained to wear the respirator, to know why and where the respirator is needed, and to understand the limitations of the respirator. An understanding of the hazard involved is necessary to enable employees to take appropriate steps necessary for their own protection.

It should be emphasized that respiratory protection is no better than the proper fit and use of the respirator. Frequent random inspections should be conducted by either the plant manager, safety engineer, industrial hygienist or medical personnel. Single-use respirators should be replaced daily by the employer. If any employee feels that his respirator does not fit or should be exchanged, he should be instructed to contact the proper authority. A respirator maintenance program should be established to ensure that respirator filters are cleaned, repaired, and replaced according to practices outlined in American National Standard Practices for Respiratory Protection, Z88-2. (41)

Appropriate sections from the NIOSH Technical Report: A Guide to Industrial Respiratory Protections are included in the Appendix to provide more complete information concerning the proper selection and use of respirators, training and fitting guidelines, respirator cleaning and maintenance and program administration.

D. Employee Education and Training

A training program for all employees exposed to cotton dust is viewed as essential for the protection of employees and is strongly recommended. Employees can do much to protect themselves if they are made aware of the hazards in the workplace. The training should include information on implemented dust control measures, work practices, respirators, medical surveillance, and the medical symptoms of respiratory disease, especially those most directly related to byssinosis such as chest tightness, frequency of symptoms and progress.

The posting of warning signs in readily visible locations is recommended in any work area where there is potential exposure to cotton dust. An employee whose workforce consists of a significant percentage of Spanish-speaking employees who cannot communicate in English should provide bilingual versions of the training program and posted warning signs.

E. Summary of Recommendations for Controlling Exposure

Reduction of worker exposure to dust which results from the processing of cotton can best be achieved by the elimination of this dust through improved engineering controls and work methods. With minor exception, achievement of effective control of cotton dust exposure should be based on a system approach rather than a single process control.

Control to within the recommended environmental limits should be achievable with application and use of existing control techniques. Efforts should be made to enclose processes and to use the process air to create a negative pressure within the equipment wherever possible. Open conveyors and material transfer points should be enclosed and exhaust ventilated. All exhaust system and air cleaner discharge points should be located downwind and well-distanced from building makeup air inlets to prevent re-entrainment of dust laden air. Open processes such as shakers and specific dust generation points should be hooded or isolated to prevent contamination of other areas.

The potential for successful dust control in the non-textile segments is strongly suggested by the success achieved by the textile industries. While there are some basic differences in the operations, the overall process configuration and dust generation mechanisms are sufficiently similar to allow transfer of the control technology.

In those limited situations where the implementation of engineering controls is not feasible or adequate in reducing dust levels to below the recommended environmental limit, work practice standards and respiratory protection measures are necessary.

Voluntary compliance by the employer to reduce worker exposure to cotton dust is strongly encouraged. It is suggested that a written safety and health policy be developed by each organization and that there is a managerial responsibility and accountability of the policy.

RECOMMENDATIONS FOR MEDICAL SURVEILLANCE

In conjunction with the environmental standard and controls, NIOSH recommends a comprehensive medical surveillance program to detect as early as possible the development of symptoms and/or respiratory impairment. The program should provide the following elements:

(1) Adequate data base
(2) Adequate follow-up
(3) Standard procedures and instrumentation
(4) Standard interpretation of results
(5) Appropriate use of results

An adequate data base can be provided only if cotton gin workers are examined prior to exposure to gin dusts. This examination should occur on the first day of employment during a gin season, and should include pre- and post-shift spirometry and standardized questionnaires. The specifications for the questionnaire and spirometry devices and the training of technicians in the use of the questionnaires and spirometry devices are detailed in the OSHA cotton dust regulations (CFR, June 23, 1978) and are not repeated here.

The present study indicates that symptoms (bronchitis) and signs of pulmonary impairment (decreased flow) develop after long-term exposure to cotton-gin dust. It would be in the interest of workers' health to detect as early as possible when these long-term effects are first noticable. It would also be in the best interest of both workers and industry to know whether effects of exposure over a ginning season linger on into the next season, or whether there is recovery of symptoms and pulmonary function between seasons. Thus, NIOSH recommends that medical testing be repeated twice during a gin season:

(1) One repeat test should be given about 4 weeks into the gin season, consisting of pre- and post-shift spirometry and questionnaire. The questionnaire could be limited to questions dealing with cough, phlegm, chest tightness and dyspnea, and changes (if any) in smoking habits.

(2) Another repeat test should be given at the end of the ginning season, with the same spirometry and questionnaire.

NIOSH recommends that such a program will not only protect individual gin workers' health, but provide on-going prospective information on health effects of exposure to cotton gin dust. This program should be viewed as an active surveillance mechanism. Therefore, all data should be actively and routinely submitted to OSHA and NIOSH, who should engage in prospective studies of these data. Through this mechanism, exposure standards can be periodically re-assessed.

Although final interpretation of medical data lies with the clinical judgment of the examining physician, judgment is aided by use of appropriate references. For pulmonary function tests, the best reference to date is the population study of Knudson, et al. (42), whose prediction values for FEV_1 are widely used and have been incorporated into the OSHA cotton dust standard. There are problems with the applicability of these prediction values to the cotton industry since they are derived from a white population in Tucson, whereas there are many blacks and Hispanics in the cotton ginning industry. Their populat on also includes persons who are not working, whereas by definition, cotton gin workers are "healthy" enough to be employed. This present NIOSH study used as a comparison group a "blue collar" working population, consisting of a mixture of whites, blacks and Hispanics from across the cotton belt. NIOSH intends to submit the analysis of these data for scientific review. If the data are generally deemed appropriate, in the future these may be used as the standard reference population to which cotton gin workers are compared.

Table 10. ELUTRIATED DUST LEVELS AT COTTON GINS BY GEOGRAPHIC REGION AND PLANT DUST LEVELS IN MICROGRAMS PER CUBIC METER

REGION=LOWER SOUTHWEST

STUDYNUM	SAMPLES	MEAN	STD	GM	GSD	MIN	MAX
721	17	237	154	195	1.99	36	736
722	21	181	94	156	1.85	18	407
723	16	509	811	303	2.45	79	3444

REGION=SOUTH CENTRAL

STUDYNUM	SAMPLES	MEAN	STD	GM	GSD	MIN	MAX
401	24	573	243	499	1.89	65	945
402	22	421	252	349	1.93	85	1038
403	19	285	185	210	2.34	15	670
404	8	362	562	212	2.45	112	1749
405	24	104	108	74	2.31	5	412
407	23	211	148	158	2.40	11	674
408	12	298	211	229	2.51	22	690
409	12	101	67	83	1.92	42	225
410	12	480	430	338	2.46	50	1293
419	19	157	119	120	2.22	21	442
420	18	149	111	114	2.26	14	382
421	9	159	102	135	1.79	56	389
422	9	141	80	117	1.93	39	273
423	22	208	161	150	2.29	7	820
424	12	355	157	320	1.65	129	689

REGION=SOUTHEAST

STUDYNUM	SAMPLES	MEAN	STD	GM	GSD	MIN	MAX
406	22	562	518	347	3.16	0	1965
411	23	427	290	339	2.18	18	1218
412	22	317	263	213	2.62	51	785
413	10	1010	456	902	1.69	351	1604
414	20	703	408	683	1.73	247	1650
415	19	252	307	162	2.34	72	1165
416	10	426	584	292	2.04	52	1995

REGION=UPPER SOUTHWEST

STUDYNUM	SAMPLES	MEAN	STD	GM	GSD	MIN	MAX
711	16	592	466	300	4.72	0	1326
712	16	1970	854	1834	1.46	1034	4548
713	17	352	1452	41	3.61	0	5935
714	9	0	0	30	1.00	0	0
715	16	660	559	442	2.83	11	1871
716	20	463	353	260	3.56	17	1163

Table 10. (contd.) ELUTRIATED DUST LEVELS AT COTTON GINS BY GEOGRAPHIC REGION AND PLANT DUST LEVELS IN MICROGRAMS PER CUBIC METER

REGION=WEST

STUDYNUM	SAMPLES	MEAN	STD	GM	GSD	MIN	MAX
701	15	356	252	305	1.72	112	1199
702	27	605	233	533	1.85	91	1063
703	18	611	266	546	1.68	105	993
704	24	510	215	468	1.53	230	927

Figure 4. ELUTRIATED DUST LEVELS AT
COTTON GINS
FOR EACH STUDY PLANT
GEOMETRIC MEAN DUST LEVELS IN MICROGRAMS PER CUBIC METER

BAR CHART OF GEO_MEAN

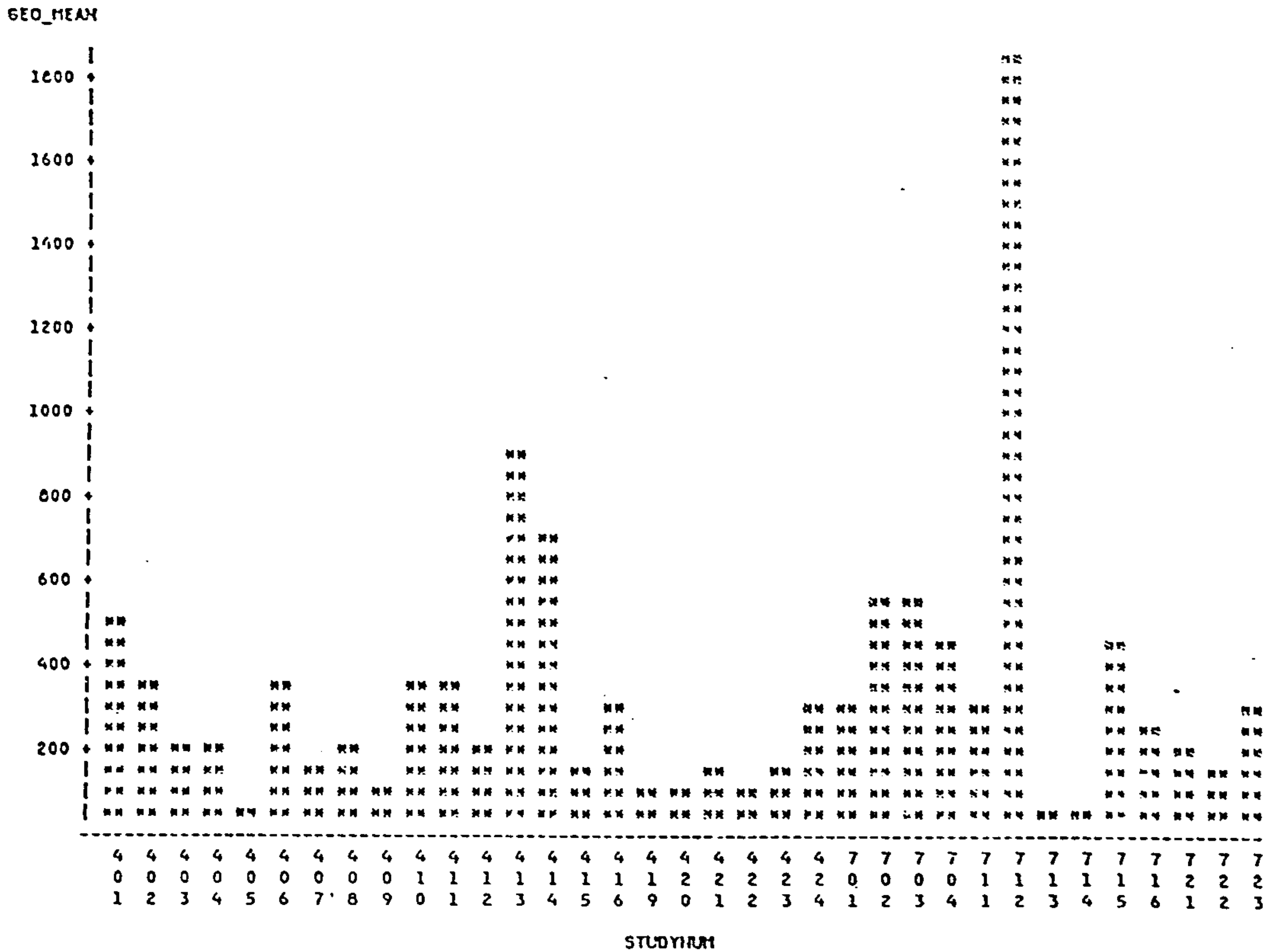


Figure 5. ELUTRIATED DUST LEVELS AT
COTTON GINS
FOR EACH GEOGRAPHIC REGION
GEOMETRIC MEAN DUST LEVELS IN MICROGRAMS PER CUBIC METER

BAR CHART OF GEO_MEAN

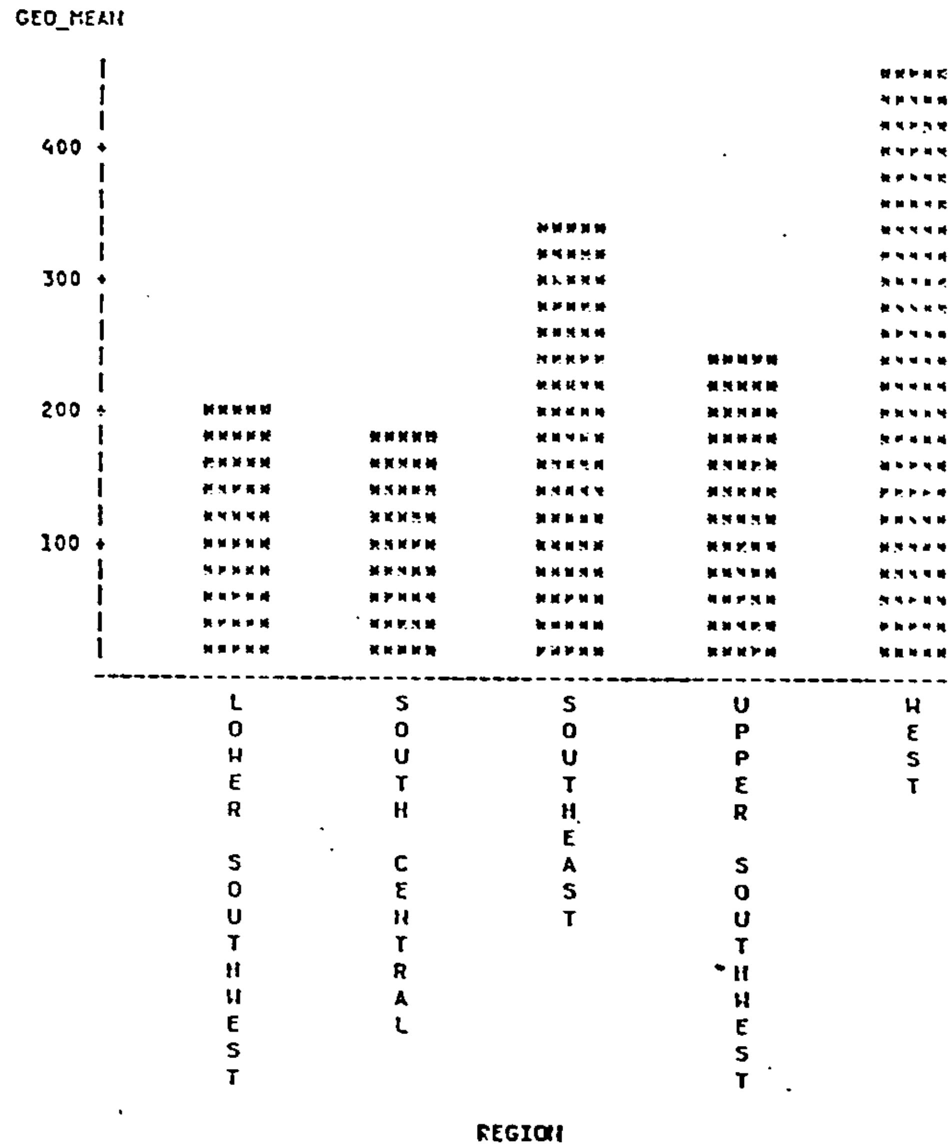


Table 11. ELUTRIATED DUST LEVELS AT COTTON GINS BY PLANT AREA

DUST LEVELS IN MICROGRAMS PER CUBIC METER

AREA	SAMPLES	MEAN	STD	GM	GSD	MIN	MAX
OFFICE	13	259	327	162	2.54	45	1206
BACKGROUND	49	112	125	81	2.41	0	652
OTHER	48	470	503	320	2.53	42	3444
SEED UNLOAD	62	216	279	126	2.03	0	1405
GIN STAND	211	560	552	370	2.69	0	4540
BALE PRESS	201	450	571	273	3.02	0	5935
YARD	25	165	112	131	2.09	18	392

Figure 6. ELUTRIATED DUST LEVELS AT COTTON GINS BY GEOGRAPHIC REGION AND PLANT AREA GEOMETRIC MEAN DUST LEVELS IN MICROGRAMS PER CUBIC METER

BLOCK CHART OF GEO_MEAN

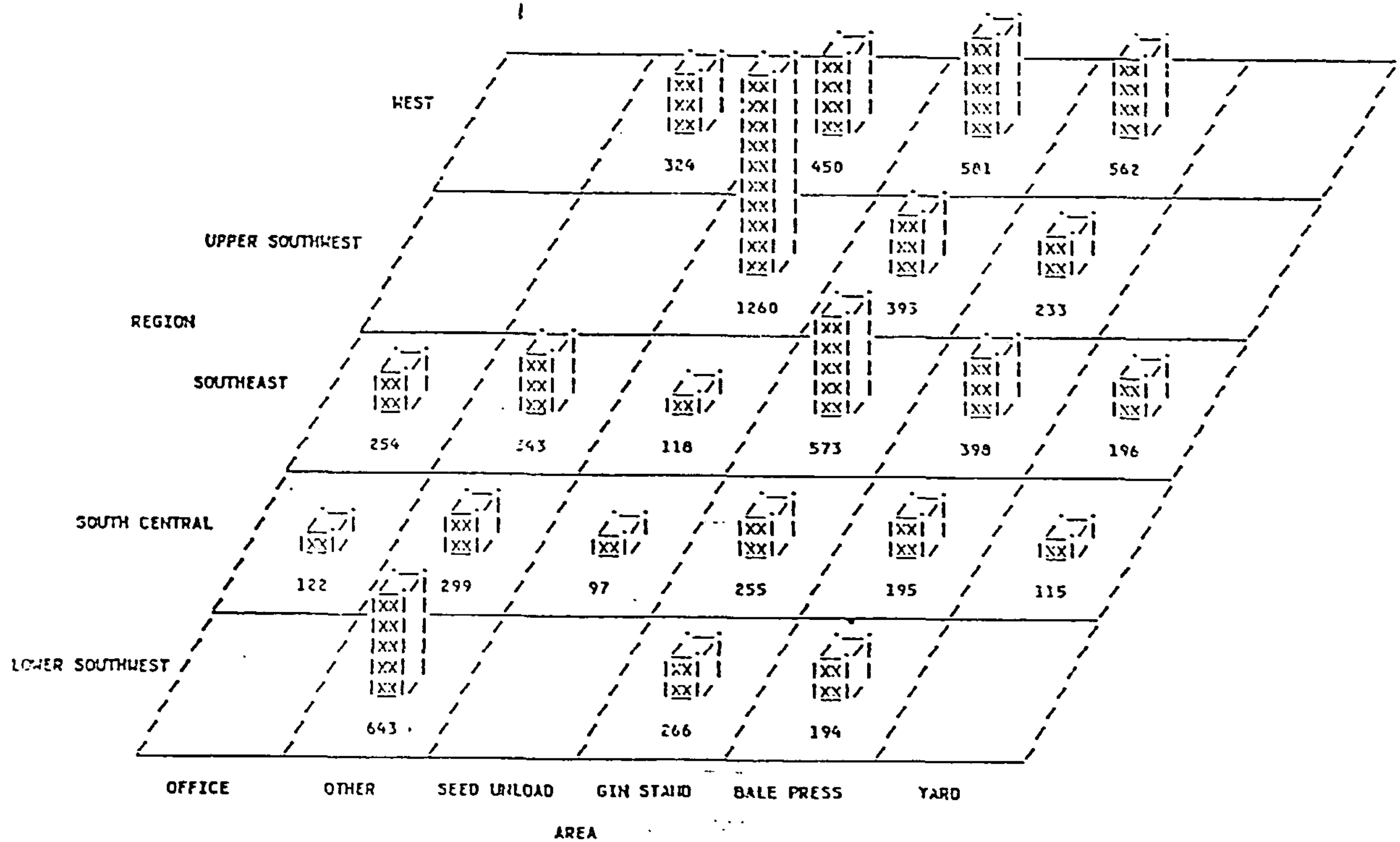


Table 12. Demographic characteristics of workers.

	Cotton gin workers		Comparison Plant workers	
	n	percent	n	percent
Sex				
Female	26	7	106	10
Male	348	93	917	90
Unknown	1	0	0	0
Total	375	100	1023	100
Race				
American Indian	1	0	11	1
Asian*	0	0	11	1
Black	108	29	455	45
Hispanic	164	44	221	22
White	101	27	320	31
Other	0	0	2	0
Unknown	1	0	3	0
Total	375	100	1023	100

*includes Pacific Islanders

Table 13. Smoking characteristics of workers.

	Never smokers	Ex-smokers	Present Smokers	Total
Cotton gin workers				
Number	128	48	199	375
Percentage	34	13	53	100
Pack years (mean)	0	18	17	-
Comparison plant workers				
Number	426	122	475	1023
Percentage	42	12	46	100
Pack years (mean)	0	18	14	-

Table 14. Age and height characteristics of workers.

	Cotton Gin Workers	Comparison plant Workers
Age (years)		
mean	34	33
median	28	30
range	16 to 79	14 to 77
S.D.	15	12
Height (cm)		
mean	171	173
median	170	173
range	151 to 203	135 to 201
S.D.	8	9

Table 15. Geographic characteristics of workers.

	Cotton Gin workers		Comparison Plant workers	
	n	percent	n	percent
West	49	13	101	10
Lower Southwest	42	11	96	9
South Central	122	33	374	36
Southeast	79	21	270	26
Upper Southwest	83	22	182	18
Total U.S.	375	100	1023	100

Table 16. Matched-pair analysis of dyspnea, bronchitis and cough.

	Cotton Gin worker prevalence (per 100)	Comparison Plant worker prevalence (per 100)	Sig.
dyspnea			
never Smokers	8	0	N.S.
present smokers	4	4	N.S.
bronchitis			
never smokers	16	3	$p < 0.01$
present smokers	21	17	N.S.
cough			
never smokers	10	4	N.S.
present smokers	10	4	N.S.

Table 17. Matched-pair analysis of any category of "respiratory disorders arising from exposure to textile vegetable dusts."

	Cotton Gin workers prevalence (per 100)	Comparison Plant workers prevalence (per 100)	Sig.
Ex-smokers	27	20	N.S.
Never smokers	22	5	p <.01
Present smokers	25	22	N.S.

Source: WHO Report OCH/81.1

Table 18. Matched-pair analysis of byssinosis prevalence (Schilling definition).

	n	Cotton Gin worker prevalence (per 100)	n	Comparison Plant worker prevalence (per 100)	Sig.
Ex-smokers	15	0	15	7	N.S.
Never smokers	67	1	67	0	N.S.
Present smokers	111	2	111	0	N.S.
Total	193	2	193	1	N.S.

Table 19. Matched-pair analysis of over-shift FEV_1 changes and pre-shift FEV_1 status.

Over-shift FEV_1 Changes

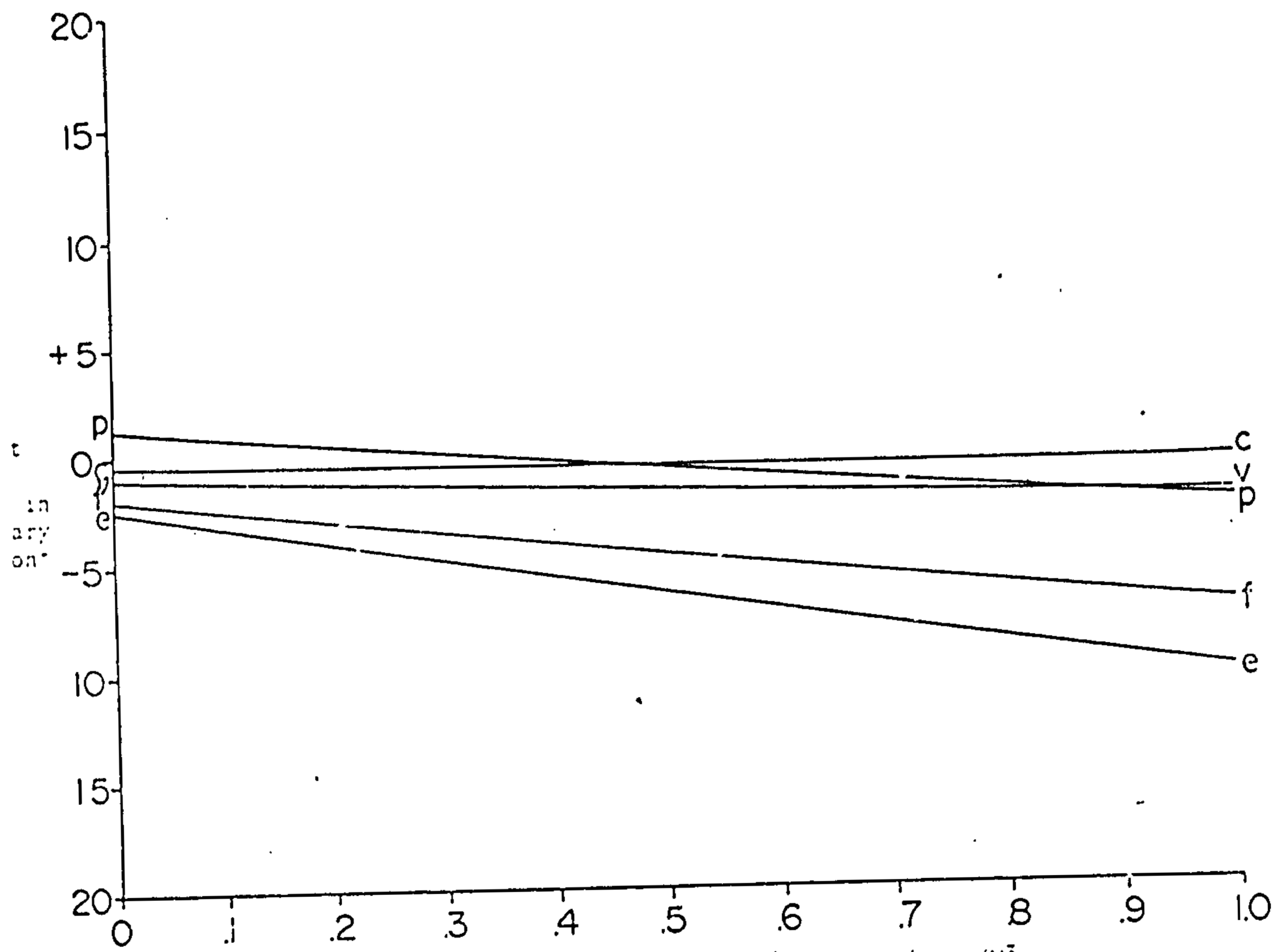
	n (pairs)	Prevalence of clinically significant FEV_1 decrements* (per 100): gin workers	comparison workers	Sig.	Mean over-shift decrement: gin workers	comparison workers	Sig.
Ex-smokers	17	6	6	N.S.	-.087	-.061	N.S.
Never Smokers	71	3	0	N.S.	-.058	-.030	N.S.
Present Smokers	98	7	5	N.S.	-.019	0.074	N.S.

Pre-shift FEV_1 Status

	n (pairs)	Prevalence of abnormal FEV_1** (per 100): gin workers	comparison workers	Sig.	Mean FEV_1: gin workers	comparison workers	Sig.
Ex-smokers	17	24	0	N.S.	3.63	4.17	$p<.01$
Never smokers	71	11	7	N.S.	3.95	3.97	N.S.
Present smokers	98	18	5	$p<.01$	3.74	3.94	$p<.05$

*Post-shift FEV_1 less than 90% of pre-shift FEV_1
**Preshift FEV_1 less than 80% of predicted value
Note: See Table 9 for matched-pair analysis descriptions

n=250



Elutriated cotton dust time-weighted average in mg/M³

Pulmonary Function	Significance of Slope
c=FVC	n.s.
v=FEV_1	n.s.
f=$FEF_{50\%}$	.03
e=$FEF_{75\%}$	n.s.
p=Peak flow	.04

*Percent shift change expressed as:

$$\frac{\text{(post-shift value--pre-shift value) (100)}}{\text{pre-shift value}}$$

Each value is adjusted for age, height, weight, race, plant, peak-years, smoking status, and sex.

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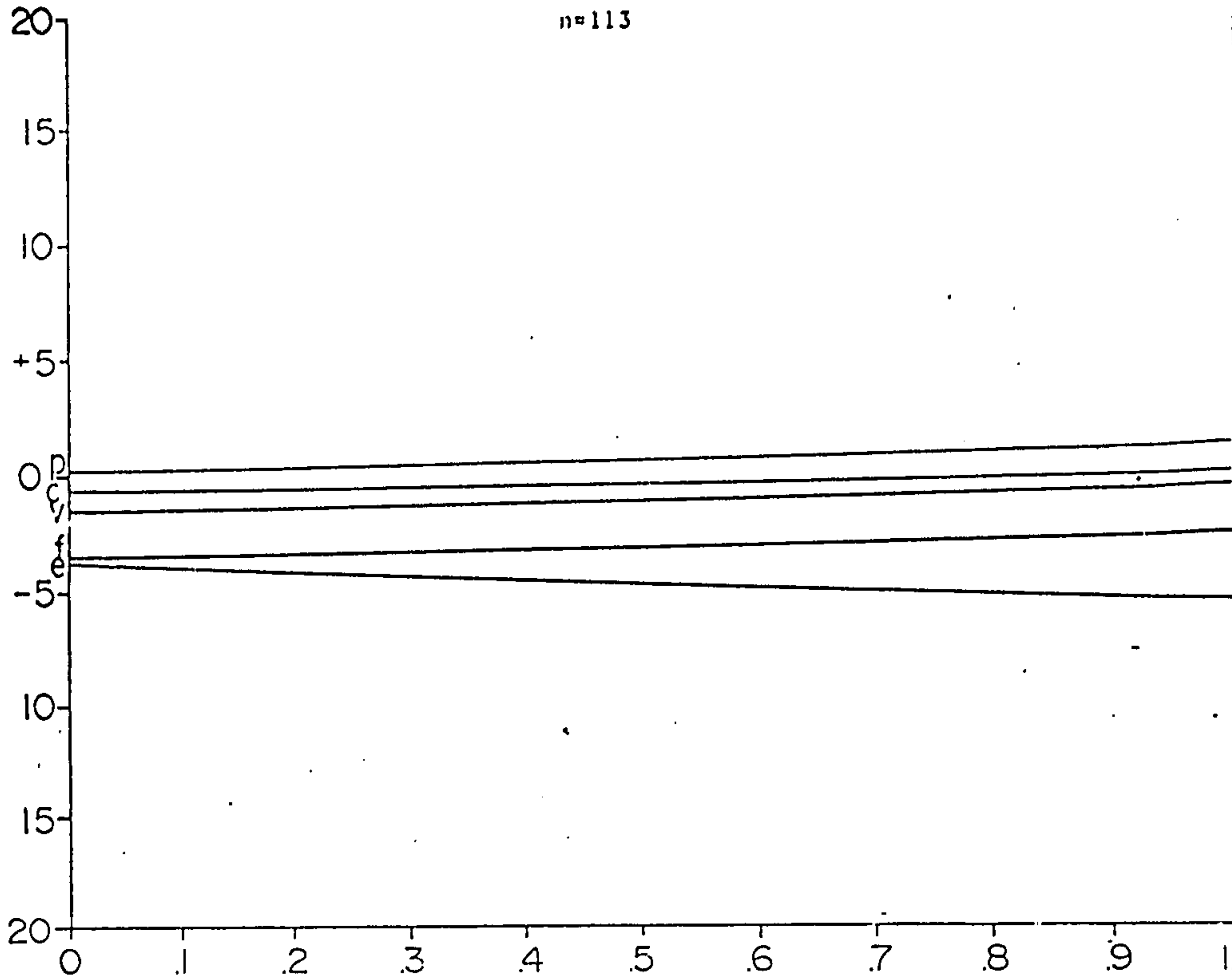

Elutriated cotton dust time-weighted average in mg/M^3

Pulmonary Function	Significance of Slope
c=FVC	n.s.
v=FEV_1	n.s.
f=$FEF_{50\%}$	n.s.
e=$FEF_{75\%}$	n.s.
p=peak flow	n.s.

*Percent shift change expressed as:

$$\frac{(\text{post-shift value--pre-shift value})(100)}{\text{pre-shift value}}$$

Each value is adjusted for age, height, weight, race, plant, pack-years, smoking status and sex.

Table 20. Model of predicted pre-shift pulmonary functions (in liters) related to elutriated cotton dust levels and months in cotton gin work.

Pulmonary Function	Months in Cotton Work	Elutriator Dust Levels (mg/M^3) .005	.527	1.391
FEV*	0	3.60	3.62	3.66
	21.5	3 60	3 60	3.61
	63.3	3.58	3.33	3.31
FVC*	0	4.48	4.49	4 52
	21.5	4.44	4.47	4.53
	63.3	4.37	4.44	4 56
$FEF_{50\%}$	0	4.80	4.83	4.88
	21.5	4 86	4.83	4 78
	63.3	4.98	4.83	4 59
$FEF_{75\%}$	0	1.77	1.81	1.86
	21.5	1.81	1 78	1.73
	63.3	1.89	1.73	1.48

*Pulmonary function values were obtained by using the appropriate values of months in cotton work and elutriator dust levels in the following model for cotton gin workers:

$$\text{Predicted Pre-shift Pulmonary Function} = a + b\begin{pmatrix}\text{months in}\\ \text{cotton work}\end{pmatrix} + c\begin{pmatrix}\text{dust}\\ \text{level}\end{pmatrix} + d\begin{pmatrix}\text{months in}\\ \text{cotton work}\end{pmatrix}\begin{pmatrix}\text{dust}\\ \text{level}\end{pmatrix} +$$

(terms for age, height, weight, race, plant packyears, smoking status and sex)

Table 21. Bronchitis and cough prevalences by categories of acute cotton dust exposure--probit analysis.

Never Smokers			Current Smokers		
Elutriator Dust*	% Bronchitis	Number	Elutrator Dust*	% Bronchitis	Number
.10	15.0	20	.06	20.0	20
.22	15.0	20	.12	30.0	20
.40	19.0	21	.17	55.0	20
.82	21.1	19	.21	25.0	20
			.38	20.0	20
			.53	5.0	20
			1.48	23.8	21

Never Smokers			Current Smokers		
Elutriator Dust*	% Cough	Number	Elutriator Dust*	% Cough	Number
.10	21.1	20	.06	25.0	20
.22	15.0	20	.12	25.0	20
.40	4.8	21	.17	45.0	20
.82	10.5	19	.21	25.0	20
			.38	30.0	20
			.53	20.0	20
			1.40	33.3	21

* in mg/M^3

Table 22. Prevalence of: "respiratory disorder arising from exposure to textile vegetable dusts" against cumulative cotton dust exposure indices--probit analysis.

Never Smokers			Present Smokers		
Dust-Years	%	Number	Dust-Years	%	Number
.302	15.4	26	.143	9.1	22
1.583	19.2	26	.492	45.5	22
20.304	34.6	26	1.220	22.7	22
			2.408	22.7	22
			4.644	27.3	22
			15.778	26.9	26

Note : Cumulative lifetime cotton dust exposure is expressed as: years-mg/M^3 and equals years in any cotton gin job times (the TWA on the day of medical study.

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GLOSSARY

American Upland	(*Gossypium hirsutum*) one of two common types of cotton grown in the United States; it has a staple length of 7/8 to 1 1/4 inches. American Pima (*Gossypium barbadense*) with a staple length of 1 3/8 to 1 9/16 inches is the other type, as is grown primarily in the El Paso area of Texas, New Mexico and Arizona
Analog	the recording a continuous values of a parameter, opposed to digital the recording of descrete values of a parameter
Andersen sampler	an ambient cascade impactor used to collect and aerodynamically size airborne particulate matter
Bale press	the machine used to compress ginned raw lint into bales at the gin, linters at the cottonseed oil mill and processed cotton waste at the waste utilization plant
Bronchitis	in this particular study, bronchitis refers to the production of phlegm on most days of the week for at least 3 months in one year
Byssinosis	from the Greek "byssus" meaning fine cloth, the characteristic respiratory disease of operatives in cotton, flax, soft hemp and possibly sisal, coir and kapok industries; periodic chest tightness, dyspnea and cough, progressing to a chronic condition, related to exposure to dust in these industries are the symptoms of the disease
Chronic bronchitis	a disease characterized by the production of phlegm on most days for at least 3 months in a year and for at least two years
Cotton	the common name of the plant species belonging to the botanical genus *Gossypium*

Cotton dust	cotton dust is a heterogeneous particulate consisting primarily of vegetable, microbial and soil materials. Bract particles and gram negative bacteria are major components of respirable cotton dusts. For compliance purposes OSHA has defined cotton dust as "dust present in the air during the handling or processing of cotton, which may contain a mixture of many substances including ground up plant matter, fiber, bacteria, fungi, soil, pesticides, non-cotton plant matter, and other contaminants which may have accumulated with the cotton during the growing, harvesting and subsequent processing or storage periods. Any dust present during the handling and processing of cotton through the weaving or knitting of fabrics, and dust present in other operations or manufacturing processes using new or waste cotton fibers or cotton fiber by-products from textile mills are considered cotton dust." (CFR 43, 27395, June 23, 1978)
Digital	recording descrete values of a parameter
Dinky press	a small press used at a cotton compress facility for squeezing the bale together to permit removal of strapping ties
Elutriated dust	dust measured by the machine known as a vertical elutriator
$FEF_{50\%}$	the forced expiratory flow at 50% of the forced vital capacity
$FEF_{75\%}$	the forced expiratory flow at 75% of the forced vital capacity
FEV_1	the forced expiratory volume; i.e., the amount of air exhaled from the lung during the first second of a forced expiratory maneuver
FVC	forced vital capacity the total amount of air which can be exhaled from the lungs in a forced expiratory maneuver

Flow-volume loop	a graphical plot of flow versus volume which is measured duing a forced expiratory maneuver
Forced expiratory maneuver	that which happens when a person takes the fullest and deepest breath of room air that he can possibly take and blows that air as rapidly and completely as he possibly can into a recording device called a spirometer
GCA Model 101	a portable, direct readout dust monitor, manufactured by GCA Corporation, used with a small vertical elutriator to provide mass concentration measurements of cotton dust
Gin	refers historically to the "engine" invented by Eli Whitney for removal of lint from cottonseed. A moden ginning operation dries and cleans seed cotton prior to separation of lint from the seed at the gin stand (see gin stand)
Gin motes	the lint wastes that are salvaged during gin lint cleaning
Gin stand	a machine which is vital to the operation of a gin and which separates cotton lint from seed cotton and drops cottonseed into a conveyor
Gin stand-roller type	a machine used in ginning facilities, which utilizes a rotating motion of a roller to draw and separate lint from seed. This type of gin stand is predominantly used to gin extra long staple cotton
Gin stand-saw type	a ginning machine which uses saws projecting through circular plates to "tear" the lint from the cottonseed
Lint	the long (generally 2 to 3 cm) cotton fiber removed from the cottonseed in the gin stand and delivered to the press box for baling. This is the fiber used in cotton yarn and fabric manufacture

Linters	the very short (less than 15 mm) cotton fibers remaining on the seed when ginning is completed. These fibers are removed from the seed in delinting machines at the cottonseed oil mills. They are not used to any great extent in yarn and fabric processing but have uses in the garnetting, chemical and cellulose industries
Maximum envelope	a composite curve created from the flow-volume loops of several of one person's forced expiratory maneuvers which are collected in one session, the curve is derived from the maximal flow at each 5 % of the forced vital capacity
mg/M^3	refers to "milligrams (of collected airborne particulate matter) per cubic meter of air"
Peak flow	the greatest value of air flow in a forced expiratory maneuver
Raw cotton	the material received in bales from the gin by the textile mill
Seed cotton	cotton material harvested usually by machine-picking or machine-stripping methods and delivered to the gin in a trailer or module. It consists of seed with attached lint and linters
Seed meat	synonymous with seed embryo. Vegetable oil is extracted from the seed meat at the cottonseed oil mills
Spindle harvester	a mechanical harvesting machine that removes cotton from the open bolls with rotating spindles, leaving unopened bolls on the plant
Stripper harvester	a mechanical harvester utilizing closely spaced fingers which project into the cotton plant and strip the cotton lint (as well as considerable leaf and branch materials) from the field

Vertical elutriator — sampling instrument designed to entrap in a filter all fine dust (particles aerodynamically sized less than or equal to 15 microns) and exclude cotton lint. This sample thus approximates a respiratory criteria which includes tracheal deposition

Waste recycler — refers to industry in which mill wastes, linters and gin motes are cleaned and baled prior to utilization by the garnetting trade

APPENDICES

A. Spirometry protocol
B. Pulmonary function testing equipment
C. Questionnaires
   - Revised English
   - Original English
   - Revised Spanish
   - Original Spanish
D. Questionnai... ...ors
   - SRI
   - NIOSH
E. Questionna...definition protocol
   - Classification of disease entities
F. Medical notification forms
G. Industrial hygiene data sheets
H. Types of comparison plants surveyed
I. Gin description form for statistical sampling
J. Code numbers and geographic regions for all of the plants in the NIOSH secondary cotton study
K. Abridged s... "A Guide to Industrial Respiratory Protection"