ASBESTOS
Health
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## ACTION ON ASBESTOS

ASBESTOS workers are unintentional victims of industrial progress. They are at risk of pulmonary fibrosis, pleural calcification, mesotheliomas and lung cancer. Asbestos exposure is now widespread, involving not only air but also drinking water, wine and beer.[1] Fibers have been found in the lungs of people without industrial asbestos exposure. Whatever the exact nature of asbestos or ferruginous bodies may be, there is no doubt that electron microscopy of the lungs of urban dwellers has shown the presence of chrysotile asbestos.[2] Although there is no evidence of asbestos-linked disease in the general population at this time, the presence of asbestos in their lungs is disturbing. Asbestos is relatively resistant to destruction by most chemical and physical means and can float freely in the atmosphere for prolonged periods. Asbestos diseases have a long latent period, 20 years or more. We therefore believe that more sweeping decisions on the control of asbestos must be made now, on the basis of "reasonable probability" rather than after a delay for a precise definition of dose-response relations.

These thoughts are reinforced by the work of Murphy and associates in this issue of the *Journal* (p 1271). Their studies of pipe coverers involved in new ship construction include better than usual exposure data and indicate a high incidence of asbestosis (38 per cent after 20 years) at what have been previously regarded as "safe" dust concentrations. A second study of Murphy et al.[3] reports two cases of pleural disease (one mesothelioma) in workers who sanded asbestos floor tiles. Since the degree of asbestos exposure was unknown, the authors simulated the working conditions and found concentrations of 1.3 fibers per milliliter of room air. This concentration is less than 1/5 of currently used threshold limit values. A fiber per milliliter of room air means that a worker breathing 15 liters per minute for eight hours inhales some $10^7$ fibers every work day. Although only a fraction of the inhaled fibers remains in the lung, these figures suggest that an alarming number will still accumulate over a 10-year period.

A recent Committee report prepared by a National Academy of Sciences panel[4] has called for control of asbestos emissions at the source and for protection of those who are exposed in their occupations. The report also calls for further research on the biologic effects and the physical characteristics of asbestos fibers; such data are urgently needed "if a range of safe exposure is to be established with confidence." Although we endorse these recommendations, we want to underline the urgent need for technical controls based on existing knowledge. Epidemiologic monitoring, physical studies of asbestos and other fibers and analysis of their effects on cells and tissues are important and must be continued. But there is now a clear need for more decisive action on control measures and the Occupational Safety and Health Act of 1970 sets the stage for such action.

Application of the technics of industrial hygiene must be accelerated. The present threshold limit value for asbestos should be lowered far below some recent proposals. National administrative mechanisms to initiate and implement action are available — the recently established National Institute for Occupational Safety and Health and the National Advisory Committee on Occupational Safety and Health foremost among them. The Secretary of Labor, under the aforementioned Act, is charged with the setting of standards and has the right of entry into and inspection of places of employment. Thus, enforcement and regulatory mechanisms as well as advisory bodies have been established by law. Among the many problems that they face, asbestos should have high priority. Technologic developments are needed in many areas: sophisticated dust control; better and harmless asbestos substitutes; and improved monitoring of both the workers and their environment. Adequately devised tax policies could provide incentives for industry to clean the air and protect the workers. Such policies, by generating action in each plant where a risk exists, can rapidly and considerably amplify efforts on the national scale.

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PLAINTIFF'S EXHIBIT
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# EFFECTS OF LOW CONCENTRATIONS OF ASBESTOS

## Clinical, Environmental, Radiologic and Epidemiologic Observations in Shipyard Pipe Coverers and Controls

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**Abstract** Low-level asbestos exposure, as occurs in pipe coverers in new ship construction, has not been considered dangerous. We surveyed 101 such workers and 94 controls matched for age, duration of employment and smoking habits in a New England yard. Dust exposure, under surveillance for 20 years, had been near the then recommended threshold limit value of 5 million particles per cubic foot (mppcf). "Asbestosis" was defined by presence of three or more of five standardized clinical abnormalities including dyspnea, rales, finger clubbing, reduced vital capacity and x-ray shadows. The latter were judged by three observers unaware of the exposure history. "Asbestosis" was 11 times more common among pipe coverers than among controls; it was found first after 13 years of exposure or 60 mppcf-years, and the prevalence was 38 per cent after 20 years. This study emphasizes that low concentrations of asbestos can lead to pulmonary fibrosis and supports the need for lower threshold limit values.

NEW uses for asbestos are found constantly, and the number of fresh cases of asbestosis reported each year is increasing. It has been known for four decades that high concentrations of dust can cause interstitial fibrosis. The biologic effects of low concentrations are still poorly defined, and information useful for setting threshold limit values has been difficult to obtain. This is, no doubt, because of the many factors that must be considered to evaluate the effects of inspired dust. These include the degree of environmental contamination over a prolonged period, availability of the entire exposed population, a control group comparable in all respects except for dust exposure and standardization of diagnostic criteria. We were able to take these aspects into account during a study of a group of shipyard pipe coverers. The concentrations of asbestos to which such workers are exposed are low[1,2] except during refitting and repair work.[3,4] Our workers had been engaged solely in new ship construction.

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The data contained in this study are from a thesis submitted by Dr. Murphy to the Faculty of the Harvard School of Public Health in partial fulfillment of the requirements for the degree of Doctor of Science in the field of Environmental Health.

We wished to determine the effect of this low-level exposure to ascertain whether the threshold limit value had been a reasonable guideline. In addition, we were interested in evaluating methods to detect the disease at the earliest possible stage to prevent further exposure. Environmental, clinical and epidemiologic aspects of this survey will be presented here, and studies of respiratory gas exchange will be reported subsequently.

### ENVIRONMENTAL SURVEY

The pipe coverers were employed in a private New England shipyard that had been engaged in construction of naval and commercial vessels since 1920. During World War II, it became principally a destroyer-building facility. Repair and refitting work was never done. The yard was one of five investigated by Fleischer et al.[5] in 1945. The pipe coverers prepared and applied insulating materials to machinery and pipes. The materials used and the procedures employed did not vary appreciably over the 20-year period.[2] Approximately 90 per cent of the work was done aboard ship and the remainder in a shop.

Abbreviations Used

| | |
|---|---|
| D: | diffusing capacity |
| $FEV_1$: | volume expired in first second |
| FVC: | forced vital capacity |
| mppcf: | million particles per cubic foot |
| PF: | peak flow |

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Figure 1. Hand-Sawing of Prefabricated Asbestos Block Aboard Ship.

*Aboard ship* the most common procedure was wiring contoured asbestos block to pipes. Prefabricated sections were tailored to fit bends by handsaw and knife (Fig. 1). The blocks were smoothed with cement containing 15 per cent asbestos and 85 per cent magnesia, and covered with asbestos cloth. Asbestos in fibrous form was stuffed into jackets and sewn around small pipes. Ventilation was provided by portable blowers on deck, but they were not always used.

*Shop work* included layout, cutting, sewing, asbestos cement mixing and fabrication of pads. In 1963, a ventilation exhaust trunk was installed over the four benches. Band-saw cutting, cement mixing and pattern cutting were dustier procedures but required less than 5 per cent of man-hours, and involved intermittent work by only a few men. Pattern cutting was done in a separate room by one man who wore a respirator.

*The insulating materials* were largely determined by United States Navy specifications. Amosite was called for most frequently because of its low thermal conductivity, light weight and strength. Chrysotile was used to a lesser extent, and crocidolite was never used. Fiberglass, cotton, calcium silicate, magnesia, hair felt and other materials were also employed, either alone or mixed with asbestos.

## Aerometric Analysis

Dust concentrations were determined in 1945[2] and again in 1965 and 1966, to coincide with these studies. The same konimeter was used according to the method of Kotze.[5] All dust particles in a high-power field were counted for the total dust count. Particles with a length-to-diameter ratio greater than 3 were called fibers. Both dust and fiber concentrations were expressed in millions of particles per cubic foot of air (mppcf). Simultaneous total dust counts were made with a midget impinger in 1965 according to the Public Health Service method.[6]

All counts were made at the worker's breathing level at all the usual sites during usual operating conditions. A time-weighted average dust exposure was calculated by multiplying the mean dust concentration at various sites by the average percentage of time spent by the workers at these sites. This was expressed in mppcf-years.

*Results* of dust counts with the midget impinger — the instrument used in setting the threshold limit value of 5 mppcf — averaged 5.2 mppcf (Table 1). Konimeter counts, as always, were higher: in areas where over 98 per cent of the man-hours were spent the overall range was from 8.2 to 61.7 mppcf (Table 1). A weighted average, which considered the amount of time spent in these locations, as well as the number of samples taken during the three periods in 1945, 1965 and 1966, was 32.7 mppcf.

## Population Studies

There were 101 pipe coverers employed at the

Table 1. Dust Concentrations in Million Particles per Cubic Foot.

A. Midget Impinger (mppcf)*:

| Location | Average Concentration (mppcf) |
|---|---|
| Cutting room | 5.7 |
| Sewing & fabrication bench | 3.0 |
| Band-saw cutting | 10.0 |
| Mixing mud | 0.8 |
| Aboard ship (various | 7.2 |
| Weighted average | 5.2† |

B. Konimeter

| Location | Yr | No. of Samples | Concentrations (mppcf) | | % Fiber |
|---|---|---|---|---|---|
| | | | range | average | |
| Sewing & fabrication | 1945 | 2 | 10.6-12.3 | 11.4 | 0.5-0.8 |
| | 1965 | 12 | 14.2-30.2 | 23.4 | 0.1-2.7 |
| | 1966 | 10 | 12.9-32.8 | 23.1 | 0.1-3.8 |
| Aboard ship | 1945 | 15 | 25.3-89.0 | 49.2 | 0.2-2.4 |
| | 1965 | 12 | 8.2-61.7 | 21.4 | 0.1-0.7 |
| | 1966 | 10 | 18.3-35.7 | 25.9 | 0.1-0.7 |

*Instrument used in setting threshold limit value of 5 mppcf.

†Simultaneous counts with Konimeter equaled 24.4 mppcf.

Yard in November, 1965. One hundred and one controls were selected from the 486 shipfitters and pipefitters employed at the time of the survey. To match them for age and duration of employment, cards with this information only were inspected in sequence, and the first worker whose age was within one year of a pipe coverer was selected provided he had spent approximately the same time at the Yard. All pipe coverers participated, but seven of the selected controls refused, leaving 94 individuals.

## METHODS

### Questionnaire

A questionnaire on respiratory symptoms[7] was administered by one observer. It was adapted from that previously given extensive trials by Fletcher and others.[8-10]

### Past History

The company medical records of all workers were examined for symptoms, signs and diagnostic impressions presumably related to cardiorespiratory disease.

### Physical Examination

Physical examination was made by one physician with particular attention to breath sounds in each of eight locations. In 1966, tape recordings were made. Adventitious sounds were defined according to the nomenclature of Chamberlain.[11] To evaluate clubbing, a tracing of all fingers was made in the frontal and lateral projection. The hyponychial angle of the right index finger was measured according to Regan et al.,[12] and an angle of 198° or greater was considered indicative of clubbing.

### Spirometry

Maximal forced expirations were recorded with a Stead–Wells spirometer, and peak flow with a Wright Peak Flow Meter. The order of tests was randomized. Five recordings were made, and the average of the last three was used to calculate the forced vital capacity (FVC), the volume expired in the first second ($FEV_1$) and the peak flow (PF). Methods of calibration and analysis were previously described[13]; normal predicted values derived from a population study of a New England town were used.[14]

### Roentgenologic Examination

Posteroanterior and lateral views were examined independently by three radiologists after identification had been masked and the films had been randomly interspersed. Results were coded as follows: 1, no abnormality; 2, abnormality not consistent with asbestosis; 3, questionably consistent with asbestosis; 4, consistent with slight asbestosis; 5, consistent with moderately advanced asbestosis; and 6, consistent with advanced asbestosis.* The reported results represent the combined readings of the three observers.

### Prevalence of Other Disease

The prevalence of tuberculosis was assessed from the roentgenograms, skin testing and sputum culture. The criteria of Fletcher and Tinker[16] were used to calculate the prevalence of nonspecific chronic obstructive lung disease. Simple and complex bronchitis was defined according to Reid et al.[17]

## RESULTS

### Description of the Populations

The control group, matched for age and duration of employment, was similar to the exposed group in color, height, weight, marital status and location of residence (Table 2). The majority of both groups had spent their lives in the general vicinity of the shipyard town. All were blue-collar workers who received hourly wages. The pipe coverers had been employed at the Yard for an average of 17.4 years, and the controls for 17.1 years.

With shipbuilding for defense, the work force varies with national crises. When not working at the Yard, members of both groups most commonly engaged in fishing, lumbering and general outdoor construction work. Cumulative years in dusty occupations other than pipe covering did not differ in the two groups. One pipe coverer had been a sandhog for five years, and one control had spent five years shoveling gravel. There were no exposures to material likely to cause pneumoconiosis in less than five years of exposure.

### Respiratory Questionnaire

The significant differences in positive responses appear in Table 2. Smoking habits were similar: according to our classification,[18] two thirds of both groups were "present smokers" (Table 2).

### Physical Examination

Dry, crackling rales with a "close-to-the-ear" sound (cellophane rales) were a most striking finding in some pipe coverers. They could be clearly identified over background noise in the tape recordings, whereas occasional fine rales could not be distinguished. Such rales not only were significantly more common in the pipe coverers (Table 2) but also were heard more often in multiple sites. For example, they occurred in three or more sites in seven pipe coverers but never in the controls.

*Four years after these interpretations were made, a modification of the International Scheme for Classification of the Radiographic Appearance of Pneumoconioses was proposed that was believed to be suitable for interpretation of asbestosis.[15] Our classification corresponds approximately as follows: "1", 0/0; "3", 0/1; "4", 1/0, 1/1 and 1/2; "5", 2/1, 2/2 and 2/3; and "6", 3/2, 3/3 and 3/4.

Table 2. Summary of Selected Results.

| Finding | 101 Pipe Coverers | | 92 Controls | | P Value |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | |
| Age (yr) | 41.5 | 11.6 | 40.9 | 11.6 | NS |
| Height (in) | 67.9 | 2.3 | 68.4 | 2.7 | NS |
| Weight (lb) | 168.0 | 23.5 | 174.7 | 27.5 | NS |
| **Respiratory symptoms** | **No. positive** | **% positive** | **No. positive** | **% positive** | |
| Cough — day — winter | 31 | 30.7 | 18 | 19.1 | NS |
| Cough — day — summer | 21 | 20.8 | 9 | 9.6 | <0.005 |
| Cough 3 yr | 25 | 24.8 | 9 | 9.6 | <0.01 |
| Phlegm — day — winter | 39 | 38.6 | 23 | 24.5 | <0.05 |
| Phlegm — day — summer | 34 | 33.7 | 12 | 12.8 | <0.005 |
| Wheezing apart from colds | 29 | 28.7 | 15 | 16.0 | <0.01 |
| Breathlessness (Fletcher III or more) | 38 | 37.6 | 23 | 24.5 | <0.05 |
| Shortness of breath, 1 flight | 26 | 25.7 | 6 | 6.4 | <0.005 |
| "Heart trouble" or "high blood pressure" | 20 | 19.8 | 15 | 16.0 | NS |
| **Smoking category** | **No. positive** | **% positive** | **No. positive** | **% positive** | |
| Never smoked | 7 | 6.9 | 7 | 7.4 | NS |
| Ex-smoker | 27 | 26.8 | 23 | 24.5 | NS |
| Present smoker | 67 | 66.4 | 62 | 66.0 | NS |
| Uncertain recording | 0 | 0 | 2 | 2.1 | NS |
| **Physical examination** | **No. positive** | **% positive** | **No. positive** | **% positive** | |
| Basilar rales: | | | | | |
| Right lower lobe | 23 | 22.8 | 5 | 5.3 | <0.005 |
| Left lower lobe | 16 | 15.8 | 7 | 7.4 | NS |
| 2 or more sites | 16 | 15.8 | 4 | 4.2 | <0.01 |
| Clubbed fingers — hyponychial angle >198° | 20 | 19.8 | 5 | 5.3 | <0.005 |
| **Pulmonary function** | **Mean** | **SD** | **Mean** | **SD** | |
| FVC (liters) | 3.9 | ± 0.76 | 4.3 | ± 0.87 | <0.001 |
| $FEV_1$ (liters) | 3.0 | ± 0.77 | 3.6 | ± 0.74 | <0.001 |
| PF (liters/min) | 478.8 | ±97.9 | 526.3 | ±84.6 | <0.001 |
| FVC % of predicted | 92.7 | ± 1.3 | 102.7 | ± 1.7 | <0.001 |
| **Roentgenologic panel interpretation** | **No. positive** | **% positive** | **No. positive** | **% positive** | |
| (1) Normal | 28 | 27.8 | 52 | 55.5 | |
| (2) Other abnormality | 2 | 1.9 | 8 | 8.5 | |
| (3) Questionable asbestosis | 27 | 26.7 | 13 | 13.8 | <0.001 |
| (4) Slight asbestosis | 31 | 30.7 | 19 | 20.1 | |
| (5) Moderately advanced asbestosis | 9 | 8.9 | 2 | 2.1 | |
| (6) Advanced asbestosis | 4 | 4.0 | 0 | 0 | |

Wheezes, rhonchi and moist rales were present equally often in both groups.

### Ventilatory Tests

There was a marked difference in mean FVC (Table 2). Peak flow and $FEV_1$ were also significantly lower in the exposed workers, and were close to the predicted level in the control group (Table 2).

### Roentgenologic Findings

Moderately advanced (code 5) or advanced asbestosis (code 6) was diagnosed six times more frequently in pipe coverers than in the controls, whereas slight asbestosis (code 4) occurred only 1.4 times more frequently (Table 2). For each of the three observers, the chances were good that the classification agreed with the exposure history when the readings were moderately advanced or advanced; the chances were much smaller when the classification was questionable or slight asbestosis. Of the two controls with a reading of "moderately advanced asbestosis," one had previously recognized pulmonary fibrosis after smoke inhalation 30 years ago, and the other had bullous emphysema with diffuse linear opacifications.

### Medical-Record Review

Forty-seven pipe coverers and 35 controls had notations concerning cardiopulmonary complaints, an insignificant difference ($p$ greater than 0.05). However, pleurisy, pleural effusion and pleural rub were noted 13 times in pipe coverers and four times in controls. Other notations that were more common in pipe coverers included bronchitis (10 and three), influenza (15 and four) and dyspnea (five and zero).

### Prevalence of Asbestosis

To assess the prevalence of this disease it became necessary to define criteria. Manifestations most commonly reported in persons with known asbestosis were used[19-23]: dyspnea on climbing one flight of stairs or less; basilar rales in two or more sites; clubbing of the fingers — that is, a hyponychial angle of 196° or greater; a vital capacity of less than 80 per cent of the predicted value; and a roentgenogram consistent with moderately advanced or ad-

vanced asbestosis (codes 5 or 6). *The presence of at least three of these signs was defined arbitrarily as necessary for an epidemiologic diagnosis.* By this definition, 11 pipe coverers had "asbestosis"; all 11 had roentgenograms coded 5 or 6, nine had reduced vital capacities, nine clubbing, eight basilar rales, and eight exertional dyspnea. Also, by this definition, one of the controls had "asbestosis" — the worker who had pulmonary fibrosis after smoke inhalation.

### Respiratory Gas Exchange

In subsequent surveys, one and three years later, we studied the role of several physiologic tests in defining and detecting this disease. Pipe coverers had significantly reduced single-breath and exercise steady-state diffusing capacities ($D_L$) whereas airways resistance, specific conductance, ventilation, carbon dioxide tension and dead space were not significantly different. Physiologic evidence of obstructive disease was equally common in both groups. All workers with clinical "asbestosis" had severely reduced $D_L$, corroborating our clinical criteria (Murphy, R. L. H., Jr., Gaensler, E. A., Redding, R. A., et al: Unpublished data).

Figure 2 shows the relation of data on respiratory gas exchange to our clinical findings. Our diagnostic criteria that focused on marked abnormalities correlated highly with impaired $D_L$. However, Figure 2 also suggests that clinical findings of lesser severity may reflect interstitial lung disease.

### Prevalence of Other Respiratory Diseases

Skin hypersensitivity to 5 tuberculin U of PPD was not significantly different in the two groups. All persons with 5 mm or more of induration submitted

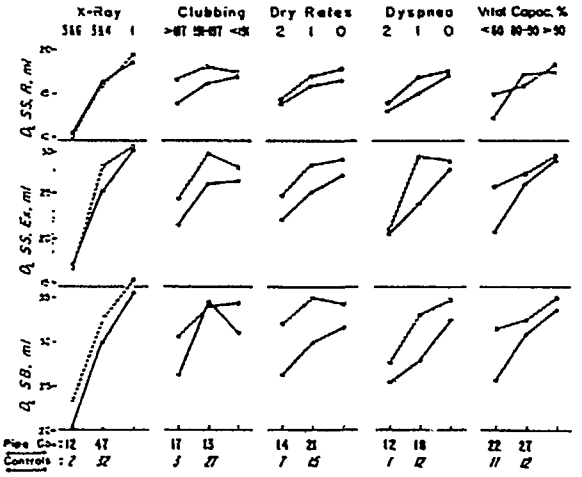



Figure 2. Relation between $D_L$ (Steady State at Rest, $D_LSS$, R; Exercise, $D_LSS$, Ex: Single Breath, $D_LSB$) and the Degree of Five Clinical Abnormalities among Pipe Coverers and Controls (Figures at Bottom Represent Numbers of Subjects with the Indicated Abnormality).

Table 3. Chronic Nonspecific Obstructive Respiratory Disease.

| Category | 101 Pipe Coverers | 94 Shipyard Controls |
|---|---|---|
| | % | % |
| 1 — no obstructive lung disease | 71.3 | 68.1 |
| 2 — chronic bronchitis only* | 18.8 | 25.5 |
| 3 — asthma only† | 0 | 0 |
| 4 — chronic obstructive lung disease only‡ | 3.0 | 3.2 |
| Combinations | | |
| 2 — 3 | 1.0 | 0 |
| 3 — 4 | 5.9 | 2.1 |
| 2 — 4 | 0 | 0 |
| 2 — 3 + 4 | 0 | 1.1 |

*Phlegm from chest at least 3 times day, 4 days/wk for at least 3 mo for past 3 yr.

†Asthma diagnosed by a physician & still present.

‡Wheezing or whistling most days or nights, or worker has to stop for breath when walking at own pace on the level, or $FEV_1$ <60% of FVC.

three 24-hour sputum specimens, none of which were positive for *Mycobacterium tuberculosis.*

Nonspecific obstructive lung disease was slightly but not significantly more common in the control group and among cigarette smokers (Table 3). Among workers with this syndrome, approximately 75 per cent of the pipe coverers and 65 per cent of the controls smoked cigarettes.

### Asbestosis and Its Relation to Dust Exposure

By our scheme, "asbestosis" was never diagnosed in persons with less than 10 years of cumulative exposure, with a progressive increase thereafter (Fig. 3). If uniform exposure over the working careers is assumed, certain conclusions can be reached from dust counts made with the midget impinger. No "asbestosis," as defined above, occurred in men exposed for less than 60 mppcf-years; 20 per cent of those exposed for 75 to 100 mppcf-years were considered to have asbestosis, and the prevalence was 38 per cent in those with exposure for more than 100 mppcf-years.

## Discussion

Building-insulation workers move from site to site and are confronted by varying situations and specifications, making supervision and assessment of dust exposure difficult. An important study confined to such workers by Selikoff, Churg and Hammond[1] showed that almost ½ of 1117 workers were considered to have roentgenologically evident asbestosis; prevalence was directly related to duration of exposure. By contrast, shipboard pipe coverers engaged in new vessel construction have a more uniform exposure. Fleischer et al.,[2] in a study already alluded to, found only three cases of asbestosis among 1074 pipe coverers, and these three had been exposed for 20 or more years. Therefore, the authors thought that such pipe covering was not a

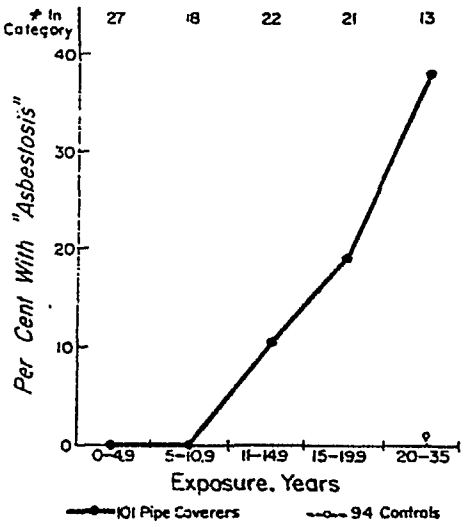



Figure 3. Relation of "Asbestosis" to Duration of Exposure.

"Asbestosis" was never diagnosed in persons with less than 10 years of cumulative exposure, and the prevalence was 38 per cent in those exposed for more than 20 years. One member of the control group had "asbestosis."

dangerous occupation. More recently, Marr[3] reported five cases of disability among 60 to 80 shipyard pipe coverers; he questioned whether this was caused by massive exposure during removal of old insulation or from many years of exposure by susceptible persons during all types of insulation work.

Our principal objective was to determine the prevalence of asbestosis in pipe coverers who had not engaged in repair work. Diagnostic criteria were based on recognized symptoms and signs of this disease because an exact assessment would have required pathological material. These signs and symptoms have been reported in other defined populations of asbestos workers with similar frequency.[19-21,23,24]

The prevalence of shortness of breath among our pipe coverers (Table 2) was similar to the 12 to 26 per cent in other asbestos workers.[1,21,22,24] In unexposed North American populations this percentage has ranged between 2.6 and 5.7[7,16,25,26] — quite comparable to our own control group with 6.4 per cent.

Rales in two or more sites were found in 15.8 per cent of the pipe coverers — a rate not very different from the 13 to 14 per cent reported by others in asbestos workers.[21,22]

In our study the observer was unaware of the roentgenographic findings at the time of auscultation. Nevertheless, 33 per cent of workers with codes 5 and 6 roentgenograms had rales in two or more sites. Dreessen et al.[21] reported rales or other adventitious sounds in 49 per cent of those with "ground-glass" markings, whereas Vigliani[22] heard such sounds in 70 per cent of workers with abnormal roentgenograms.

Clubbing of the fingers in 19.8 per cent of pipe coverers was more frequent than that in other studies[21,24]; also, the 5.3 per cent prevalence in the controls was slightly larger than in other normal groups.[27] However, the mean hyponychial angle of controls considered clubbed was only 200° as compared to that of the clubbed pipe coverers, which was 205°.

Vital-capacity measurements were usually lacking in the earlier surveys.[1,21,22] Kleinfeld[24] reported an average FVC of 81 per cent of predicted in 56 workers exposed for more than 14 years, but he used different prediction formulas. The mean FVC of 4.0 liters in 21 Australian asbestos workers did not differ much from that of our pipe coverers. Hunt's exposed population[28] is difficult to compare because knowledge of the diffusing capacity is required for interpretation. Our regression equations were derived from a population survey.[14] Since such surveys include disabled people, they generally yield lower values than surveys of industrial workers. For example, our pipe coverers had an average FVC of 92.7 per cent based upon our population survey, whereas it was only 75.2 per cent with the use of normal values from 2770 persons engaged in heavy labor and mining.[29] Pipe coverers over the age of 55 had a mean FVC that placed them in the same category as workers with advanced silicosis.[29] The FVC of all pipe coverers was also lower than the mean of paper-mill, flax and polyurethane-foam workers.[25,26,30]

Concerning radiographic findings, some observers have considered early changes evidence of asbestosis,[1,21,22] whereas others have not.[21,23,33,34] At any rate, our 19.9 per cent prevalence of moderately advanced or advanced asbestosis (codes 5 and 6) was much higher than the 0.27 per cent in the only other survey of shipyard pipe coverers engaged in new vessel construction,[3] but it was about the same as in building-insulation workers.[1]

### Effect of Duration of Exposure and Age

The prevalences of clinical signs and symptoms of "asbestosis" increased with duration of exposure (Fig. 4). The prevalences also rose with age (Fig. 5), and therefore the association between age and cumulative years of exposure was high (r equal to 0.7, p equal to 0.001). The advantage unique to this study was that the control group allowed examination of the relative importance of age: in the controls there was no clear association between age and these abnormalities except in vital capacity (Fig. 5).

### Accuracy of Diagnosis

How likely is it that the 11 workers considered to have "asbestosis" did indeed have this disease? They were offered a medical examination, including

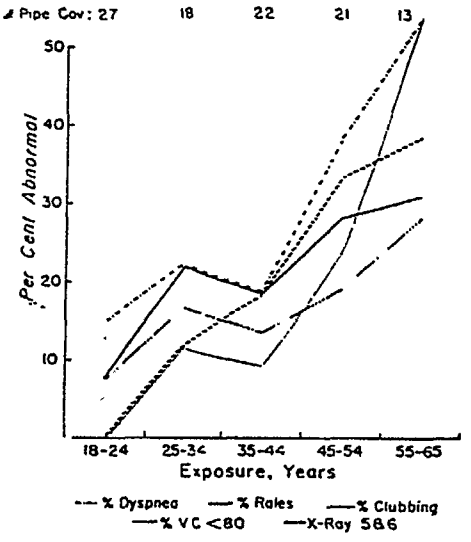



Figure 4. Increases with Duration of Exposure in Prevalence of Dyspnea, Rales, Clubbed Fingers, Reduced Vital Capacity and Roentgenologic Abnormalities.

detailed pulmonary-function studies, by a group of internists not associated with this study. In the eight who consented, no illness other than asbestosis was discovered to account for the signs and symptoms. Two of these men have since died, and both had severe asbestosis. Of the remaining three who refused detailed examination, two have died; autopsy in one showed asbestosis and cor pulmonale, and the other died of bronchopneumonia.

The accuracy of a "negative" diagnosis is much more difficult to assess. Only one worker so classified has died. His history, physical examination and ventilatory-function studies had all been normal at the time of this survey, and his chest roentgenogram showed slight asbestosis (code 4). When he died of peritoneal mesothelioma, the lungs showed minimal chronic interstitial pneumonitis. Conclusions should not be drawn from this single case, but the prevalences reported here probably are too low. Our subsequent surveys were designed to investigate this possibility.

What is the likelihood that other disease caused the findings that we attributed to asbestosis? Medical-record review, the respiratory questionnaire, physical examination, skin testing, sputum examination and roentgenograms did not uncover any excess cardiac disease, tuberculosis or other pulmonary disease. There was no significant difference in smoking habits in the entire population of pipe coverers and controls.

### Asbestosis and Dust Exposure

The concept of a dose-response relation was introduced by Merewether and Price in 1930,[19] but the first information useful for calculating threshold limit values came from Dreessen et al. in 1938.[21] They found clear-cut asbestosis among those exposed to dust concentrations exceeding 5 mppcf and none at lower concentrations. Therefore, tentatively, they regarded 5 mppcf as a threshold value.[21] These observations were confirmed by Vigliani.[22] In retrospect, the choice of 5 mppcf on the basis of the data then available, was open to question; in the dust counts in the textile mills no distinction was made between cotton and asbestos fibers. Furthermore, among those who were exposed at or just above this threshold (that is, 5.0 to 9.9 mppcf), 13 of 19 were considered to have asbestosis after 10 years, and six of 37 after only five years. In relation to the dose-times-time relation, over ½ the workers exposed to 100 mppcf-years had asbestosis. Dividing 100 mppcf-years by the recommended threshold

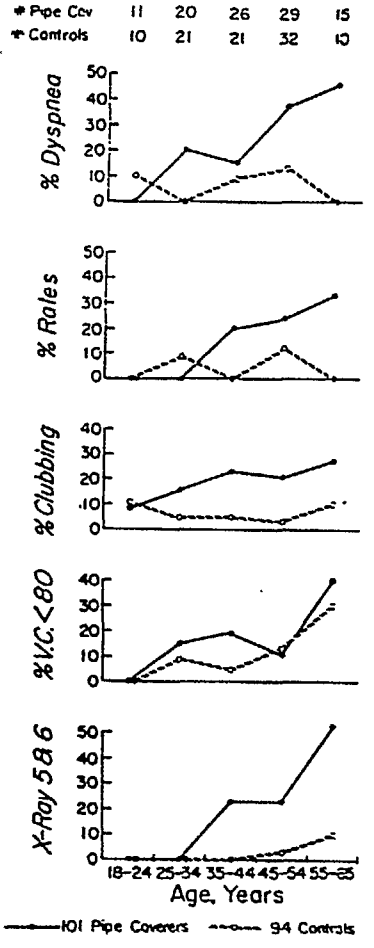



Figure 5. Higher Prevalences of Clinical Abnormalities Seen in Older Pipe Coverers but Not in Older Controls.

Since the association between age and cumulative years of exposure (Fig. 4) was high (r equal to 0.7, p less than 0.001), the importance of aging in relation to these abnormalities was reviewed in the controls; no clear association with age was found except in vital capacity.

limit value of 5 mppcf should have prompted the conclusion that the risk of asbestosis was great after only 20 years of exposure. Indeed, other observations have suggested that asbestosis becomes evident after approximately this degree of total dust exposure: Wells[35] began to see the disease after 50 to 60 mppcf-years, and Fulton[36] reported a 17 per cent prevalence after exposure from 27 to 75 mppcf-years.

In our study, asbestosis became evident after a total exposure of 60 mppcf-years, and the earliest case was found after 13 years of employment. Fleischer's prevalence in the same shipyard was much lower because, in 1945, less than 10 per cent of the workers had been exposed for more than 10 years. These observations indicate that prolonged exposure to low concentrations of asbestos is hazardous and support the lowering of the threshold-limit values.

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