

R1336

PB90-155904

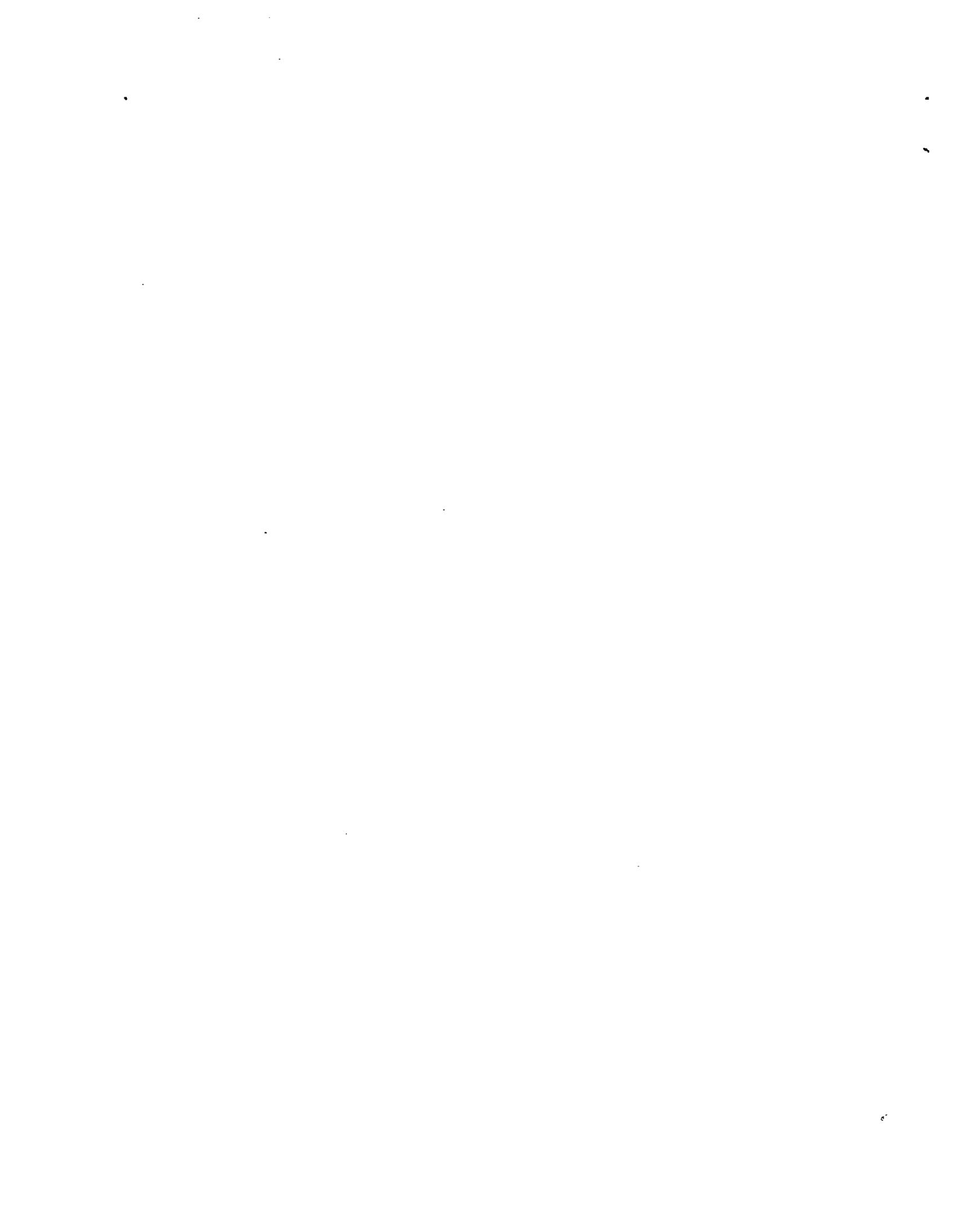


EPIDEMIOLOGY OF ASBESTOS RELATED DISEASES

John M. Dement, Ph.D.  
Division of Respiratory Disease Studies  
National Institute for Occupational Safety and Health  
Morgantown, West Virginia

July, 1981

REPRODUCED BY  
U.S. DEPARTMENT OF COMMERCE  
NATIONAL TECHNICAL  
INFORMATION SERVICE  
SPRINGFIELD, VA 22161



<b>REPORT DOCUMENTATION PAGE</b>		1. REPORT NO.	2.	3. Recipient's Accession No. PE 90 1559 04 /AS	
4. Title and Subtitle Epidemiology of Asbestos Related Diseases				5. Report Date 81/07/00	
7. Author(s) Dement, J. M.				6.	
9. Performing Organization Name and Address Division of Respiratory Disease Studies, NIOSH, Morgantown, West Virginia				8. Performing Organization Rept. No.	
12. Sponsoring Organization Name and Address				10. Project/Task/Work Unit No.	
				11. Contract (C) or Grant(G) No. (C) (G)	
15. Supplementary Notes				13. Type of Report & Period Covered	
				14.	
16. Abstract (Limit: 200 words) Although there were several anecdotal reports from earlier times, the first well documented case of asbestosis was reported in 1906 in a worker engaged in the production of asbestos (1332214) textiles. In 1917 a report of ten cases of pulmonary fibrosis occurring at a Pennsylvania facility was published. The first detailed epidemiologic study of asbestos workers was undertaken in Great Britain in 1928. The first indication that asbestos might be a human carcinogen came in 1935 with the report of three independently diagnosed cases of lung cancer detected during autopsy of asbestos workers. Epidemiologic studies have now repeatedly demonstrated an association between asbestos exposure and increased mortality due to asbestosis, lung cancer, pleural and peritoneal mesothelioma, and gastrointestinal cancer. In some studies asbestos exposure has also been associated with increased risks for laryngeal cancer and cancer of the buccal cavity and pharynx. Studies which have been concerned with exposure to crocidolite (12001284), amosite (12172735), anthophyllite (17068789), tremolite (14567738), and chrysotile (12001295 ) were highlighted. Other topics reviewed included asbestos contamination of other minerals, the combined effects of asbestos exposure and tobacco smoke, mortality and pleural radiographic changes, and mixed fiber exposures.					
17. Document Analysis a. Descriptors					
b. Identifiers/Open-Ended Terms NIOSH-Publication, NIOSH-Author, Textiles-industry, Asbestos-fibers, Asbestos-dust, Asbestos-workers, Asbestos-products, Respiratory-system-disorders, Mortality-data, Risk-analysis, Epidemiology					
c. COSATI Field/Group					
18. Availability Statement			19. Security Class (This Report)		21. No. of Pages 49
			22. Security Class (This Page)		22. Price R03



## EARLY OBSERVATIONS

### Asbestosis

The first well documented case of asbestosis was reported by H. Montague Murray in 1906, although there were several anecdotal reports prior to this time (42,64). Murray documented a case of pulmonary fibrosis at autopsy in a worker engaged in the production of asbestos textiles. This worker reported that he was the sole survivor of 10 men who started with him in the carding room; the others had died (presumably of asbestos related diseases).

Following the report by Murray, Pancoast et al. (1917) reported 17 cases of pulmonary fibrosis in a Pennsylvania plant (72). In 1924, Cooke published another detailed autopsy report of a 33 year old woman suffering from asbestosis (9). Necropsy findings included pulmonary fibrosis, pleural thickening, pleural calcification, and heart enlargement. Further cases were reported by Mills in 1930, Donnelly (1933), Lynch and Smith (1931), Seiler and Gilmour (1931), Wood and Gloyne (1930), Oliver (1927), Simson (1928), Stewart (1928), and Pancoast and Pendergrass (1926) (13,46,61,71,73,82,96,97,108). By 1930, more than 75 asbestosis cases were reported in the literature.

Early case reports stimulated concern and in 1928 the first detailed epidemiologic study of asbestos workers was undertaken by the Ministry of Labour in Great Britain. Results were published by Merwether and Price in 1930 (57). This was

a cross-sectional chest x-ray study of 363 workers engaged in production of asbestos textiles. Of this group, 95 (26.2%) were found to have pulmonary fibrosis and the prevalence of fibrosis with 20 or more years employment was over 80%.

In the United States, Donnelly (1936) reported a cross-sectional chest X-ray study of 151 asbestos workers which found a pulmonary fibrosis prevalence of 59% among workers employed 4 years or more (14). Schull (1936) reported chest X-ray studies of 100 workers dismissed from North Carolina asbestos plants due to disability and found a 55% prevalence of moderate or advanced asbestosis (93).

In 1937 the U.S. Public Health Service undertook the first detailed epidemiologic study of asbestos workers in the United States with results published by Dressen et al. in 1938 (15). A total of 511 employees were studied in this cross-sectional study and worker exposures were estimated by the impinger method. A dose-response relationship was found between extent of asbestos exposure and clinical symptoms of asbestosis. This study resulted in a recommended occupational exposure limit of 5 million particles per cubic foot of air (MPPCF) in the United States.

#### Lung Cancer and Mesothelioma

The first indication that asbestos might be a human carcinogen came in 1935. Lynch and Smith (in the United States) and Gloyne (in England) independently reported three cases of lung

cancer detected during autopsy studies of asbestos workers (23,47). All three workers had died of asbestosis. Other case reports followed in Egbert and Geiger in 1936, Gloyne in 1936, and Nordmann in 1938 (17,22,69). In the 1947 annual report of the Chief Inspector of Factories in England, Merewether stated that of 365 asbestosis deaths, 65 (17.8%) also had cancer of the lung at autopsy (56). This compared to a prevalence of lung cancer of only 1.3% for cases certified at death as having silicosis.

Despite early suggestions, the first detailed epidemiologic study to conclusively demonstrate an association between asbestos exposure and lung cancer was not published until 1955 by Doll (12). Doll studied the mortality experience of a cohort of 113 asbestos textile workers employed more than 20 years. Among this group, 11 lung cancer deaths were observed compared to only 0.8 expected--based on the mortality experience of England and Wales.

Asbestos exposure is associated with mesothelial tumors of pleural and peritoneal tissues. Lee and Selikoff have reviewed early reports associating asbestos exposures and mesothelioma with the first cases reported in 1947 (42). However, conclusive evidence of an association between asbestos exposure and mesothelioma was not available until 1960 when Wagner et al. reported 33 pleural mesotheliomas in the crocidolite mining area of South Africa (100).

## MORTALITY

Epidemiologic studies have repeatedly demonstrated an association between asbestos exposure and increased mortality due to asbestosis, lung cancer, pleural and peritoneal mesothelioma, and gastrointestinal cancer (98,99). In some studies, asbestos exposure has also been associated with increased risks for laryngeal cancer and cancer of the buccal cavity and pharynx. Table 1 contains a brief summary of important mortality studies and significant findings. In this Section, mortality studies are reviewed with emphasis on asbestosis and lung cancer risk differences by fiber type, industry, and smoking patterns.

### Mixed Fiber Exposures

In most plants processing asbestos, several different types of asbestos may be used or have been used in the past. Typically, chrysotile and one or more amphiboles are used.

Asbestos insulation workers have been extensively studied in the United States and other countries. Selikoff et al. (85) studied the mortality experience of 632 insulation workers followed between 1943 and 1962 and observed 45 lung cancer deaths whereas only 6.6 were expected. Of the 255 deaths in this cohort, 28 (11%) were due to asbestosis and 3 (1.2%) to mesothelioma. An SMR of 309 was observed for cancer of the stomach, colon, and rectum.

A much larger cohort of 17,800 insulation workers was followed by Selikoff et al. between 1967 and 1976 (88,89).

Among this cohort, 2271 deaths were observed including 429 lung cancers (SMR=406), 78 asbestosis deaths, and 49 deaths due to mesotheliomas. Significant increased mortality was also observed for cancers of the esophagus, stomach, colon-rectum, larynx, buccal cavity and pharynx, and kidney. Only 2 of the 78 asbestosis deaths occurred prior to 20 years from onset of employment, based on death certificate information. Review of all available autopsy, surgical, and clinical material indicated an additional 90 deaths were due to asbestosis, 57 to lung cancer, and 126 to mesothelioma.

Elmes and Simpson studied mortality of 162 insulation workers in Belfast between 1940 and 1975 (18,19). Among this cohort, 122 deaths were observed including 16 (13.1%) due to asbestosis and 13 (10.7%) to mesothelioma. A large excess due to respiratory cancer was observed.

There are several important studies of mortality among textile workers exposed to mixed asbestos types. In an early study in the United States published in 1963, Mancuso and Coulter observed more than a three-fold excess risk of lung cancer among workers producing textile and friction products (48). Fourteen percent of the 195 deaths were due to asbestosis and 2 (1%) were due to mesotheliomas.

Mortality among employees in the plant initially studied by Doll in 1955 has been investigated by Knox et al. (39,40), and more recently by Peto et al. (75,76). Peto studied 1106

men and women who had worked 20 or more years in asbestos exposed areas. Among those who were first employed after 1933 (when control regulations were enacted) 31 lung cancer deaths were observed whereas 19.3 were expected. Additionally, 35 deaths were observed due to non-malignant respiratory disease versus 25 expected, and there were 5 deaths due to pleural mesothelioma. Dust exposures in this plant were reported to be generally above 5 fiber/cc until about 1970.

Newhouse (65,66) and Newhouse et al. (67) have studied patterns of mortality among 4600 male and 922 female workers in a plant which produced chiefly asbestos textiles but later asbestos insulation products. Exposures were classified as low to moderate (5-10 fibers/cc) and severe (>10 fibers/cc). Among males, there were 46 mesothelial tumors and an SMR for lung cancer of 538 was observed for those employed more than ten years in the severe exposure group. In those with lowest exposure, a lung cancer SMR of 154 was observed. Deaths from chronic respiratory diseases were 1.8 times expected in the highest exposure group. A remarkable cancer SMR was observed among females in the highest exposure group (21 observed versus 0.8 expected). Both males and females were found to have smoked more than the comparison population; however, this could only account for 10% to 20% of the observed excess lung cancer mortality.

The asbestos cement product industry is one of the largest consumers of asbestos in the United States. In

addition to their asbestos exposure, workers in this industry may also be exposed to low levels of crystalline silica and trace metals. Weill et al. reported mortality patterns among 5645 asbestos cement product workers with a minimum of 20 years since initial employment (102). Exposures for the cohort were estimated and expressed as MPPCF x yrs. Among those exposed to greater than 100 MPPCF x yrs, 23 lung cancers were observed versus 9.3 expected. No excess lung cancer risk was reported among those with cumulative exposures less than 100 MPPCF x yrs. Two pleural mesothelioma deaths were observed. Weill et al. reported that exposure to crocidolite in addition to the (predominant) chrysotile used in cement products increased the lung cancer risk in comparison to chrysotile (exposure) alone. The unusually low SMRs for all causes regardless of exposure category suggest some form of cohort selection bias operative in this study. Additionally cohort follow-up was less complete than desired.

Crocidolite

Wagner et al. in 1960 reported 33 pleural mesotheliomas among men working in crocidolite mines and mills and the population living in the vicinity of these mills in the Northwest Cape Province of South Africa (100). The high incidence of mesotheliomas in this area has been confirmed by other investigations (8,26,101).

Crocidolite was commonly used in production of gas mask canisters during World War II and mortality among these workers has been investigated. Jones et al. studied the mortality of 1088 workers exposed between 1940 and 1945 and followed through 1976 (28,29). Twenty-two pleural and 7 peritoneal mesotheliomas were observed and a linear relationship was observed between employment duration and the risk of mesothelioma. There was also a modest excess of bronchial carcinoma. Similar results have been reported by McDonald and McDonald who studied a smaller cohort of gas mask workers in Canada and found that 7% of all deaths were due to mesotheliomas (49).

#### Amosite

Mortality patterns among a cohort of workers producing amosite asbestos insulation between 1941 and 1945 has been reported by Selikoff et al. (87) and more recently by Seidman et al. (80,81). This group of 820 men were observed over a 35 year period during which 528 deaths occurred: 15 (2.8%) were due to asbestosis and 1 was due to mesothelioma (by death certificate information). Review of available surgical, pathological, and clinical data for this group identified 13 additional mesotheliomas and 15 additional cases of asbestosis. Overall there were 83 lung cancers observed whereas 23.1 were expected and among those employed less than one month, 3 lung cancers were observed versus 1.3 expected. Anderson et al. have observed four confirmed

cases of mesothelioma among household contacts of workers at this plant (1).

#### Anthophyllite and Tremolite

The only location in the world where anthophyllite has been commercially mined and processed is Finland. These ores are also known to contain smaller quantities of tremolite. Mortality among workers in two Finnish mines and mills has been studied by Meurman et al. (59,60). In their first report, 1092 workers were followed from 1936 until 1974. A relative risk for lung cancer of 1.6 was observed and there were 13 (5.2%) asbestosis deaths but no deaths due to mesothelioma. Their subsequent study concerned 793 workers with known smoking histories with 10 additional years of follow-up. A relative risk for lung cancer of 19 was observed for smoking asbestos workers and 1.6 for asbestos workers who did not smoke. Asbestosis mortality was found to be equally frequent among smokers and nonsmokers. All lung cancer cases with more than 10 years of exposure were also found to have asbestosis.

#### Chrysotile

Chrysotile is the major asbestos fiber type used in the United States, but most of this fiber is imported from Canada. The mortality of Quebec chrysotile miners and millers has been extensively studied by McDonald et al. (50,53-55). The most recent report for this cohort included 10,939 men who had been employed one or more months and followed between 1926 and

1975. An overall SMR for lung cancer of 125 was observed; 42 deaths (1.3%) were due to asbestosis and 11 to mesothelioma. A nearly linear dose-response relationship was reported for lung cancer. Increased mortality was also observed for cancer of the stomach and esophagus but no other gastrointestinal sites. Similar patterns of lung cancer and asbestosis mortality have been reported by Rubino et al. in Italian chrysotile miners and millers where an SMR for lung cancer of 206 was observed among those with sufficient latency (79).

The McDonald et al. studies demonstrated a surprisingly low lung cancer risk even in the highest exposure group. Nicholson et al. have reported larger excesses from lung cancer and asbestosis in their study of chrysotile miners and millers in Quebec (68). This latter study cohort consisted of 544 miners and millers with at least 20 years seniority and followed between 1961 and 1977. A total of 28 lung cancers were observed versus 11.1 expected (SMR=252). There were 30 deaths due to noninfectious respiratory diseases whereas only 6.7 were expected. Of these 30 deaths, 26 were due to asbestosis. Only one mesothelioma (pleural) was observed.

Mortality among chrysotile asbestos miners and millers in the Urals has been investigated by Kogan et al. (41). The overall cancer mortality risk was found to be 1.6 times that for the general male population and was higher in mining than in milling. Among males, the relative risk for lung cancer was 2.0 and ranged from 1.4 to 2.1 for females. The lung cancer

risk was considerably greater in older age groups having longest latency. No mesotheliomas were reported; however, Kogan et al. attributed this to insufficient experience of pathologists in that geographic area.

There have been several studies of factory populations exposed only to chrysotile. Weiss (106) studied a small cohort of 264 workers in a plant producing asbestos millboard and reported no excess cancer mortality. However, there were only 66 deaths (2 of which were due to asbestosis) and cancer latency was not taken into account in the analysis.

A facility manufacturing asbestos textile, friction, and packing products has been studied by Robinson et al. (77). Chrysotile constituted over 99% of the total quantity of asbestos processed per year in this plant except during World War II; the remaining 1% was corcidolite and amosite. The cohort consisted of 2722 males and 544 females followed between 1940 and 1975. Among males, an overall lung cancer SMR of 135 was observed but among females the excess lung cancer risk was much higher with an overall SMR of 824. There were 76 deaths in males due to noninfectious respiratory disease but only 16.4 expected. Again, the chronic respiratory disease risk was higher among females with an SMR of 1555. There were 4 mesotheliomas among females and 13 in males.

Dement et al. (10) have reported mortality among a cohort of asbestos textile workers exposed only to chrysotile. This cohort consisted of 768 white males employed at least 6 months

and followed between 1940 and 1975. There were 26 lung cancers observed versus 7.47 expected. Of the 191 deaths in this cohort, 15 (7.9%) were due to asbestosis or pulmonary fibrosis and one (0.5%) was due to a peritoneal mesothelioma. Linear relationships were demonstrated between cumulative fiber dose and the risk of mortality for lung cancer and noninfectious respiratory diseases. An SMR for lung cancer of 223 was observed for the lowest cumulative exposure category of less than 30 fibers/cc x years.

#### Asbestos Contamination of Other Minerals

Both serpentines and amphiboles may be found as contaminants in other mined and processed ores and may result in significant asbestos fiber exposures to workers in these operations.

Amosite belongs to the cummingtonite-grunerite amphibole mineral group. Fibers and cleavage fragments of cummingtonite-grunerite occur in some iron formations and have been found in high concentrations in Lake Superior as a result of mining and milling operations. Gillam et al. (21) studied mortality among gold miners exposed to cummingtonite-grunerite and found a 3-fold excess risk of lung cancer and a 2-fold excess of non-malignant respiratory disease, excluding influenza and pneumonia. However, workers in this mine were also exposed to silica. McDonald et al. (52) in a subsequent study of the same mine, examined the mortality experience of persons with at least 21 years of employment with the company. This study demonstrated excess mortality due to pneumoconiosis (mainly silicosis),

tuberculosis, and heart disease but no overall excesses of malignant diseases were found. However, when the population was stratified by exposure, respiratory cancer was elevated in the highest exposure group. The Gilliam and McDonald studies may not be directly compared since the McDonald study included persons never exposed underground and this diluted the cohort with minimally exposed workers.

Commercial talc deposits are sometimes found to contain serpentines (chrysotile, antigorite, and lizardite) and fibrous and non-fibrous amphiboles. Kleinfeld et al. (33,38) demonstrated significantly increased proportionate mortality due to lung cancer and nonmalignant respiratory disease among talc miners and millers in New York State exposed to fibrous anthophyllite and fibrous tremolite. Brown et al. (7) have reported a further mortality of talc miners and millers in one company mining this same ore body. This cohort consisted of 398 workers followed between 1947 and 1975. Among this cohort, 10 respiratory cancers were observed whereas only 3.5 were expected. Approximately a 3-fold excess risk of non-malignant respiratory disease was reported; however, only one death due to mesothelioma was observed.

#### Effects of Smoking

Smoking and asbestos exposure are more than additive in their combined ability to increase the risk of lung cancer. Hammond et al. reported results of their 10 year follow-up of

8,220 asbestos insulation workers with known smoking status (25). The mortality experience of these workers was compared with that expected among smokers and non-smokers of the American Cancer Society's prospective cancer prevention study. Asbestos workers who did not smoke showed approximately a 5-fold risk of lung cancer compared to the non-smoking control population. On the other hand, a more than 50-fold risk of lung cancer was observed for smoking asbestos workers compared to non-smoking controls. A similar multiplicative effect was observed by Selikoff et al. among a factor cohort producing amosite insulation (91).

Although less striking, cigarette smoking may also contribute to the risk of death due to asbestosis. Hammond et al. reported that asbestosis death rates of smoking asbestos workers were 2.8 times as high as that of non-smoking asbestos workers. Meurman (59) found less association between asbestosis mortality and smoking; he reported 7 of 42 asbestosis deaths among non-smokers.

#### Mortality and Pleural Radiographic Changes

The relationship between pleural thickening and calcification and subsequent mortality is important insofar as surveillance of asbestos workers is concerned. Edge studied the mortality of 429 shipyard workers with plaques and compared this to matched controls without plaques (16). Among those with plaques, 23 mesotheliomas were observed and workers with plaques had 2.5 times the lung cancer risk of those without plaques.

Sheers observed 6 mesothelioma deaths among 410 dockyard workers with plaques but just 2 mesotheliomas in those with only pleural fibrosis (92). Neither of these studies established causality between pleural changes and subsequent development of mesothelioma or lung cancer because asbestos exposure was not controlled for in the analysis. Meurman has shown that anthophyllite asbestos workers have a high prevalence of pleural changes but a minimal mesothelioma risk (59,60). However, plaques and pleural thickening do indicate an asbestos exposure and this fact alone places the worker at an increased risk for lung cancer and asbestosis.

#### RESPIRATORY MORBIDITY

All types of asbestos have been shown in epidemiologic studies to be associated with asbestosis, pleural thickening, and pleural calcification. Available evidence from cross-sectional and prospective respiratory disease studies provide little evidence that any one type of asbestos is more biologically active than another in so far as X-ray or clinical changes are concerned (98,99). These findings are fully supported by animal bioassay data.

Important epidemiologic studies of respiratory morbidity among asbestos workers are summarized in Table 2. In these studies, various objective measures of effect or disease outcome have been used including chest roentgenographs,

spirometry, measures of diffusion capacity, and chest auscultation. Subjective data such as respiratory symptoms obtained by questionnaire have also been used. In diagnosis of "definite asbestosis" most studies have relied upon combinations of objective and subjective data.

#### Mixed Fiber Exposures

Early cross-sectional studies of chest roentgenographs of asbestos workers by Merewether and Price, Donnelly, Schull, and Dressen et al. demonstrated a striking prevalence of pulmonary fibrosis of as much as 80% for workers employed more than 20 years (14,15,57,93).

Several studies have been conducted among insulation workers. Selikoff et al. studied chest films of 1,117 insulation workers exposed to chrysotile and amosite (84,86). A 50% overall prevalence of pulmonary fibrosis was observed increasing to 90% among those employed more than 30 years. Pleural calcification showed an increasing prevalence with latency reaching 57.9% at 40 years since initial employment. Pleural fibrosis (thickening) occurred earlier than calcification. Murphy et al. also studied shipyard insulation workers and found a prevalence of asbestosis 11 times that of age matched, non-exposed controls (62,63). Exposures among this group were thought to be low.

Cross-sectional data from an asbestos textile plant processing a mixture of asbestos types were used by the

British Occupational Hygiene (BOHS) in establishing occupational exposure standards (6). Among 290 workers employed after dust controls were installed in 1933, only 8 workers (2.7%) demonstrated X-ray changes considered consistent with asbestosis. Basal rales was taken as an early disease marker with a 1% risk estimated for a working lifetime of 50 years at an average exposure of 2 fibers/cc. Workers at this same plant were subsequently studied cross-sectionally by Lewinsohn (43). This latter and much larger study demonstrated a significantly greater prevalence of pulmonary fibrosis; reaching 40.5% among workers employed from 30 to 39 years. Pleural fibrosis (thickening) was observed in 1.6% of those employed 1-9 years and in 50% of workers employed more than 40 years.

Berry et al. reported the results of a prospective study of workers employed in the same plant studied by Lewinshon (43). This study consisted of 379 persons completing 10 or more years employment by 1971. Possible asbestosis was diagnosed based on one or more combinations of basal rales or crepitations, radiological changes, a falling transfer factor, and restrictive lung function changes. Among these 379 men, 60 cases of possible asbestosis were diagnosed by the factory medical officer, whereas 85 cases were diagnosed by an independent clinician. Using plant exposure data, it was estimated that the cumulative dose necessary for a 1% incidence for crepitations, possible

asbestosis, and certified asbestosis was 43 fiber/cc-yr, 55 fiber/cc-yr, and 72 fiber/cc-yr, respectively. Two cases of certified asbestosis were observed among non-smokers and nine among ex-smokers, suggesting a contributory smoking role. Weiss reported similar findings in his study of 100 asbestos textile workers where a 24% prevalence of pulmonary fibrosis was observed in non-smokers versus 40% for smokers (105,106). Gregor et al. demonstrated progression of radiological changes in asbestos workers referred to the British Pneumoconiosis Medical Panel without further asbestos exposures (24).

Lung function and chest film effects of exposure to asbestos cement dust have been studied by Weill et al. (104,105). This study included 859 workers in two asbestos cement plants administered respiratory symptom questionnaire, spirometry, and chest films. Cumulative dust exposures were estimated and expressed as MPPCF-yr. Both small rounded and linear opacities were observed, indicating the possible role of small quantities of silica present in cement dust. Among those with a cumulative exposure less than 50 mppcf-yr, an approximately 4% prevalence of small opacities (rounded or irregular, profusion  $\geq 1/0$ ) was observed; the prevalence of these changes increased to 30% with an exposure of more than 400 mppcf-yr. Pleural changes were seen in 11% of those in the lowest exposure category. Both FVC and FEV<sub>1</sub> were reduced in those with X-ray changes. There was no apparent interaction effect of cigarette smoking on the development of diffuse fibrosis.

Jones et al. studied the progression of radiographic abnormalities and lung function changes among 204 asbestos cement workers between 1970 and 1976 (30). Films were read side-by-side in known order and ranked according to progression. These authors concluded that: (1) progression of small opacities depended upon both average and cumulative exposure; (2) declines in lung function were related to both smoking and cumulative exposure; and (3) pleural abnormalities progressed as a function of time. Disease incidence was not estimated in relation to exposure.

#### Anthophyllite and Tremolite

Respiratory morbidity among Finnish anthophyllite miners and millers has been studied by Meurman et al. (60). Among 787 active employees, a threefold excess of dyspnea and a twofold excess of cough were observed among asbestos workers compared to controls. The prevalence of dyspnea was not found to be associated with smoking habits.

A high prevalence of pleural plaques has been reported among persons residing near anthophyllite mines and mills in Finland (31,58). In two mining communities where mass roentgenological surveys were conducted, prevalences of pleural plaques of 9% and 6.5% were observed compared to less than 0.1% for the Finnish population.

Talc deposits found in upper New York state contain both anthophyllite and tremolite. Workers in talc mines and mills in this area have been shown to experience pulmonary fibrosis,

pleural changes, and restrictive lung function changes (32,34-37,74,94,95). A recent cross-sectional study of lung function and chest X-rays among talc workers in this area was reported by Gamble et al. (20). Compared with coal and potash miners, talc miners and millers were found to have an increased prevalence of cough and dyspnea along with reduced FEV<sub>1</sub>, FVC, and flow rates. Talc workers with more than 15 years employment were found to have a 33% prevalence of pleural calcification and pleural thickening. Recent exposures in these operations were reported by Dement and Zumwalde (11). Time-weighted-average fiber exposures were found to range from 0.8 to 16.0 fibers/cc with 12-19% identified as tremolite and 38-45% anthophyllite.

#### Chrysotile

Radiological changes, lung function, and respiratory symptoms among Canadian chrysotile miners and millers have been extensively studied by McDonald et al. (50,51) and Becklake et al. (2). A total of 1,015 current employees were given chest X-rays, underwent pulmonary function studies and were administered a standard British Medical Research Council Questionnaire on respiratory symptoms. Both persistent cough and phlegm (bronchitis) and breathlessness on exercise were found to increase with exposure. The prevalence of bronchitis rose to 50% among smokers in the highest dust exposure categories. The prevalence of breathlessness was not affected by smoking but rose to greater than 40% in those with cumulative dust

exposures over 800 mppcf-years. The prevalence of irregular small opacities ( $>1/0$  ILO/UC) in the lowest exposure category was found to be 1.8% for the Thetford mine and 6.4% for the Asbestos mine. Prevalences increased to 26.4% for Thetford and 10.9% for Asbestos in the group with exposures more than 800 mppcf-yr. The prevalence of pleural thickening was found to be less strongly related to exposure. Among various lung function parameters measured, both FVC and  $FEV_1$  declined more with exposure. Those with small opacities of category 2/1 or greater were found to have significantly reduced functional residual capacity, residual volume, and single-breath diffusing capacity at rest. Only FVC and  $FEV_1$  were reduced in those with earliest roentgenographic changes.

Cross-sectional respiratory disease studies have been conducted among chrysotile miners and millers in Newfoundland and Corsica (5,83). Selikoff studied 485 current employees of a chrysotile mine in Newfoundland and found a 5% prevalence of parenchymal abnormalities (ILO U/C  $\geq 1/0$ ) (83). This prevalence increased to 11.5% among those employed more than 10 years. The prevalence of pleural changes was less than that observed for parenchymal changes.

Boutin et al. studied chest films of 16 ex-workers of chrysotile mines and mills in Corsica which had been closed in 1965 (5). Compared with controls, chrysotile miners and millers had 2.4 times the risk of parenchymal abnormalities

and 2 times the risk of pleural abnormalities. Exposure levels among these workers were extremely high ranging from 85 to 267 MPPCF.

The above studies of chrysotile asbestos workers have been cross-sectional by design and have likely underestimated risks since: (1) those who develop severe disease are likely to have already left employment, and (2) chest film changes may develop after termination of employment, or changes may be progressive without additional exposure. Liddell et al. studied chest film changes in a 20 year longitudinal study of chrysotile miners and millers (44). These authors observed a 20 year cumulative incidence for small irregular opacities of 16%, a pleural calcification incidence of 5.3%, and a pleural thickening incidence of 5.3%. Only the incidence of small opacities was strongly associated with smoking. Rubino et al. studied the progression of chest film changes among retired chrysotile asbestos miners and millers and found that 39% of those who had initial films with a profusion of 1/0 or greater, demonstrated progression without further exposure (78). Becklake et al. also studied radiological changes after withdrawal from asbestos exposure (3). Parenchymal progression was observed in 7% of the films, pleural progression in 19.8%, and both parenchymal and pleural progression in 2.3%. These changes were found to be independent of age and smoking but parenchymal "attacks" occurred more among those with higher asbestos exposure prior to employment termination.

Relationships between radiological findings and subsequent mortality among chrysotile miners and millers have been studied by Liddell and McDonald (45). This study consisted of 4559 whose latest film had been read according to the UICC/Cincinnati classification system with mortality follow-up from time of film assessment through 1975. Overall, this cohort experience significantly increased mortality for all causes (SMR=144), lung cancer (SMR=177), pneumoconiosis (31 cases), other respiratory diseases (SMR=127); diseases of the heart (SMR=136), cancer of the oesophagus or stomach (SMR=170), and cerebrovascular diseases. There were 5 pneumoconiosis deaths among those classified as having normal radiographs; however, the risk of death due to pneumoconiosis was 11.75 times greater among those with "less-than-normal" films. The lung cancer relative risk for those with chest film changes was 3.24 and most who died of lung cancer were found to be smokers. Small parenchymal opacities were present in most but not all persons whose deaths were attributed to lung cancer. The authors concluded that the chest radiograph was useful for surveillance of asbestos workers but was limited due to radiological progression after withdrawal from exposure and by the carcinogenic risk associated with dust retained in the lung.

## REFERENCES

1. Anderson, H.A., Lilis, R., Daum, S.M., and Selikoff, I.J.: Asbestosis among household contacts of asbestos factory workers. Ann NY Acad Sci 330:387-399, 1979.
2. Becklake, M.R., Fournier-Massey, G., Rossiter, C.E., and McDonald J.C.: Lung function in chrysotile asbestos mine and mill workers of Quebec. Arch Environ Health 24(6):401-409, 1972.
3. Becklake, M.R., Liddell, F.D.K., Manfreda, J., and McDonald, J.C.: Radiological changes after withdrawal from asbestos exposure. Br J Ind Med 36:23-28, 1979.
4. Berry, G., Gilson, J.C., Holmes, S., Lewinsohn, H.C., and Roach, S.A.: Asbestosis: A study of dose-response relationships in an asbestos textile factory. Br J. Ind Med. 36:98-112, 1979.
5. Bountin, C., Viallat, J.R., and Bellenfant, M.: Radiological features in chrysotile asbestos mine and mill workers in Corsica. In: Biological Effects of Mineral Fibres, J. C. Wagner (Ed.), International Agency for Research on Cancer, Scientific Publication No. 30, 507-510, 1980.
6. British Occupational Hygiene Society: Hygiene standards for chrysotile asbestos dust. Ann Occup Hyg 11:47, 1968.
7. Brown, D.P., Dement, J.M., and Wagoner, J.K.: Mortality patterns among miners and millers occupationally exposed to asbestiform talc. In: Dusts and Disease, R.A. Lemen and J.M. Dement (Eds.), Park Forest South, Illinois: Pathotox Publishers, Inc., 317-324, 1979.

8. Cochrane, J.C. and Webster, I.: Mesothelioma in relation to asbestos fibre exposure. *South African Med J* 12:279-281, 1978.
9. Cooke, W.E.: Fibrosis of the lungs due to the inhalation of asbestos dust. *Br Med J* 2:147, 1924.
10. Dement, J.M., Harris, R.L., Symons, M.J., and Shy, C.: Estimates of dose-response for respiratory cancer among chrysotile asbestos textile workers. In: *Proceedings of the 5th International Conference on Inhaled Particles and Vapours*, BOHS, 1980.
11. Dement, J.M. and Zumwalde, R.D.: Occupational exposures to talcs containing asbestiform minerals. In: *Dust and Disease*. R. Lemen and J.M. Dement (Eds.). Park Forest South, Illinois: Pathotox Publishers, 287-305, 1979.
12. Doll, R.: Mortality from lung cancer in asbestos workers. *Br J Ind Med* 12:81-86, 1955.
13. Donnelly, J.A.: Pulmonary asbestosis. *Am J Pub Health* 23:1275-1281, 1933.
14. Donnelly, J.A.: Pulmonary asbestosis: Incidence and prognosis. *J Ind Hyg* 18:222-278, 1936.
15. Dressen, W.C., DallaValle, J.M., Edwards, T.J., Miller, J.W., Sayers, R.R., Eason, H.F., and Trice, M.F.: A study of asbestosis in the asbestos textile industry. *Public Health Bulletin* 217, 1938.
16. Edge, J.R.: Incidence of bronchial carcinoma in shipyard workers with pleural plaques. *Ann NY Acad Sci* 330:289-294, 1979.

17. Egbert, D.S. and Geiger, A.J.: Pulmonary asbestosis and carcinoma. Report of a case with necropsy findings. *Am Rev of Tuberculosis* 34:143-146, 1936.
18. Elmes, P.C. and Simpson, M.J.C.: Insulation workers in Belfast. A further study of mortality due to asbestos exposure (1940-1975). *Br J Ind Med* 34(3):174-180, 1977.
19. Elmes, P.C. and Simpson, M.J.C.: Insulation workers in Belfast, III, mortality 1940-1966. *Br J Ind Med* 28:226-236, 1971.
20. Gamble, J., Fellner, W., and DiMeo, M.J.: Respiratory moridity among miners and millers of asbestiform talc. In: *Dusts and Disease*, R.A. Lemen and J.M. Dement (Eds.). Park Forest South, Illinois: Pathotox Publishers, Inc., 307-316, 1979.
21. Gillam, J.D., Dement, J.M., Lemen, R.A., Wagoner, J.K., Archer, V.E., and Blejer, H.P.: Mortality patterns among hard rock gold miners exposed to an asbestiform mineral. *Ann NY Acad Sci* 271:336-344, 1976.
22. Gloyne, S.R.: A case of oat cell carcinoma of the lung occurring in asbestosis. *Tubercle* 18:100-101, 1936.
23. Gloyne, S.R.: Two cases of squamous carcinoma of the lung occurring in asbestosis. *Tubercle* 17:5-10, 1935.
24. Gregor, A., Parkes, R.W., duBois, R., and Turner-Warwick, M.: Radiographic progression of asbestosis: Preliminary Report. *Ann NY Acad Sci* 330:147-156, 1979.

25. Hammond, E.C., Selikoff, I.J., and Seidman, H.: Asbestos, exposure, cigarette smoking, and death rates. Ann NY Acad Sci 330:473-490, 1979.
26. Harrington, J.S.: Asbestos and mesothelioma in man. Nature (London) 232:54-55, 1971.
27. International Agency for Research on Cancer: IARC Monographs on the evaluation of carcinogenic risk of chemicals to man. Asbestos 14, 1977.
28. Jones, J.P., Pooley, F.D., and Smith, P.G.: Factory populations exposed to crocidolite, asbestos--A continuing survey. International Agency for Research on Cancer, Inserm Symposium Series 52. IARC Scientific Publication No. 13, 117, 1976.
29. Jones, J.S.P. Smith, P.G., Pooley, F.D., et al.: The consequences of exposure to asbestos dust in a wartime gas-mask factory. In: Biological Effects of Mineral Fibres. J.C. Wagner (Ed.). International Agency for Research on Cancer, Scientific Publication No. 30, 637-653, 1980.
30. Jones, R.N., Diem, J.E., Glindmeyer, H., Weill, H., and Gilson, J.C.: Progression of asbestos radiographic abnormalities: Relationships to estimates of dust exposure and annual decline in lung function. In: Biological Effects of Mineral Fibres. J.C. Wagner, Ed., International Agency for Research on Cancer, Scientific Publication No. 30, 537-543, 1980.

31. Kilviluoto, R.: Pleural calcification as a roentgenologic sign of non-occupational endemic anthophyllite - asbestos. ACTA Radiologica (Supplement) 194:1-67, 1960.
32. Kleinfeld, M., Giel, C.P., Majeraonowski, J.F., and Messite, J.: Talc pneumoconiosis: a report of six patients with post mortem findings. Ind Hyg Rev. 6:5-29, 1964.
33. Kleinfeld, M., Messite, J., and Kooyman, O.: Mortality among talc miners and millers in New York State. Ind Hyg Rev, NY Dept. of Labor, 9:3-12, 1967.
34. Kleinfeld, M., Messite, J., Kooyman, O., and Shapiro, J.: Pulmonary ventilatory function in talcosis of the lung. Ind Hyg Rev 7:14-23, 1965.
35. Kleinfeld, M., Messite, J., and Langer, A.J.: A study of workers exposed to asbestiform minerals in commercial talc manufacture. Env Res 6:132-143, 1973.
36. Kelinfeld, M.J., Messite, J., Shapiro, J., Kooyman, O., and Swencicki, R.: Lung function in talc workers: A comparative physiologic study of workers exposed to fibrous and granular talc dusts. Ind Hyg Rev 7:3-13, 1965.
37. Kleinfeld, M., Messite, J., Swencicki, R., and Sarfaly, J.: Lung function changes in talc pneumoconiosis. JOM 7:12-17, 1965.
38. Kleinfeld, M., Messite, J., and Zaki, H.: Mortality experiences among talc workers. A follow-up study. JOM 16:345-349, 1974.

39. Knox, J.F., Doll, R.S., and Hill, I.D.: Cohort analysis of changes in incidence of bronchial carcinoma in a textile asbestos factory. *Ann NY Acad Sci* 132:526-535, 1965.
40. Knox, J.F., Holmes, S., Doll, R., and Hill, I.D.: Mortality from lung cancer and other causes among workers in an asbestos textile factory. *Br J Ind Med* 25:293-303, 1968.
41. Kogan, F.M., Guselnikova, N.A., and Gulevskaya, H.R.: Cancer mortality rate among workers in the asbestos industry in the Urals. *Gig i Sanit* 37(7):29, 1972.
42. Lee, D.H. and Selikoff, I.J.: Historical background to the asbestos problem. *Environ Res* 18:300-314, 1979.
43. Lewinsohn, H.C.: The medical surveillance of asbestos workers. *Roy Soc Health J* 92(2):69-77, 1972.
44. Liddell, D., Eyssen, G., Thomas, D., and McDonald, C.: Radiological changes over 20 years in relation to chrysotile exposure in Quebec. In: *Inhaled Particles IV*, W. H. Walton (Ed.). Oxford: Pergamon Press, 799-812, 1977.
45. Liddell, F.D.K. and McDonald, J.C.: Radiological findings as predictors of mortality in Quebec asbestos workers. *Br J Ind Med* 37:257-267, 1980.
46. Lynch, K.M. and Smith, W.A.: Pulmonary asbestosis I. Report of bronchial carcinoma and epithelial metaplasia. *Am J Cancer* 36:567-572, 1931.

47. Lynch, K.M. and Smith, W.A.: Pulmonary asbestosis III. Carcinoma of the lung in asbesto-silicosis. *Am J Cancer* 14:56-64, 1935.
48. Mancuso, T.F. and Coulter, E.J.: Methodology in industrial health studies. The cohort approach, with special reference to an asbestos company. *Arch Environ Health* 6:210-226, 1963.
49. McDonald, A.D. and McDonald, J.C.: Mesothelioma after crocidolite exposure during gas mask manufacture. *Environ Res* 17:340, 1978.
50. McDonald, J.C., Becklake, M.R., Gibbs, G.W., McDonald, A.D., and Rossiter, C.E.: The health of chrysotile asbestos mine and mill workers of Quebec. *Arch Environ Health* 28(2):61-68, 1974.
51. McDonald, J.C., Becklake, M.R., Fournier-Massey, G., and Rossiter, C.E.: Respiratory symptoms in chrysotile asbestos mine and mill workers of Quebec. *Arch Environ Health* 24(5):358-363, 1972.
52. McDonald, J.C., Gibbs, G.W., Liddell, F.V.D., and McDonald, A.D.: Mortality after long exposure to cummingtonite grunerite. *Am Rev Respir Dis* 118:271-277, 1978.
53. McDonald, J.C. and Liddell, F.D.K.: Mortality in Canadian miners and millers exposed to chrysotile. *Ann NY Acad Sci* 330:1-9, 1979.

54. McDonald, J.C., Liddell, F.D.K., Gibbs, G.W., Eysen, G.E., and McDonald, A.D.: Dust exposure and mortality in chrysotile mining, 1910-75. *Br J Ind Med* 37:11-24, 1980.
55. McDonald, J.C., McDonald, A.D., Gibbs, G.W., Siemiatycki, J., and Rossiter, C.E.: Mortality in the chrysotile asbestos mines and mills of Quebec. *Arch Environ Health* 22:677-686, 1971.
56. Merewether, E.R.A.: In: Annual Report of the Chief Inspector of Factories for the year 1947. London: Her Majesty's Stationery Office. pp 56-58, January, 1947.
57. Merewether, E.R.A. and Price, C.W.: Report on the effects of asbestos dust on the lungs and dust suppression in the asbestos industry I. Occurrence of pulmonary fibrosis and other pulmonary affections in asbestos workers II. Processes giving rise to dust and methods for its suppression. London: Her Majesty's Stationery Office, 1930.
58. Meurman, L.O.: Pleural fibrocalcific plaques and asbestos exposure. *Environ Res* 2:30-46, 1968.
59. Meurman, L.O., Kilviluoto, R., and Hakama, M.: Combined effects of asbestos exposure and tobacco smoking on Finnish anthophyllite miners and millers. *Ann NY Acad Sci* 330:491-495, 1979.
60. Meurman, L.O., Kilviluoto, R., and Hakama, M.: Mortality and morbidity among the working population of anthophyllite asbestos miners in Finland. *Br J Ind Med* 31(2):105-112, 1974.

61. Mills, R.G.: Pulmonary asbestosis: Report of a case. Minn Med J 13:495-499, 1930.
62. Murphy, R.L., Ferris, B., and Burgess, W.A.: Effects of low concentrations of asbestos. Clinical, environmental, radiologic and epidemiologic observations in shipyard pipe coverers and controls. N Eng J Med 285(23):1271-1278, 1971.
63. Murphy, R.L.H., Gaensler, E.A., Ferris, B.G., et al.: Diagnosis of asbestosis. Observations from a longitudinal survey of shipyard pipe coverers. Am J Med 65(3):488-498, 1978.
64. Murray, M.: As reported by Lee, D.H.K. and Selikoff, I.J.: Historical background to the asbestos problem. Environ Res 18:300-314, 1979.
65. Newhouse, M.L.: A study of the mortality of workers in an asbestos factory. Br J Ind Med 26:294-301, 1969.
66. Newhouse, M.L.: Cancer among workers in the asbestos textile industry. In: Proceedings of the Conference on Biological Effects of Asbestos. P. Bogovski, J.C. Gibson, V. Timbrell, and J.C. Wagner, (Eds.). International Agency for Research on Cancer, 203-208, 1973.
67. Newhouse, M.L., Berry, G., Wagner, J.C., and Turok, M.E.: A study of the mortality of female asbestos workers. Br J Ind Med 29(2):134-141, 1972.

68. Nicholson, W.J., Selikoff, I.J., Seidman, H., Lilis, R., and Formby, P.: Long-term mortality of chrysotile miners and millers in the Thetford Mines, Quebec. *Ann NY Acad Sci* 330:11-21, 1979.
69. Nordmann, M.: The occupational basis for asbestosis in asbestos workers. *J Ind Hyg* 20:184, 1938.
70. Noro, L.: Occupational and non-occupational asbestosis in Finland. *Am Ind Hyg Assoc J* 29:195-201, 1968.
71. Oliver, T.: Clinical aspects of pulmonary asbestosis. *Br Med J* 2:1026, 1927.
72. Pancoast, H.K., Miller, T.C., and Landis, H.R.M.: A roentgenologic study of the effects of dust inhalation upon the lungs. *Trans Assoc of Am Physicians* 32:97-108, 1917.
73. Pancoast, H.K. and Pendergrass, F.P.: *Pneumoconiosis: A Roentgenological Study*. New York: Paul B. Hoeber Inc., 1926.
74. Pano, F.W., Patton, J.R., and Hobbs, A.A.: Pneumoconiosis in the talc industry. *Am J Roent and Rad Ther* 47:507-524, 1942.
75. Peto, J.: Dose-response relationships for asbestos-related disease: Implication for hygiene standards, Part II, Mortality. *Ann NY Acad Sci* 330:195-204, 1979.
76. Peto, J., Doll, R., Howard, S.V., Kinlen, L.J., and Lewinsohn, H.C.: Mortality study among workers in an English asbestos factory. *Br J Ind Med* 34(3):169-173, 1977.

77. Robinson, C.F., Lemen, R.A., and Wagoner, J.K.: Mortality patterns, 1940-1975, among workers employed in an asbestos textile fiction and packing products manufacturing facility? In: Dusts and Diseases. R.A. Lemen and J.M. Dement (Eds.), Park Forest South Illinois: Pathotox Publishers, Inc., 131-143, 1979.
78. Rubino, G.F., Newhouse, M., Murray, G., Scansetti, G., Piolatto, G., and Aresini, G.: Radiologic changes after cessation of exposure among chrysotile asbestos miners in Italy. *Ann NY Acad Sci* 330:157-161, 1979.
79. Rubino, G.F., Piolatto, G., Newhouse, M.L., et al.: Mortality of chrysotile asbestos workers at the Balangero Mine, Northern Italy. *Br J Ind Med* 36:187, 1979.
80. Seidman, H.R., Lilis, R., and Selikoff, I.J.: Short-term asbestos exposure and delayed cancer risk. In: Third International Symposium on Detection and Prevention of Cancer. H.E. Niebergo (Ed.), New York: Marcel Dekker, Inc., 943-960, 1977.
81. Seidman, H., Selikoff, I.J., and Hammond, E.C.: Short-term asbestos expsure and long-term observation. *Ann NY Acad Sci* 330:61-89, 1979.
82. Seiler, H.E. and Gilmour, M.D.: A case of pulmonary asbestosis. *Br Med J* 1:1112, 1931.
83. Selikoff, I.J.: Clinical survey of chrysotile asbestos miners and millers in Baie Verte, Newfoundland--1976, Report to the National Institute of Environmental Health Sciences, December 22, 1977.

84. Selikoff, I.J.: The occurrence of pleural calcification among asbestos insulation workers. *Ann NY Acad Sci* 132:351-367, 1965.
85. Selikoff, I.J., Churg, J., and Hammond, E.C.: Asbestos exposure and neoplasia. *JAMA* 188(1):142-146, 1964.
86. Selikoff, I.J., Churg, J., and Hammond, E.C.: The occurrence of asbestos among insulation workers in the United States. *Ann NY Acad Sci* 132:139-155, 1965.
87. Selikoff, I.J., Hammond, E.C., and Churg, J.: Carcinogenicity of amosite asbestos. *Arch Environ Health* 25(3):183-186, 1972.
88. Selikoff, I.J., Hammond, E.C., and Seidman, H.: Cancer risk of insulation workers in the United States. In: *Proceedings of the Conference on Biological Effects of Asbestos*. P. Bogovoki, J.C. Gilson, V. Timbrell, and J.C. Wagner (Eds.). International Agency for Research on Cancer, 209-216, 1973.
89. Selikoff, I.J., Hammond, E.C., and Seidman, H.: Mortality experience of insulation workers in the United States and Canada, 1943-1976. *Ann NY Acad Sci* 330:91-116, 1979.
90. Selikoff, I.J. and Lee, D.H.: *Asbestos and Disease*. New York: Academic Press, Inc., 1978.
91. Selikoff, I.J., Seidman, H., and Hammond, E.C.: Mortality effect of cigarette smoking among amosite asbestos factory workers. *J Natl Cancer Inst* 65(3):507-513, 1980.

92. Sheers, G.: Asbestos-associated disease in employees of Devonport Dockyard. *Ann NY Acad Sci* 330:281-287, 1979.
93. Shull, J.R.: Asbestosis. A roentgenologic review of 71 cases. *Radiology* 27:279-292, 1936.
94. Siegal, W., Smith, A.R., and Greenburg, L.: The dust hazard in tremolite mining, including roentgenological findings in talc workers. *Am J Roentgenology and Radium Ther* 49:11-29, 1942.
95. Siegal, W., Smith, A.R., and Greenburg, L.: Study of talc miners and millers. *Industrial Bull* 22:3-12, 1943.
96. Simson, F.W.: Pulmonary asbestosis in Africa. *Br Med J* 1:885, 1928.
97. Stewart, M.J.: The immediate diagnosis of pulmonary asbestosis at necropsy. *Br Med J* 2:509, 1928.
98. U.S. Public Health Service, National Institute for Occupational Safety and Health. Criteria for a Recommended Standard: Occupational Exposure to Asbestos. Publication No. HSM 72-10267, 1972.
99. U.S. Public Health Service, National Institute for Occupational Safety and Health. Workplace Exposure to Asbestos: Review and Recommendations. Publication No. DHHS (NIOSH) 81-103, 1980.
100. Wagner, J.C., Sleggs, C.A., and Marchand, P.: Diffuse pleural mesothelioma and asbestos exposure in the North Western Cape Province. *Br J Ind Med* 17:260-271, 1960.

101. Webster, I.: Malignancy in relation to crocidolite and amosite. In: Proceedings of the Conference on Biological Effects of Asbestos. P. Bogovski, J.C. Gilson, V. Timbrell, J.C. Wagner (Eds). International Agency for Research on Cancer, 195-198, 1973.
102. Weill, H., Hughes, J., and Waggenpack, C.: Influence of dose and fiber type on respiratory malignancy risks in asbestos cement manufacturing. Am Rev Respir Dis 120:345-354, 1979.
103. Weill, H., Waggenpack, C., Bailey, W., Ziskind, M., and Rossiter C.: Radiographic and physiologic patterns among workers engaged in manufacture of asbestos cement products. A Preliminary Report. JOM 15(3):248-252, 1973.
104. Weill, H, Ziskind, M.M., and Waggenpack, C.: Lung function consequences of dust exposure in asbestos cement manufacturing plants. Arch Environ Health 30(2):88-97, 1975.
105. Weiss, W.: Cigarette smoking, asbestos, and pulmonary fibrosis. Am Rev Respir Dis 104:223-227, 1971.
106. Weiss, W.: Mortality of a cohort exposed to chrysotile asbestos. JOM 19(11):737-740, 1977.
107. Weiss, W. and Theodas, P.A.: Pleuropulmonary disease among asbestos workers in relation to smoking and type of exposure. JOM 20:341-345, 1978.
108. Wood, W.B. and Gloyne, S.R.: Pulmonary asbestosis. Lancet 1:445, 1930.

TABLE 1

## SUMMARY OF MORTALITY STUDIES OF ASBESTOS EXPOSED POPULATIONS

Author(s)	Date	Study Population	Fiber Type	Study Design	Summary of Important Findings
Doll	1955	113 Textile workers employed 20 or more years	Mixed	Retrospective Cohort, 1922-1953	11 lung cancers observed versus 0.8 expected, 14 death certificates mentioned asbestosis.
Mancuso & Coulter	1963	1,495 Workers producing textile, friction products	Mostly Chrysotile	Retrospective Cohort, 1940-1960	28 asbestosis deaths, 19 lung cancers observed versus 5.6 expected, 5 peritonium neoplasms (2 were mesotheliomas).
Selikoff, Churg and Hammond	1964	632 Insulation workers with 20 or more years employment	Mixed	Retrospective Cohort, 1943-1962	12 asbestosis deaths, 45 lung cancers observed versus 6.6 expected. Increased gastrointestinal cancer, 3 pleural mesotheliomas.
Knox et al.	1965, 1968	1,014 Textile workers	Mixed	Retrospective Cohort, 1922-1966	27 lung cancers observed versus 10.75 expected, 42 with asbestosis on death certificate. Authors suggested reduce risks after controls added in 1933.
Newhouse	1969, 1973	4,500 Textile workers	Mixed	Retrospective Cohort, 1933-1968	Significant excesses for lung cancer among workers in highest exposure category. 24 mesotheliomas among males.
Newhouse et al.	1972	922 Female textile & friction product workers	Mixed	Retrospective Cohort, 1942-1968	14 lung cancers observed versus 0.5 expected in those working 2 years in highest exposure jobs. Approximately 3-fold excess of respiratory disease mortality in this group. Overall 11 mesotheliomas

Continued

39

Author(s)	Date	Study Population	Fiber Type	Study Design	Summary of Important Findings
Selikoff, Hammond and Churg	1968	370 Insulation workers with >20 years employment	Mixed	Retrospective Cohort, 1963-1967	Observed strong interactive effect between asbestos exposure and smoking for lung cancer. 10 mesothelioma deaths observed and 15 asbestosis deaths.
Elmes and Simpson	1971, 1977	162 Insulation workers	Mixed	Retrospective Cohort, 1940-1975	16 asbestosis deaths, 13 mesotheliomas. Large excess risk for respiratory cancer throughout follow-up period.
McDonald, et al.	1971, 1974, 1979, 1980	11,379 asbestos miners & millers	Chrysotile	Retrospective Cohort, 1926-1975	Among those achieving > 20 years latency, overall lung cancer SMR = 125, with 42 pneumoconiosis deaths and 11 mesothelioma deaths. Linear dose-response observed for lung cancer and pneumoconiosis.
Enterline & Henderson	1972, 1978	1,075 retired asbestos product workers	Chrysotile and Amphiboles	Retrospective Cohort, 1941-1973	Lung cancer SMR = 270; 19 asbestosis deaths. Linear dose-response observed for lung cancer with SMR = 198 at 62 MPPCF-yrs. and SMR = 778 at 976 MPPCF-yrs.; 2 mesothelioma deaths.
Selikoff et al.	1973, 1979	17,800 Insulation workers	Mixed	Retrospective Cohort, 1967-1976	429 lung cancers observed versus 105.6 expected; 78 asbestosis deaths and 49 mesotheliomas.
Meurman et al.	1974	1,092 asbestos mine & mill workers	Antho-phyllite	Retrospective Cohort, 1936-1974	21 lung cancers observed versus 13 expected; 13 asbestosis deaths but no mesotheliomas. A strong interactive effect on lung cancer with smoking and asbestos exposure was observed.

Continued

Author(s)	Date	Study Population	Fiber Type	Study Design	Summary of Important Findings
Peto et al. and Peto	1977 1979	1,106 textile workers employed >10 years	Mixed	Retrospective Cohort,	36 respiratory cancers observed versus 19.3 expected among those only employed in controlled areas. Significant excess of non-malignant respiratory diseases.
Weiss	1977	264 paper & millboard workers	Chrysotile	Retrospective Cohort, 1945-1974	2 asbestosis deaths among a total of 66 deaths. No excess of lung cancer but numbers were small; no mesotheliomas reported.
Jones et al.	1976, 1979	1,088 gas mask workers during WW II	Crocidolite	Retrospective Cohort, 1939-1976	12 lung cancers observed versus 6.3 expected in women; 17 mesothelioma deaths. Linear dose-response for mesothelioma with employment duration; 3 mesotheliomas observed among those exposed 5-10 months.
Edge	1976, 1979	429 shipyard workers with pleural plaques	Mixed	Prospective Follow-up 1968-1974	19 bronchogenic cancers observed versus 4.0 expected 23 mesotheliomas observed. Shipyard workers with plaques had 2.5 times lung cancer risk when compared to matched controls without plaques.
Hughes & Weill	1979	5,645 Asbestos cement workers, >20 years latency	Chrysotile & Crocidolite	Retrospective Cohort, 1940-1973	23 lung cancers observed versus 9.3 expected among those with cumulative fiber exposures >100 MPPCF/yr. 2 pleural mesotheliomas observed versus 4.4 expected among those not exposed to crocidolite.
Sheers	1979	410 dockyard workers with pleural plaques or pleural fibrosis	Mixed	Prospective Follow-up 1967-1976	6 mesothelioma deaths among those with plaques and 2 with only pleural fibrosis. Author suggested pleural plaques are of greater biological significance than

Continued

41

Author(s)	Date	Study Population	Fiber Type	Study Design	Summary of Important Findings
Seidman, Selikoff and Hammond	1979	820 men producing insulation between 1941-1945	Amosite	Retrospective Cohort, 1961-1975	83 lung cancers observed versus 23.9 expected. Among 61 men employed <1 month, 3 lung cancers observed versus 1.3 expected. 4 mesotheliomas by death certificate diagnosis but an additional 10 identified using necropsy data. 15 deaths observed due to asbestosis.
Hammond, Selikoff	1979	12,051 insulation workers with >20 years latency	Mixed	Retrospective Cohort, 1967-1976	Asbestos workers who did not smoke had 5 times risk of lung cancer compared to nonsmoking controls. Smoking asbestos workers had 53 times the lung cancer risk of non-asbestos exposed persons who also did not smoke.
Robinson, Lemen, and Wagner	1979	3,276 workers producing textile, friction products	Mostly Chrysotile	Retrospective Cohort, 1940-1975	Overall lung cancer SMR = 136 for males and 824 among females. Some increasing trends in lung cancer with employment duration. Large excesses due to asbestosis. 17 mesothelioma deaths observed.
Nicholson et al.	1979	544 Chrysotile miners & millers, >20 years employment	Chrysotile	Retrospective Cohort, 1961-1977	28 lung cancers observed versus 11.1 expected. 26 cases of asbestosis observed; 1 pleural mesothelioma observed.
Dement et al.	1980	768 Textile workers	Chrysotile	Retrospective Cohort, 1940-1975	26 lung cancers observed versus 7.47 expected. 15 asbestosis deaths and 1 mesothelioma death. Linear dose-response for lung cancer with SMR = 223 at cumulative exposures <30 fiber/cc x yrs.
Brown, Dement, and Wagoner	1979	398 Talc miners & millers	Antho-phyllite & Tremolite	Retrospective Cohort, 1947-1975	9 lung cancers observed versus 3.3 expected. Significant excess due to non-malignant respiratory

TABLE 2  
SUMMARY OF RESPIRATORY MORBIDITY STUDIES OF ASBESTOS EXPOSED POPULATIONS

Author(s)	Date	Study Population	Fiber Type	Study Design	Summary of Important Findings
Selikoff, Churg, and Hammond	1965	1,117 Insulation workers	Chrysotile and Amosite	Cross-sectional, no external controls	50% prevalence of pulmonary fibrosis. Increasing prevalence of all chest film changes with employment duration increasing to 90% prevalence at >30 years.
Kilviluoto et al.	1960, 1965, 1979	Persons in Central Finland	Anthophyllite Tremolite	Case Series	Pleural calcification observed in persons only secondarily exposed to asbestos. Pleural changes unrelated to lung cancer mortality.
Selikoff	1965	1,117 Insulation workers	Chrysotile and Amosite	Cross-sectional, no external controls	Pleural calcification showed increasing prevalence reaching 57.9% among those with 40 years since first exposure. Pleural fibrosis occurred earlier than calcification, 50% of cases were bilateral.
McDonald et al.	1972	1,015 Chrysotile miners and millers	Chrysotile	Cross-sectional, no externals	Shortness of breath increased with estimated cumulative dust exposure but bronchitis showed little correlation.
Becklake et al.	1972	1,015 Chrysotile miners and millers	Chrysotile	Cross-sectional, no externals	FVC found to decrease with estimated cumulative dust exposure in smokers and non-smokers. Same trends seen in FEV <sub>1</sub> . Obstructive impairment seen in high exposure group. Few trends in diffusing capacity.

Continued

Author(s)	Date	Study Population	Fiber Type	Study Design	Summary of Important Findings
McDonald et al.	1974	5,082 miners and millers with chest films	Chrysotile	Mortality follow-up	Increased mortality observed for those with parenchymal changes but not in those with only pleural changes, 32 deaths observed due to all respiratory diseases versus 8 expected.
Liddell et al.	1977	267 miners and millers with chest films	Chrysotile	Prospective follow-up	During 20 year period, the following cumulative incidence was reported: small opacities 16%, pleural thickening 5.3%, pleural calcification 5.3%, obliteration of c/p angle 7.3%.
Weis	1971	100 asbestos textile workers	Unknown	Cross-sectional, no external controls	Overall prevalence of fibrosis 36% with 24% prevalence in nonsmokers and 40% in smokers. None of 11 nonsmokers with exposures less than 20 years showed fibrosis.
BOHS	1968	290 asbestos textile workers	Mixed	Cross-sectional, no external controls	Basal rates used as early disease marker, 1% risk estimated for a working lifetime of 50 years at 2 fibers/cc.
Lewinsohn	1972	1,287 asbestos textile workers	Mixed	Cross-sectional, no external controls	Prevalence of pulmonary fibrosis 0% with 0-9 years exposure up to 40.5% with 30-39 years exposure. Pleural fibrosis prevalence 1.6% in 0-9 years and 50% in 40-49 years exposure group.

Continued

Author(s)	Date	Study Population	Fiber Type	Study Design	Summary of Important Findings
Jerry et al.	1979	379 asbestos textile workers	Mixed	Prospective follow-up	6.6% of workers had "possible" asbestosis after 16 years follow-up and an average exposure of 5 fibers/cc. Cumulative exposure for 1% incidence of "possible asbestosis" for 40 years employment estimated to be 55 fiber/cc x years.
Weill et al.	1973	908 asbestos cement workers	Mixed	Cross-sectional, no external controls	Overall prevalence of small rounded opacities 1/0 or greater was 3.1%, for small irregular opacities prevalence was 2.5%. Reduced FEV <sub>1</sub> , FEF <sub>25-75</sub> and FEV <sub>1</sub> /VC ratio found in those with X-ray abnormalities.
Weill et al.	1975	859 asbestos cement workers	Mixed	Cross-sectional, no external controls	Prevalence of small rounded and irregular opacities 4% in lowest exposure group and 30% in highest. Pleural changes 11% in lowest exposure group and 30% in highest. FVC and FEV <sub>1</sub> reduced in those with X-ray changes.
Weiss and Theodos	1978	98 workers age 40 or over in two plants	Chrysotile and Amosite	Cross-sectional, no external controls	Prevalence of profusion (1/1) 17.5% in chrysotile workers and 16.5% in mixed fiber workers. Pleural thickening prevalence 17.5% in chrysotile workers and 35.4% in mixed fiber workers. Smoking found to be significant factor in those exposed to amosite.

Author(s)	Date	Study Population	Fiber Type	Study Design	Summary of Important Findings
Selikoff et al.	1977	485 miners and millers	Chrysotile	Cross-sectional, no external controls	10% prevalence of all radiographic abnormalities. Pleural changes seen in 3% of all workers. Prevalence of abnormalities among those employed less than 5 years was 5% with 3% being parenchyma changes (profusion $\geq 1/0$ ).
Jones et al.	1979	204 asbestos cement workers	Mixed	Prospective follow-up 1970-1976	Progression of small opacities dependent upon both average and cumulative exposure. Lung function declines were associated with smoking and cumulative exposure. Pleural abnormalities progressed more as a function of time with little association with additional exposure.
Anderson.	1979	Household contacts of factory workers	Amosite	Cross-sectional, age, sex matched controls	35.9% prevalence of X-ray abnormalities compared to a 4.6% prevalence among control group. Pleural abnormalities more prevalent than parenchymal changes.
Gamble, Fellner, and DiMeo	1979	121 talc miners and millers	Anthophyllite and Tremolite	Cross-sectional, external comparison populations	Talc workers with greater than 15 years employment had increased prevalence of pleural abnormalities compared to comparison populations, FEV <sub>1</sub> and FVC reduced in association with dust and fiber exposures.
Irwig et al.	1979	1,801 miners and millers with chest films	Crocidolite and Amosite	Cross-sectional, no external controls	Prevalence of pleural changes increased from 2.5% for workers with less than 1 year employment to 33.6% for workers with 15 or more years. Parenchymal changes ( $>1/0$ ILO) found in 2.3% of workers less than 1 year employed and 26.7% in workers employed more than 15

Continued

46

Author(s)	Date	Study Population	Fiber Type	Study Design	Summary of Important Findings
Gregor et al.	1979	119 asbestos workers referred to Pneumoconiosis Medical Panel	Mixed	Prospective follow-up	One-third of workers showed progression after 6 years follow-up and no further asbestos exposure. Progression frequency higher among those with profusion >1/1 or 1/2 (ILO) 8.1% with minimal or no pulmonary fibrosis and deceased during follow-up died of pleural mesothelioma.
Rubino et al.	1979	56 retired chrysotile miners and millers and surviving >3 years	Chrysotile	Prospective follow-up	39% of persons with abnormal films (profusion >1/0 ILO) showed progression after an average follow-up of 8 years. 7.9% of workers with normal initial films developed radiographic changes.
Murphy et al.	1971, 1978	101 shipyard pipe coverers and 95 controls	Mixed	Cross-sectional with further follow-up, matched controls	Prevalence ratio of asbestosis 11 times greater than controls. Asbestosis evident after cumulative exposures of 60 MPPCF-years.