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A Survey of Asbestos-related Disease in Trades and Mining Occupations and in Factory and Mining Communities as a Means of Predicting Health Risks of Non-Occupational Exposure to Fibrous Minerals*

by

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ABSTRACT: A review which is based on thirty six published epidemiological studies is given of the disease patterns that have developed among industrial workers, miners, and millers who were exposed to dusts of one or more of the commercial asbestos minerals or to dusts from minerals perceived to be asbestos-like. Health data is also reviewed for those who were exposed to asbestos dusts in a non-occupational setting. From the published reports it is clear that there are very significant differences in the health effects of the several asbestos or asbestos-like minerals.

Of the commercial asbestos utilized in the United States about 95% has been chrysotile or "white" asbestos, about 2% amosite or "brown" asbestos, and about 2% crocidolite or "blue" asbestos. The common white asbestos has had the least effect on those occupationally exposed whereas blue asbestos has had the most effect. Despite the wide dissemination of white asbestos in our environment; in schools, homes, public buildings, brake lining emissions, etc., there is no evidence that the very frequent non-occupational exposures to this form of asbestos has caused any harm. On the other hand, nonoccupational exposure to blue asbestos has been conclusively proven to have caused significant mortality. The different health effects of the various forms of asbestos require different regulatory responses and remedial actions.

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INTRODUCTION

The Problem

The widespread use of amphibole and serpentine asbestos[1] by industrial society for such items as service in brake and clutch facings, electrical and heat insulation, fireproofing materials, cement water pipe, tiles, filters, packings, and construction materials, has contributed greatly to human safety and convenience. Yet, while our society was accruing these very tangible benefits, many asbestos workers were dying of asbestosis, lung cancer, and mesothelioma.

The hazards of certain forms of asbestos under certain conditions have been so great that several countries have taken extraordinary actions to greatly reduce or even ban their use. Recent experiments with animals demonstrate that the commercial asbestos minerals as well as other fibrous materials can cause tumors to form when the fibrous particles are implanted within the pleura. These experiments have convinced some health specialists that asbestos-related diseases can be caused by many types of elongate particles; the mineral type according to these health specialists, is not the important factor in the etiology of disease, but rather the size and shape of the particles which enter the human body.

The question now before the World's health and regulatory establishments is whether the hazards of asbestos outweigh the benefits. Should the asbestos minerals and perhaps other asbestos-like minerals be banned from use? Minerals belonging to the amphibole group are particularly important in this regard for they are ubiquitous and commonly have crystalline habits which are considered by some to be asbestos-like.

The Dilemma

The concern for human health, the great usefulness of many asbestos products, the appearance of asbestos minerals or asbestos-like minerals in the natural background and in many kinds of mining operations, and the uncertainty of the exact health effects of different kinds of minerals, different mineral particle sizes, and different mineral dust concentrations combine to present a formidable problem to minerals scientists, the

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1/At present, the most widely used definition of asbestos in the United States, is from the notice of proposed rule-making for "Occupational Exposure to Asbestos" published in the Federal Register (Oct. 9, 1975, p. 4765[illegible], 47660) by the U.S. Occupational Safety and Health Administration (OSHA). In this notice, the naturally occurring amphibole minerals amosite, crocidolite, anthophyllite, tremolite, and actinolite and the serpentine mineral chrysotile are classified as asbestos if the individual crystallites or crystal fragments have the following dimensions: length greater than 5 micrometers, maximum diameter less than 5 micrometers, and a length-to-diameter ratio of 3 or greater. Any product containing any of these minerals in this size range is also defined as asbestos.

minerals industries, and legal and health professionals. Must the use of all commercial asbestos be stopped? Must all mine dusts containing such particles be controlled to the lowest feasible levels and wastes from those mines be considered toxic and thus isolated from surrounding air and water? Must all asbestos be eliminated from our drinking water, our schools, and our public buildings? Must we cease to use asbestos in brake linings, cement water pipe, and structural building materials? Must even low levels of non-occupational exposure to asbestos or asbestos-like materials be avoided at any cost?

In order to obtain an insight that will enable us to intelligently address these questions I will review the role of asbestos in the world economy, the important geological occurrences of commercial asbestos, give estimates of asbestos-related mortality in the United States in the recent past, and document the incidence of asbestos-related disease in the trades occupations, the mining and milling occupations, and in those non-occupationally exposed to asbestos or asbestos-like minerals. As we will see, the six asbestos minerals used in commerce are not identical in their crystal structure, chemical composition, abundance, and geologic occurrence; nor do the different asbestos dusts have the same impact on human health. Instead of treating all asbestos minerals as equally potent carcinogens (apparently the prevailing opinion in the United States) each mineral should be examined on its own merits and demerits with regard to its usefulness to society and its potential to cause disease.

ASBESTOS IN THE WORLD ECONOMY

Early Beginnings

Whereas the general use of asbestos in international commerce dates only to the late 19th century, its utility in human culture goes back to at least 2500 B.C. Archeological studies (Europaeus-Äyräpää, 1930) show that the inhabitants of the Lake Juojarvi region of East Finland knew how to strengthen earthenware pots and cooking utensils with anthophyllite asbestos. This asbestos probably came from the same areas where it has been commercially exploited in recent times. Until recently, however, most other uses of asbestos were trivial; such as its fabrication into such curiosities as cremation cloth, tablecloths, lamp wicks, and purses. Even well into the last century, asbestos could not be regarded as a product of commerce unless one included such endeavors as the small industry developed in Russia during the rule of Peter the Great where chrysotile asbestos from the Urals was used for a short period of time in the production of textiles.

In the 1860's and 1870's, the market for asbestos products rapidly changed - probably for three reasons; the need for insulation for the new steam technology, the formation of an international trading company of Italian and English entrepreneurs, and the reopening of the chrysotile asbestos deposits of northern Italy and simultaneous exploitation of the vast chrysotile resources in Quebec. The supply for the first time was ample, the market was ready.

The Modern Industry

The reopening of the asbestos deposits of northern Italy, deposits which had been worked as far back as Roman times, marked the beginning of the modern asbestos industry. By 1890, the asbestos industry was full blown, with hundreds of applications being introduced (Jones, 1890); by the turn of the century the large South African crocidolite deposits had been opened up and the Russian deposits in the Urals were once again producing in large quantity. Within a few years, the amosite deposits of the Transvaal would be exploited.

From the time of the first recorded use of asbestos by Stone Age man to 1900 the total world production of all types of fiber was probably about 200,000 metric tonnes, certainly no more than 300,000 tonnes. Of this 150,000 tonnes came from Quebec. By 1980 more than 100 million tonnes of asbestos had been mined throughout the World; of this more than 90 percent was chrysotile and more than 5 percent crocidolite and amosite. Nearly 40 million tonnes of this total World production was chrysotile mined in Quebec Province near the towns of Thetford Mines and Asbestos. Total production of anthophyllite asbestos to date is probably no more than 400,000 tonnes; 350,000 tonnes being produced by Finland alone. Production of tremolite asbestos has been sporadic and it has been mined in various parts of the World for short periods of time. Total production to date for this form of asbestos is probably no more than a few thousand tonnes. Commercial exploitation of actinolite asbestos is practically unknown.

The World asbestos production for 1978 is given in Table 1. Russia leads with 46.1 percent and Canada is second with 28.9 percent of the world output. Both countries mine only chrysotile asbestos and most of the fiber comes from the Urals and Quebec. The third leading asbestos producer is the Republic of South Africa (7.1 percent); the asbestos ore consists of amosite, crocidolite, and chrysotile. These three countries furnished 82.1 percent of the World's asbestos in 1978. The other countries listed in Table 1 produce mostly chrysotile.

COMMERCIAL ASBESTOS

The Asbestos Minerals

Standard references published over the past 50 years usually list six forms of commercial asbestos; the amphibole varieties are amosite, crocidolite, anthophyllite, tremolite, and actinolite, the serpentine variety is chrysotile. A detailed understanding of the chemistry and crystal structures of these asbestos minerals postdate their discoveries; thus some of the older literature can be confusing with regard to mineral identifications.

Chrysotile, $Mg_3Si_2O_5(OH)_4$, one of the three common polymorphs of serpentine is generally fibrous although non-fibrous varieties are known. About 90 percent of the past and about 95 percent of the present World production of asbestos was or is the chrysotile form.

Amosite is the very rare asbestiform variety of grunerite amphibole, $(Fe,Mg)_7Si_8O_{22}(OH)_2$; this varietal name is derived from the word Amosa - an acronym for the company "Asbestos Mines of South Africa" (Hall, 1918, p. 13-14). This valuable commercial asbestos is mined only in the Transvaal Province of South Africa.

Crocidolite is the asbestiform variety of riebeckite amphibole, ideally $Na_2(Fe^{2+},Mg)_3Fe^{3+}_2Si_8O_{22}(OH)_2$, and has been mined in only four localities; in the Transvaal and Cape Provinces of South Africa, in the Hammersley Range area of Western Australia, and in the Cochabamba area of Bolivia. Only the South African mines are still active.

The only other form of amphibole asbestos that has been mined commercially on a significant scale is anthophyllite, $(Mg,Fe)_7Si_8O_{22}(OH)_2$, from the Paakkila area of East Finland. With the Finnish mines now closed there is now very little anthophyllite asbestos production anywhere in the World.

There are numerous reports of minor occurrences of tremolite asbestos, $Ca_2Mg_5Si_8O_{22}(OH)_2$, and relatively few reports of occurrences of actinolite asbestos, $Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$. Tremolite and actinolite asbestos are now, as they have been in the past, of little economic importance.

The Important Geological Occurrences of Commercial Asbestos

Many minerals, including the amphiboles and some serpentines, are described variously as fibrous, asbestiform, acicular, filiform, prismatic; these terms suggest an elongate habit. Although such minerals are extremely

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Table 1. World asbestos production in 1978 (Clifton, 1979)

Fiber Locality	Production (in thousands of metric tonnes)
Chrysotile	
North America	
Canada	1620
United States	93
South America	
Argentina	1
Brazil	100
Europe	
Bulgaria	21
Italy	162
U.S.S.R.	2582
Yugoslavia	10
Africa	
Zimbabwe	210
South Africa	118
Swaziland	48
other	1
Asia	
China	210
Cyprus	37
India	21
Japan	7
Korea	7
Taiwan	1
Turkey	10
Oceania	
Australia	58
(World chrysotile total)	5317
Crocidolite	
South Africa	210
Amosite	
South Africa	71

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common, in only relatively few places do they have physical and chemical properties suitable to be valuable as commercial asbestos. Locally, amphibole minerals may show an asbestiform habit, for example in vein fillings and in areas of secondary alteration, but usually they do not appear in sufficient quantity to be profitably exploited.

Deposits of commercial asbestos are found in four types of rocks: (I) - alpine-type ultramafic rocks including ophiolites (chrysotile, anthophyllite, and tremolite), (II) - stratiform ultramafic intrusions (chrysotile and tremolite), (III) - serpentinized limestone (chrysotile), and (IV) - banded ironstones (amosite and crocidolite). Type I deposits are by far the most important and probably account for more than 85 percent of the asbestos ever mined. The most important Type I deposits are those of Quebec and the Urals.

Type II deposits are found mostly in South Africa, Swaziland and Zimbabwe. These furnish mostly chrysotile asbestos. Type III deposits are small; the most notable of these are located in Globe, Arizona and in the Carolina area of the Transvaal Province of South Africa. Type IV deposits are found only in the Precambrian banded ironstones of the Transvaal and Cape Provinces of South Africa and of Western Australia. Only the South African deposits are still in production. A complete review of the geological occurrences of commercial asbestos is given by Ross (1981).

HEALTH HAZARDS OF ASBESTOS

Diseases Related to Asbestos Exposure

Three principal diseases are related to exposure to one or more of the commercial asbestos minerals. These are: (1) lung cancer which includes cancer of the trachea, bronchus, and lung proper; (2) mesothelioma, a cancer of the pleural and peritoneal membranes which invest the lung and abdominal cavities, respectively; and (3) asbestosis, a diffuse interstitial fibrosis of the lung tissue often leading after long exposure to severe loss of lung function and respiratory failure. The occurrence of lung cancer in asbestos workers is also complicated by the association with cigarette smoking which leads to considerable difficulty in assigning relative risks of asbestos exposure to smokers. Mesothelioma, a disease which is usually fatal in one to two years after diagnosis, is rare, accounting for less than 300 deaths per year in the United States and Canada.

Some epidemiological studies suggest that asbestos workers may suffer excess cancer of the digestive tract (Selikoff and Lee, 1978); other studies do not support this conclusion (McDonald and McDonald, 1980; Meurman et al., 1974; Rubino et al., 1979; Nicholson et al., 1979). Some question still exists then as to the role played by asbestos in the etiology of digestive tract cancers. Becklake (1976), Selikoff and Lee (1978), and Simpson (1979) give a complete review of the subject of asbestos and disease.

Particle size and shape appear to be the factors controlling whether mineral particles enter and remain in the lung or are removed from the lung after entering. Particles such as asbestos fibers which have diameters greater than approximately 5 µm cannot enter the bronchial airways, those having smaller diameters do. Particles having diameters less than 1.5 µm are particularly dangerous for they can penetrate to the smaller bronchioles and even to the alveolar sacs (Davis, 1981). Most particles which enter the upper respiratory tract (the mainstem, bronchi, and bronchioles) are quickly and effectively removed by the mucocilliary escalator. A second lung clearance mechanism operates in the lower respiratory tract (the respiratory bronchioles and alveoli). Here, pulmonary macrophages engulf the foreign particles (phagocytosis) and then: (1) move to the upper respiratory tract to where the mucociliary escalator is operative or (2) move through the alveolar wall into the interstitium and eventually to the lymph channels.

Asbestos fibers which are longer than approximately 10 µm are not readily phagocytized by the macrophage cells and thus tend to remain in the lower respiratory tract or they may penetrate the pleural membrane and enter the interpleural space. Asbestosis may occur when such fibers remain in the lung parenchyma for lengthy periods of time. The asbestos fibers can stimulate deposition of excess interstial collagen and reticulin fibers. This causes the alveolar septa to become thickened with ensuing impairment of oxygen uptake (Davis, 1981). Long-term residency of fibers in the lung and pleura may also induce lung cancer and mesothelioma; the mechanisms by which this takes place are far from being understood.

As will be described later, pleural cancer seems to be induced by crocidolite asbestos but not by chrysotile or anthophyllite asbestos. Lung cancer is caused by chrysotile, anthyophyllite, amosite, and crocidolite asbestos; particularly in asbestos workers who smoke cigarettes. Two completely different substances, asbestos and cigarette smoke, combine to produce a very significant risk to those who have been heavily exposed to asbestos dusts.

Generally, asbestos-related diseases appear in asbestos workers only after many years have elapsed since first exposure. A significant increase in the lung cancer death rate appears 10 to 14 years after first exposure and peaks at 30 to 35 years. The mesothelioma death rate becomes significant 20 years after first exposure but continues to climb even after 45 years have elapsed. The asbestosis death rate becomes significant 15 to 20 years after first exposure and apparently peaks at 40 to 45 years (Selikoff et al., 1980a).

Epidemiology

Before considering the mortality studies of the various occupational groups exposed to asbestos, we should briefly consider the role the three important types of asbestos (amosite, crocidolite, and chrysotile) played in the commerce of North America and Europe, the areas where the major epidemiological studies of asbestos workers were made.

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In North America, chrysotile entered the market in large quantities early in this century. Crocidolite was apparently first used in the United States in 1912 when 9 tonnes were imported, but it was not until World War I that its use for high temperature insulation became established - particularly in the ship building industry. By 1930, 35,000 tonnes of crude crocidolite fiber had been imported into the United States. Import statistics for crude crocidolite asbestos from South Africa into the United States are given in Tables 2a and 2b. Large amounts of manufactured goods containing crocidolite were also imported but tonnage estimates cannot be made. Not until the mid 1930's did amosite asbestos gain a market in North America when it began to replace crocidolite for high temperature insulation. Crocidolite was milled in Bound Brook, New Jersey in 1920 and in 1924 the operation moved to larger facilities in Millington, New Jersey. The many advertisements in the trade journal Asbestos from 1920 to 1945 indicate that crocidolite was used in many products and particularly for insulation of steam boilers, locomotives, and pipes. As an example, a product containing crocidolite asbestos and called "85% Magnesian Sectional Pipe Covering" was advertised monthly in Asbestos from 1920 to 1945 (see also, McCullagh, 1980). Amosite, crocidolite, and chrysotile were almost universally used aboard ship during World War II; amosite for high temperature boilers and pipes, crocidolite for packings exposed to acids or salt water, and chrysotile for low temperature and electric insulation.

The use of asbestos in Europe paralleled that in North America, with one notable exception - the extensive use of crocidolite asbestos as a sprayed-on coating to fireproof ships,[1/] railroad cars, buildings, etc. Sprayed-on coatings were also used in the United States after World War II but the coatings contained, with few exceptions, chrysotile rather than crocidolite. Sprayed-on asbestos coatings were not used on U.S. ships; the principal use being to fireproof steel building girders and as acoustical coatings in schools and offices.

Asbestos trades workers. A very significant increased incidence relative to the general male population, of lung cancer, asbestosis and mesothelioma is found in men who were employed in the "asbestos trades" - insulation of steam locomotives, boilers, ships, buildings; fabrication and installation of asbestos-containing textiles, roofing materials, cement products, tiles, wallboards, brake linings, clutch facings, filters, packings, gaskets, etc. Those in the "trades" generally used several types of asbestos minerals during their working careers; most commonly these were chrysotile, crocidolite and amosite, rarely anthophyllite. Significant exposures by any group of workers, at least for the past 40 years, to tremolite or actinolite asbestos dusts has probably not occurred.

[1/]Mesothelioma is prevalent in the shipyard workers of Europe; at Walcheren, Wilhelmshaven, Plymouth, Trieste, Hamburg, Nantes, Rotterdam, Malmö (McDonald and McDonald, 1977). The extensive use of crocidolite aboard European ships prior to and during World War II is suggested to be an important factor in the etiology of this disease.

Table 2a. Minimum estimates of imports of crude crocidolite asbestos from South Africa into the United States (1907-1929),* (1940-1945)**, (1946-1974).***

Year(s)	Crocidolite crude (short tons)
1907-1908	probably none
1909-1910	no data
1911	little
1912	9
1913	1
1914	no data
1915	probably none
1916	1184
1917	2081
1918	837
1919	1056
1920	2979
1921	704
1922	1684
1923	2040
1924	1457
1925	606
1926	4873
1927	5587
1928	?
1929	9952
Total (1907-1929)	35,050 short tons
1940	2708
1941	2976
1942	4213
1943	4808
1944	2946
1945	3100
Total (1940-1945)	20,751 short tons
1946-1974	346,796 short tons

*Some of the imports were shipped through England. Small amounts of chrysotile may be included in import figures but no amosite. Figures do not include any manufactured asbestos products. Most crocidolite came from the South Cape Prov., some may have come from the Transvaal. Source: Mineral Resources of the United States (1907)...(1929) U.S. Geological Survey, Washington, D.C.

**Crocidolite composed 19.4% of the South African crude asbestos imports into the U.S. during this period - which totaled 107,039 short tons, over 80,000 tons was amosite asbestos. Sources: Minerals Yearbook (1940)...(1945), U.S. Bureau of Mines, Washington, D.C. Mineral Trade Notes, Confidential Series, No. 1-31, U.S. Bureau of Mines, U.S. Dept. Interior, Washington, D.C. (1940-1945).

***Minerals Yearbook (1946)....(1974) U.S. Bureau of Mines, Washington, D.C.

Table 2b. Imports of all crude asbestos from South Africa (1930-1939)*

Year(s)	Asbestos Crude (short tons)
1930	3635
1931	2290
1932-33	1370
1934	4269
1935	2529
1936	?
1937	3025
1938	4248
1939	6422
Total	27,788 short tons**

*Import statistics do not differentiate between various forms of asbestos. Little chrysotile was imported from South Africa thus the figures are for mostly amosite plus crocidolite. Import data for crocidolite during World War II suggests that at least 20% of the 1930-39 imports were crocidolite. The amosite market was just developing in the U.S. in the 1930's. Most of the crocidolite was from the Cape Province.

**Assuming a ratio of 4:1 of amosite: crocidolite based on WWII import figures, at least 5558 short tons of crocidolite was imported into the U.S. from 1930 to 1939.
Sources: Mineral Resources of the United States (1930)(1931). U.S. Geological Survey, Washington, D.C. Minerals Yearbook (1932)... (1939). U.S. Bureau of Mines, Washington, D.C.

Statistical data for 21 mortality studies of defined cohorts of asbestos trades workers (mostly male) are presented in Tables 3a and 3b. Of those that are continuing prospective studies, the most recent update is given. Twelve of the studies are of asbestos factory workers, eight are of asbestos insulation workers, and one is of asbestos construction workers. In all, 50,143 individuals were followed (1,517 were female); of the 7,166 listed deaths 1,198 (16.7 percent) were reported as due to lung cancer and 402 (5.61 percent) were reported as due to mesothelioma. In the 21 studies, the lung cancer mortality accounted for 6.1 to 26.6 percent of all deaths; mesothelioma mortality accounted for 0 to 16.1 percent of all deaths (Tables 3a, 3b, Fig. 1). The workers involved in study No. VI worked only with chrysotile, those involved in Studies X and XXI worked mostly with crocidolite, and those in the remaining studies probably worked with more than one form of asbestos.

Estimates of expected cancer mortality are very difficult to predict, for cancer rates are modified by the individual's "lifestyle" as well as by occupation. The "lifestyle" contribution to lung cancer is cigarette use. To better assess the significance of these health studies it is necessary to examine the cancer-mortality patterns of cigarette smokers who were not exposed to asbestos dusts. Unless prevalence of smoking within the study group is carefully evaluated it is impossible to predict accurately the health effects of occupational exposure to carcinogens such as asbestos, radon gas, and arsenic. Unfortunately, in few of the studies listed in Tables 3a and 3b have adequate assessments been made of the proportion of workers who smoke cigarettes.

The contribution of cigarette smoking to the increased incidence of disease has been evaluated in several studies and has lead to a consensus that this habit produces a very significant increase in risk of dying of lung cancer as well as of the various cardiovascular diseases. The largest study of cigarette smokers is that of E. Cuyler Hammond and colleagues under the auspices of the American Cancer Society. This study is based on questionnaires and mortality follow-up accomplished in the United States between July 1960 and June 1971 for approximately 51,000 men (Hammond et al., 1978). The proportional mortality of lung cancer (percent lung cancer deaths relative to deaths by all causes), based on the Hammond study, is shown graphically in Figure 2. For a group of men who all smoke cigarettes (cohort of 100 percent smokers), lung cancer mortality is approximately 7 percent at age 45, reaches a maximum of approximately 10 percent at age 70, then decreases slightly at older ages. For a cohort of male non-smokers, lung cancer mortality is 2 percent at age 45 and then decreases continuously to approximately 1 percent at age 95.

Smoking is most prevalent in blue-collar occupations relative to professional and managerial occupations (Sterling and Weinkam, 1978). This prevalence also holds true for the asbestos trades, mining, and milling occupations. In a group of 13,722 asbestos insulation workers, whose smoking habits were recorded, 70 percent had a history of cigarette smoking (Selikoff and Hammond, 1975; Saracci, 1977). In a group of 1,015 chrysotile asbestos miners and millers 85 percent were smokers (McDonald et al., 1974). Data given in Figure 2 predicts that the lung cancer mortality for a cohort

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Table 7. Cohort mortality studies of asbestos [illegible] workers, [illegible] mining miners and millers (see Table 4). Most recent update of prospective studies I-XI are given (1964-1982).

Study		I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Cause of death[1]	number of deaths	[illegible] et al., 1982	Kleinfeld et al., 1967	Mancuso and El-Attar, 1967	Selikoff et al., 1979[4]	Elmes and Simpson, 1977	Weiss, 1977	Peto et al., 1977	Peto et al., 1977 Peto, 1980 [5]	Nicholson et al., 1979	McDonald & McDonald, 1980	Henderson & Enterline, 1979
All causes (000-999)	Obs.(Exp.)	351 (343)	65	301	646(316.20)	122(54)	66(108.76)	210(191.31)	186(167.67)	270(188.19)	56	781(648.67)
	Obs./Exp.	1.02			2.41	2.26	0.61	1.10	1.11	1.46		1.20
Cancer-all sites (140-239) or (140-209)	Obs.(Exp.)	74 (80.2)	23	96	172(56.36)	66	13(17.41)	59(51.32)	60(42.77)	90(30.93)	23	173(108.80)
	Obs./Exp.	0.92			3.05		0.75	1.15	1.17	2.40		1.59
	% all deaths	21.1	50.0	30.6	30.4	54.1	19.7	28.1	18.6	36.1		22.2
Cancer-lung, trachea, bronchus (162)	Obs.(Exp.)	28 (33.0)	10(1.42)	41	79(17.47)	35	4(4.32)	30(10.30)	29(18.30)	35(12.53)	8	64(23.30)
	Obs./Exp.	0.85	7.0		4.52		0.93	1.68	1.50	2.79		2.62
	% all deaths	8.0	21.7	11.3	17.7	28.7	6.06	14.8	15.6	12.6	10.3	7.80
Mesothelioma-peritoneum, pleura (158,163)	Obs.(Exp.)[2]	2 (<1.06)	3	9	23	13	0	5	4	26	9	2
	% all deaths	0.6	6.52	2.49	5.17	10.7	0	2.38	2.15	9.40	16.1	0.26
Cancer-digestive system (150-159)	Obs.(Exp.)			20								55(30.90)
	Obs./Exp.											1.30
	% all deaths			5.54								7.04
Cancer-G.I. tract (150-154)	Obs.(Exp.)	18 (19.6)	5(1.79)		24(10.57)	13	4(3.82)			15(7.99)	3	
	Obs./Exp.	0.92	2.79		2.27		1.04			1.88		
	% all deaths	5.1	10.9		5.38	10.7	6.06			5.47	5.36	
Respiratory disease (460-519)	Obs.(Exp.)					30		35(25.02)	31(23.22)	42(12.16)		66(38.38)
	Obs./Exp.							1.40	1.36	3.46		1.72
	% all deaths					[illegible]		[illegible]	16.7	16.3		8.71
Non-infectious respiratory disease (516-519)	Obs.(Exp.)										4	
	Obs./Exp.											
	% all deaths										7.14	
Asbestosis (515.2)	Obs.(Exp.)[3]	0	2	39	26	19	2			35	2	19
	% all deaths	0	4.35	10.8	5.83	15.6	3.03			12.0	3.57	2.43
Pulmonary tuberculosis (010-011)	Obs.			11		3					3	
	% all deaths			3.05		2.46					5.36	
Number in cohort		1600	152	1493	7380	162	264	963	679	600	176	1075
Number of males (females)		No females	152(0)	1265(228)	7380(0)	162(0)	264(0)	679(284)	679(0)	not reported	93(83)	1075(0)
% dead		-	30.3	24.2	6.12	75.3	24.2	21.8	27.4	39.8	30.0	72.7
Site		Asbestos works Cardiff, Wales	Insulators, New York State	Asbestos Co., U.S.A.	Insulators, US Midwest, Central U.S.A	Insulators, Belfast, N. Ireland	Asbestos factory	Asbestos textile factory, UK	Asbestos textile factory, UK	Asbestos products factory, USA	Assemblers, gas mask with asbestos filter pads	Asbestos company, U.S.A.
Observation period		1936-1977	1945-1965	1940-1964	1967-1971	1940-1975	1945-1974	1933-1974	1933-1974	1959-1975	1940-1975	1941-1973
Years exposed		>0.5	>15	varies	not reported	varies	>1	>10	>10	varies	1-2	3-53
Years since first exposure		>15	>15	varies	not reported	varies	varies	>10	>10	varies	varies	varies
Controls		Death rates, SE Wales	U.S. National Rates, 1960	Internal, <2 yrs.	U.S. National death rates	Male rates, N. Ireland	U.S. National death rates	National death rates, UK	National death rates, UK	Not reported	Not reported	U.S. National Rates
Smoking data		[illegible]	Minimal	Not reported	Not reported	5 non-smokers	Not reported	Not reported	Not reported	Not reported	Not reported	Not reported
Exposure data		some	Not reported	Not reported	Not reported	Not reported	<2f./cm³ since 1972	yes(1952-1974)	3 to 15 f./cm³ (1930-72)	Not reported	Light exposure	yes
Asbestos type		Chrysotile [illegible], crocidolite + [illegible]	Not reported	Not reported	chrysotile, amosite	Not reported	chrysotile only	chrysotile, crocidolite	chrysotile, some crocidolite	Not reported	Mostly crocidolite, some chrysotile	chrysotile, amosite, crocidolite

[1]International Classification of Diseases, [illegible] revision (ICD-8)
[2]Within the United States mesothelioma mortality unrelated to asbestos exposure accounted for approximately one death in 10,000 in 1972 (estimated from data given by McDonald and McDonald, 1980)
[3]Asbestosis is rarely caused by mineral dusts other than commercial asbestos
[4]Sub-cohort of cohort XVII (Table 3b)
[5]Sub-cohort of cohort VII

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Table 5b. Cohort mortality studies of asbestos trades workers; excluding miners and millers (see Table 4). Most recent update of prospective studies (I-XXI) are given (1979-1981).

Study		XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI
Cause of death[1]	number of deaths	Puntoni et al., 1979	Newhouse and Berry, 1979	Weill et al., 1979	Selikoff et al., 1979a[4]	Selikoff et al., 1979a[4]	Selikoff et al., 1979a	Selikoff et al., 1979b[4]	Selikoff et al., 1980	Clemmensen and Hjalgrim-Jensen, 1981	Hilt et al., 1981
All causes (000-999)	Obs.(Exp.)	14(11.42)	705(560.0)	601(000.1)	470(320.9)	62(64.0)	2271(1650.9)	79(75.2)	300(150.4)	Not given	13
	Obs./Exp.	1.4?	1.36	0.60	1.05	0.96	1.37	1.05	1.99		[illegible]
Cancer-all sites (140-239) or (140-209)	Obs.(Exp.)	6(1.14)	305(130.01)	120(156.6)	210(57.0)	20(10.1)	995(319.7)	39(16.2)	116(33.4)	167(151.13)	7
	Obs./Exp.	1.00	2.35	0.77	3.60	1.90	3.11	2.40	3.47	1.11	
	% all deaths	37.4	43.6	20.0	43.9	32.3	43.8	49.4	38.2		53.8
Cancer-lung, trachea, bronchus (162)	Obs.(Exp.)	5(0.96)	130(46.01)	51(40.2)	93(13.3)	13(2.9)	486(105.6)	21(5.7)	60(10.1)	44(27.11)[5]	3(0.21)
	Obs./Exp.	5.12	2.80	1.00	6.99	3.45	4.60	3.60	5.96	1.61	14.29
	% all deaths	26.1	17.6	8.00	19.5	14.1	21.4	26.6	19.7		23.1
Mesothelioma peritoneum, pleura (158,163)	Obs.(Exp.)[2]	None reported	67	0	38	3	175	8	14	3	2
	% all deaths		8.99	0	7.95	4.44	7.71	10.1	4.61		15.4
Cancer-digestive system (150-159)	Obs.(Exp.)		60(44.2)	25(50.1)							
	Obs./Exp.		1.36	0.50							
	% all deaths		8.95	4.16							
Cancer-G.I. tract (150-154)	Obs.(Exp.)				43(15.1)	3(1.5)	99(59.4)	3(3.1)	16(8.0)	31(20.07)	1
	Obs./Exp.				2.85	2.00	1.67	0.97	2.00	1.04	
	% all deaths				9.00	4.00	4.36	3.80	5.26		7.6
Respiratory disease (460-519)	Obs.(Exp.)	10(1.70)	102(78.0)								
	Obs./Exp.	0.05	1.31								
	% all deaths	52.4	13.7								
Non-infectious respiratory disease (510-519)	Obs.(Exp.)				45(9.3)	7(1.1)	212(59.0)	14(3.7)	24(4.7)		
	Obs./Exp.				4.84	6.36	3.59	4.30	5.11		
	% all deaths				9.41	11.3	9.34	17.7	7.00		
Asbestosis (515.2)	Obs.(Exp.)[3]				44	6	168	13	18		
	% all deaths				9.30	9.00	7.40	16.4	5.92		
Number in cohort		4?	5?22	5645	632	813	17,800	440	582	5686	?
Number of males (females)		[illegible]	4600(922)	5645(0)	632(0)	813(0)	17,800(0)	440(0)	582(0)	5686(0)	70(0)
% dead		44.?	13.5	10.6	..	7.44	12.8	18.0	52.2	-	65.?
Site		Insulators, shipyards, Genoa, Italy	Asbestos textile factory, E. London	Asbestos cement company, New Orleans, LA	NY-NJ insulation workers	NY-NJ insulation workers	No. American asbestos workers	Insulators, US shipyards	Amosite textile factory, NJ	Asbestos cement factory, Denmark	Construction, 1920-1930, Norway
Observation period		1961-1975	1933-1975	to 1974	1943-1976 first employed (1943)	1943-1976 first employed>1943	1967-1976	1967-1976	1961-1977	1943-1976	1953-1980
Years exposed		varies	>10	varies	varies	varies	varies	varies	varies	varies	
Years since first exposure		varies	>10	>20	most >20	>20	varies	varies	>20	varies	varies
Controls		male rates, Genoa	not given	death rates, US, Louisiana, matched controls	US death rates	US death rates	US death rates	US death rates	Death rates, NJ, smoking adj.	Death rates, Danish provincial towns	Death rates, Norway
Smoking data		Not reported	yes	None	Not reported	Not reported	Not reported	Not reported	yes	yes	?
Exposure data		Not reported	yes	<10 to >200 mppcf-yr.	Not reported	Not reported	Not reported	Not reported	heavy	yes	heavy
Asbestos type		Not reported	Crocidolite, amosite, chrysotile	Chrysotile, amosite, crocidolite	Not reported	Not reported	Not reported	Not reported	Amosite, some chrysotile	Chrysotile, amosite, some crocidolite	Crocidolite only

[1]/International Classification of Diseases, 8th Revision (ICD.8)
[2]/Within the United States mesothelioma mortality unrelated to asbestos exposure accounted for approximately one death in 10,000 in 1972 (estimated from data given by McDonald and McDonald, 1980)
[3]/Asbestosis is rarely caused by mineral dusts other than commercial asbestos
[4]/Sub-cohort of cohort XVII
[5]/Excludes trachea

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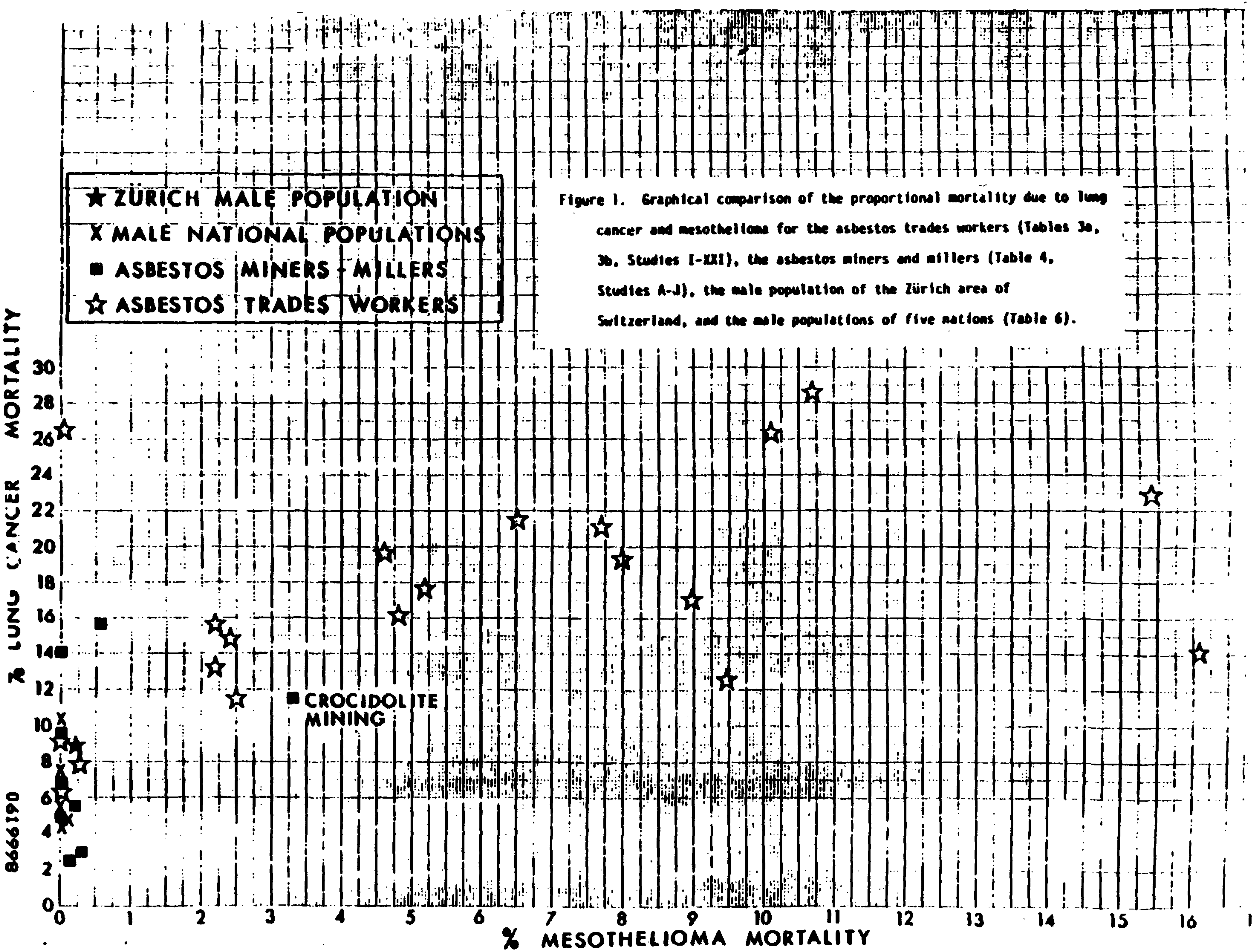

Figure 1. Graphical comparison of the proportional mortality due to lung cancer and mesothelioma for the asbestos trades workers (Tables 3a, 3b, Studies I-XXI), the asbestos miners and millers (Table 4, Studies A-J), the male population of the Zürich area of Switzerland, and the male populations of five nations (Table 6).

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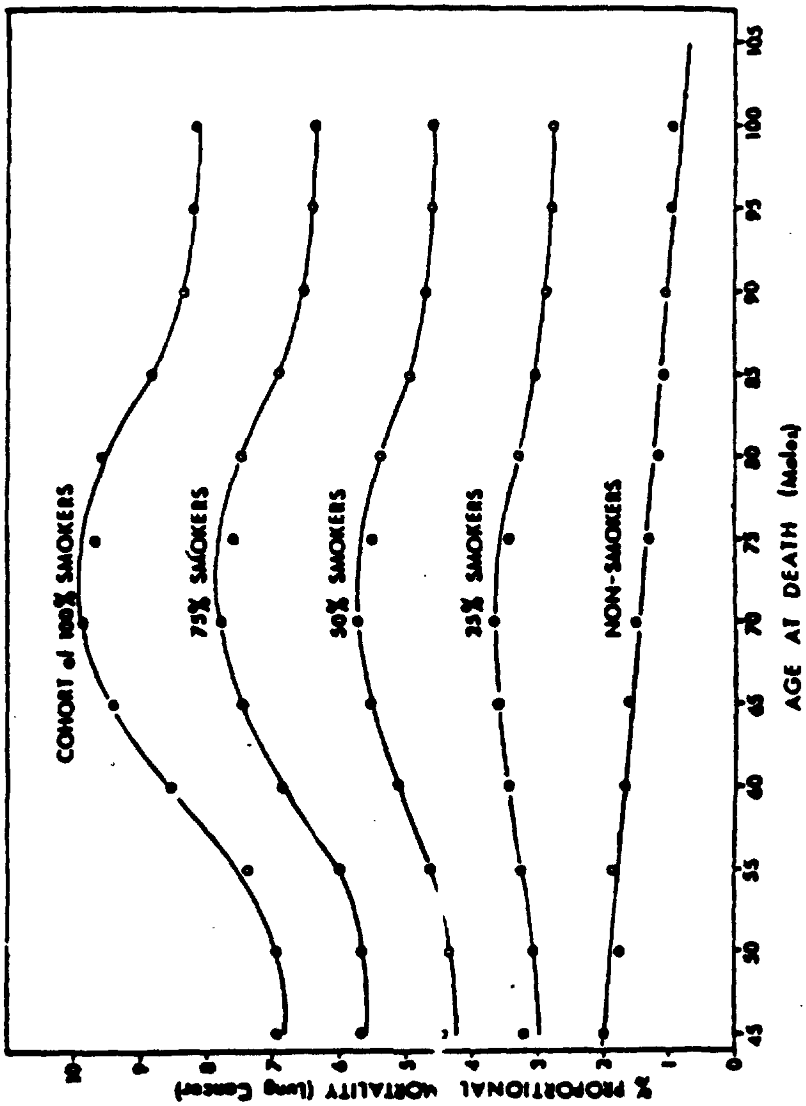

Figure 2. Percent of lung cancer deaths in males relative to deaths by all causes (proportional mortality - lung cancer) plotted with respect to age for four groups (cohorts) having different cigarette-smoking characteristics and for a cohort of non-smokers. For example, for a cohort of 70-year old males which is composed of 75 percent cigarette smokers, 7.8 percent of all deaths at age 70 are predicted to be from lung cancer. Graphical presentation based on data from Hammond et al. (1978).

composed of 75 percent smokers would be at least 6 to 7.5 percent, regardless of occupation. In Tables 3a and 3b we see that the lung cancer mortality for the total of 21 cohorts of asbestos "trades" workers was 16.7 percent - approximately three times that expected if mortality predictions were based only on the apparent smoking habits.

The risk of lung cancer due to asbestos exposure is lower in non-smokers than in smokers (Saracci, 1977, J. C. McDonald, 1980b). There appears to be no relationship between smoking habits and the incidence of mesothelioma, the disease is equally prevalent in smokers and non-smokers alike. Of the studies listed in Tables 3a and 3b, only Study No. VI of chrysotile factory workers shows a lung cancer mortality that would be expected from the smoking habits alone.

Asbestos miners and millers. Men working in the mining and milling of asbestos ore are generally exposed to only one form of fiber. A few exceptions occur in the mining regions of South Africa where some workers have been employed in crocidolite, amosite, and chrysotile mines. Anthophyllite and tremolite asbestos miners may have been exposed to some chrysotile asbestos, for these minerals can coexist in metamorphosed ultramafic rocks, for example, those of Paakkila, Finland.

Epidemiological studies of asbestos miners and millers who were exposed to only one form of asbestos are useful to understand how the different asbestos minerals affect human health. Table 4 gives the mortality data for the five major epidemiological studies of asbestos miners and millers. In addition three studies are given of miners exposed to cummingtonite and grunerite amphibole dusts and one study of tunnel workers exposed to hornblende amphibole dust. Some classify these amphiboles as asbestos even though they do not possess the physical properties requisite to be valuable commercially. Such a classification has been made in the case of taconite mining by the courts (United States District Court for Minnesota, 380 F. Supp. 11) and by the U.S. Environmental Protection Agency (Reserve Mining vs. EPA, U.S. Court of Appeals Eighth Circuit, March 14, 1975); the latter has sued to prevent the Reserve Mining Company from dumping taconite tailings into Lake Superior because of the perception that these tailings contain "amosite asbestos" and thus constitute a threat to public health. For a complete review of the case see 514 Federal Reporter, 2d Series, 492-542, 1975; 256 North Western Reporter, 2nd Series, 808-852, 1977. Of interest regarding this suit are the health studies of the Reserve iron ore miners exposed to cummingtonite and grunerite in the taconite rock (Table 4, Study B) and on the Homestake gold miners exposed to cummingtonite in

Table 4. Mortality from selected causes in the principal epidemiological studies of commercial asbestos miners and millers and other hard rock miners and tunnel workers exposed to rock dust containing minerals sometimes defined as asbestos[1]

Cause of Death[2]	Number of Deaths	Study A [illegible] men 1936-1967	B 5751 men 1952-1976	C 932 men 1955-1972	D 440 men 1960-1973	E 1321 men 1937-1973	F -- 1943-1977	G 933 men 1946-1975	H 544 men 1961-1977	J 10939 men 1910-1975	Totals (excluding Study F)
All causes (000-999)	Observed Expected Obs./Exp.	216	298 344 0.87	294 225 1.30	71 52.9 1.34	631 549.7 1.15	519 600.3 0.86	332 214.4 1.55	178 159.9 1.11	4463	6483
Respiratory cancer (162)	Obs. % all deaths Exp. Obs./Exp.	21 9.7 12.6 1.67	15 5.0 17.9 0.84	21 7.1 13.15 1.60	10 14.1[3] 2.7 3.0	16 2.5 16.5 0.97	60 11.6 38.9 1.54	10 3.0 10.4 0.96	28 15.7 11.1 2.5	250 5.6	371 5.7
Mesothelioma, peritoneum, pleura (158,163)	Obs. % all deaths	0 0	0 0		0 0	11 0.167	17 3.3	17 0.307	1 0.56	10[5] 0.22	11 + 2? 0.17+0.03
Gastro-intestinal cancer (150-154) or (150-159)	Obs. % all deaths Exp. Obs./Exp.	7 3.2 14.9 0.47	20 6.7 17.6 1.14	10 3.4 11.13 0.90		39 6.2 35.1 1.11		19 5.7 19.3 0.98	10 5.6 9.5 1.05	168 3.8	273 4.2
Pneumoconiosis (500-519)	Obs. % all deaths		4[7] 1.3	20 6.8	5 7.0	37 5.9	21[4] 4.0	20 6.0	30 16.9	46[6] 1.0	
Asbestosis (515.2)	Obs.	13						9	26		
Silicosis (515.0)	Obs.					35					
Respiratory tuberculosis (010-011)	Obs. % all deaths	36 16.7		11 3.7		39 6.2	4 0.77	18 5.4		248 5.6	
Locality		North Savo, Finland	Minnesota, U.S.A.	Manhattan I. N.Y., U.S.A.	Lead, SD, U.S.A.	Lead, SD, U.S.A.	Wittenoom, W. Australia	Balangero, Italy	Quebec, Canada	Quebec, Canada	
Type of Mining		asbestos	iron ore	tunneling	gold	gold	asbestos	asbestos	asbestos	asbestos	
Type of Rock		ultramafic	taconite	schist, gneiss, amphibolite	qtz-cummingtonite schist	qtz-cummingtonite schist	banded ironstone	serpentinite	serpentinite	serpentinite	
Suspected mineral pathogen		anthophyllite asbestos	cummingtonite, grunerite, quartz	hornblende, quartz	cummingtonite, hornblende, quartz	cummingtonite, hornblende, quartz	crocidolite asbestos, quartz	chrysotile asbestos	chrysotile asbestos	chrysotile asbestos	
Source		Meurman et. al., 1974	Higgins, 1981	Selikoff, 1978	Gillam et al., 1976	McDonald et. al., 1978	Hobbs et al., 1980	Rubino et al., 1979	Nicholson et al., 1979	McDonald et al., 1980	

1/ Cummingtonite, grunerite, and hornblende (Studies B, C, D, E) may be defined as "asbestos" in U.S. Federal Regulations
2/ International Classification of Diseases, 8th revision (ICD-8)
3/ Inc[illegible] the maxillary sinus and one mediastinal carcinoma (unspecified). See footnote 2/ in text.
4/ Pneumoconiosis Board Records (Western Australia) show pneumoconiosis of mixed type, asbestosis, silico-asbestosis, and silicosis.
5/ Two mesothelioma victims worked with crocidolite in addition to chrysotile.
6/ Pneumoconiosis is probably predominantly asbestosis since rock dust contains little crystalline silica (quartz, etc.)
7/ "Selected respiratory disease"

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Table 5. Mortality Data (Jones et al., 1980a) for a Cohort of 951 Women* (578 traced) who assembled Asbestos-Bearing Filter Pads in English Factories (1939-1944).

Cause of Death	Observed	% Mortality	Asbestos Exposure
All causes	166	100	Crocidolite and chrysotile
G.I. cancer	10	6.0	---
Other cancer	35	21.1	---
Mesothelioma	16	10.2	Crocidolite only
Mesothelioma	1		Crocido'ite and chrysotile
Lung cancer	11	7.2	Crocido ite only
Lung cancer	1		Crocidolite and chrysotile

*727 (139 dead) were exposed to only crocidolite, 102 (10 dead) to only chrysotile, 99 (15 dead) to crocidolite plus chrysotile, and 23 (2 dead) unknown exposure.

To make further comparisons it is useful to examine the mortality with respect to lung cancer and mesothelioma in national populations. In Table 6

Table 6. Cancer mortality in men over 24 years of age for 5 nations (McDonald and McDonald, 197?)

Nation	All Deaths (year)	Lung cancer No.(%)*	Mesothelioma No.(%)*
England-Wales	278,617 (1970)	24913 (8.9)	15? (0.06)
Finland	22,332 (1970)	1586 (7.1)	? (0.04)
Italy	272,795 (1970)	11867 (4.7)	not reported
U.S.A.	988,620 (1969)	50481 (5.1)	250 (0.03)
Canada	82,052 (1970)	4312 (5.3)	25 (0.03)
Totals	1,624,416	93159 (5.7)	437 (0.03)

*percent of all deaths (proportional mortality)

are given the lung cancer and mesothelioma mortality of all males over 24 years of age in five nations. These data are plotted in Figure 1. We find that the average lung cancer mortality of these five national populations is 5.7 percent, a figure identical to the 5.7 percent average mortality of the miners and tunnel workers (Table 4, excluding crocidolite miners). The mesothelioma mortality of the five national populations is 0.03 percent (Table 6) and is probably significantly underreported because of: (1) the great difficulty in diagnosing this disease, even after autopsy (McDonald and McDonald, 1977, 1980; Vejlsted and Hansen, 1980; Kannerstein and Churg, 1980; Legha and Muggia, 1977) and (2) complications arising in properly and consistently coding this disease for later information retrieval.

It may be more meaningful to compare mesothelioma mortality among asbestos workers and miners, in whom this disease is anticipated, with the mortality in a population where the determinations of the causes of death are based on a large number of autopsies and where asbestos exposure is minimal. A review the gold-bearing schists (Table 4, Study D, E)2/. Studies B and E show no evidence of asbestos-related diseases appearing in the study groups.

Mortality comparisons, trades vs. mines. The cancer mortality pattern for those in the asbestos trades and mining occupations is graphically presented in Figure 1 where percent lung cancer mortality is plotted with respect to percent mortality due to mesothelioma. The studies of the asbestos trades workers (Tables 3a, 3b; Fig. 1, open stars) show a very significant excess of mortality due to mesothelioma relative to that found in the miners (Table 4, Fig. 1, solid squares) - with one exception, the crocidolite miners of Western Australia (Study F).

In regard to high mesothelioma mortality, it is important to note two health studies of specialized factory workers who, during World War II, were employed at the task of manufacturing asbestos-bearing filter pads and of placing them into gas mask canisters. One study (McDonald and McDonald, 1978) was of Canadian workers who, at three factories, were involved with the manufacture or handling of crocidolite-bearing filter pads. The maximum duration of exposure during the period 1939-1941 was no more than two and a half years. The cohort studied was composed of 93 men and 83 women (Study X, Table 3a). Of the 56 now dead, 8 died of lung cancer (14.3%) and 9 of mesothelioma (16.1%).

The second study (Jones et al., 1976, 1980a) was of a cohort of 951 women who worked either at a factory in Nottingham, England or at a factory in Birmingham, England. The Nottingham group worked for only five months in the years 1939-1940 assembling "civilian filter pads" that contained chrysotile asbestos. The Birmingham group worked for up to four and half years during the period 1940-1944 assembling "military filter pads" that contained crocidolite asbestos. The crocidolite was thought to have come from Wittenoom, Western Australia. The mortality data is given in Table 5. None of those exposed only to chrysotile died of lung cancer or mesothelioma whereas there were 11 lung cancer deaths and 16 mesothelioma deaths among those who worked only with crocidolite. None of the women in either factory, as far as is known, was exposed to asbestos occupationally apart from their wartime work. Dust levels, as with the Canadian gas mask workers, was considered to be very light to moderate.

2/Study E (McDonald et al., 1978) discredits Study D (Gillam et al., 1976). Study D was made on a sub-cohort of the Study E cohort. The latter study is much more complete; satistically it is based on 631 deaths whereas Study D is based on 71 deaths. In addition, Study D presents an implausible mortality pattern: (1) No deaths due to silicosis, tuberculosis, or silico-tuberculosis were reported despite the fact that the mining company has been coping with a quartz dust problem for a century and (2) a 14.1 percent respiratory cancer mortality (incorrectly included as respiratory cancer were a sinus and a mediastinal carcinoma) was attributed to "cummingtonite asbestos" yet no mortality due to asbestosis was reported. The cummingtonite found in the quartz-cummingtonite schist host rock is not asbestos; but rather, garden-variety rock-forming amphibole.

has been made by Rüttner (1978) of the deaths in the Zürich area of Switzerland where there are no asbestos mines, mills, or industries and where the cause of death is often determined by autopsy. Among the 28,110 male deaths (all autopsied) from 1961 to 1976, 51 deaths were due to mesothelioma (0.18 percent) and 2466 were due to lung cancer (8.8 percent). Among women (22,583 deaths) 23 were caused by mesothelioma (0.10 percent) and 368 caused by lung cancer (1.6 percent). The proportional mesothelioma mortality for hard-rock miners, tunnel workers, and asbestos miners (other than crocidolite) is 0.17 to 0.20 percent (Table 4). The asbestos trades workers, by contrast, have an average mesothelioma mortality of 5.6 percent (Table 3).

Among the asbestos miners and millers there is no question that those exposed to heavy concentrations of chrysotile and anthophyllite dust over long periods of time have suffered a significant excess mortality due to lung cancer and asbestosis - but not to mesothelioma (Studies A, H, Table 4). The most detailed health study of asbestos miners to date is that of the chrysotile asbestos miners of Quebec (Table 4, Study J). Here, McDonald et al. (1980) have carefully documented the relationship between lung cancer incidence and cumulative dust exposure. The average dust concentrations that the miners and millers experienced during the working day were divided into four categories depending on the work tasks performed during their careers in the mines. These are: low level 2.5 to 4.2 mpcf[3/], medium level 4.3 to 9.4, high level 11.4 to 23.6, and very high level 46.8 to 82.6 mpcf. The mean within these four categories in terms of chrysotile fibers per cm^3 is: low 10 fibers/cm^3, medium 21 fibers/cm^3, high 95 fibers/cm^3, and very high 194 fibers/cm^3. For the men exposed for over 20 years (see Table 17, column A) in the low and medium dust categories (averaging 6.6 mpcf or approximately 20 fibers/cm^3) total mortality was less than expected (SMR = 0.94). For these men there was a slight risk of excess lung cancer (SMR = 1.15) and respiratory tuberculosis (SMR = 1.14). As exposures of 20 fibers/cm^3 are an order of magnitude higher than that experienced now (dust levels for the past few years have been maintained at less than 2 fibers/cm^3), miners working a lifetime under the present dust levels are not expected to present any significant health problems relative to those in other mining industries (Liddell, 1981).

McDonald et al. (1980) have also studied the health statistics of a cohort of 440 women who also worked in the Quebec chrysotile asbestos mines and mills. Of the 84 who have died there was one death due to lung cancer and one due to mesothelioma.

3/mpcf = millions of particles of rock dust per cubic foot. Conversions of this figure into asbestos fibers per cubic centimeter, the usual measurement for industrial hygiene monitoring, is difficult but an approximate and conservatively small figure is: 1 mpcf = 3 fibers/cm^3 (McDonald et al., 1980, p. 21, 23; see also McDonald and Becklake 1976).

Crocidolite exposure. There are persuasive data, many already surveyed, which show that crocidolite asbestos is much more hazardous than chrysotile, anthophyllite, and amosite. Of the mining populations of the world, only those in the crocidolite mining areas of the Cape Province of South Africa and at Wittenoon Gorge, Western Australia have a statistically significant increase in mortality due to mesothelioma. Also, mesothelioma deaths have been reported among the residents of these areas who are not employed in the mines or mills. For example, Webster (1978) reports that the South African Asbestos Tumour Reference Panel placed 712 cases of mesothelioma on the register, which included all the known cases since 1956. Of these occupational and environmental background was established for 420 cases. Actual mining exposure accounted for 139 of the 420 cases of which 120 were in connection with Cape crocidolite mining and two with Transvaal crocidolite mining. There were only four mesothelioma cases in those associated with amosite mining and two of these had been exposed to Cape crocidolite as well. In the chrysotile mining industry there was only one case - a miner from Rhodesia. Of the 100 environmental cases (those not employed in any occupation where asbestos is used) 93 had been exposed to Cape crocidolite, two to Transvaal crocidolite, and one possibly to amosite.

Additional prevalence studies in the Cape Province (Talent et al., 1980) discovered 65 active cases of mesothelioma in people who had presented themselves for medical examination. Fifteen of these cases appeared in two groups, numbering 755 and 947 individuals, who were once employed in the crocidolite mines. An additional thirty eight mesothelioma cases appeared in a survey of certain patients at the St. Michael's Hospital in Kuruman, Cape Province, who were not responding to treatment for suspected pulmonary tuberculosis. Fourteen of these mesothelioma patients were known to have worked in the crocidolite asbestos mines. Lastly, 12 of the 65 cases appeared in a medical survey of 53 females who, in the past, hand-cobbed crocidolite asbestos.

In contrast to the prevalence of mesothelioma in the Cape Province, this disease is very rare in the Transvaal where all of the world's amosite is mined. Wagner et al. (1960), in regard to their initial discovery of the association of crocidolite asbestos with mesothelioma, state (p.260) "the tumour (referring to mesothelioma) is rarely encountered elsewhere in South Africa. During the past five years, with the exception of the present series (in Cape Province), no neoplasm of this nature has been diagnosed amongst 10,000 lungs examined at the Pneumoconiosis Bureau in Johannesburg, or in the Pathology Department of the South African Institute for Medical Research."

The incidence of mesothelioma in Zimbabwe (Rhodesia), a country which is a major producer of chrysotile but mines no other form of asbestos, is very low. In a communication to Mostert and Meintjes (1979), the Secretary of the Rhodesia Pneumoconiosis Board stated that no cases of mesothelioma were reported in the mining industry. It is of interest to note that two cases of mesothelioma were reported in the Rhodesian railway industry, a locomotive engineer and a storeman. The locomotives were insulated with crocidolite asbestos to which these two men were exposed (Mostert and Meintjes, 1979). Cochrane and Webster (1978) report 12 cases of mesothelioma in men employed as insulators in the locomotive workshops of the South African Railways.