NATIONAL INVENTORY OF SOURCES AND EMISSIONS OF ASBESTOS (1970)

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ABSTRACT

Atmospheric emissions of asbestos from various sectors of the Canadian economy have been estimated for the year 1970. A summary of emission factors is given in Table 1. Total emissions were estimated to be 16 392 tons, of which 99.4% was lost during the mining and milling of asbestos fibre, 0.03% during the manufacture of asbestos products, and 0.57% during the consumption of asbestos products, principally automobile brake linings.

Provincial emissions are shown in Table 2 and, with point source locations, in Figure 1. With its major asbestos production centres in the Eastern Townships, the Province of Quebec had the largest emission total, accounting for 81.5% of the total for Canada.

Two points are worth noting in using the results of this study. First, emissions have been presented in units of short tons. Health hazards are related, however, more to the number of asbestos fibres in the air than to their total weight.

Unfortunately as asbestos can occur as fibres of both macroscopic and microscopic dimensions, as well as in clumps containing several fibres, it is impossible to relate weight emissions to fibre emissions. A weight emission which might seem negligible may still constitute a significant health hazard.

The second point concerns the health hazards of asbestos exposure. Although many of the asbestos dose—response relationships and damage mechanisms remain obscure and controversial, it has been established that hazards vary with the type of asbestos. Crocidolite, or blue asbestos, is the most carcinogenic variety of asbestos, and a crocidolite emission must therefore be considered more serious than emission of some other type of asbestos. Essentially all asbestos emissions in Canada are of the chrysotile variety.

RÉSUMÉ

On a évalué pour 1970 les émissions atmosphériques d'amiante provenant de divers secteurs de l'économie canadienne. Le tableau 1 donne un résumé des facteurs d'émission. Les émissions totales ont été évaluées à 16 392 tonnes, dont 99.4% proviennent de l'exploitation minière et du traitement de la fibre d'amiante, 0.03% de la fabrication des produits à base d'amiante et 0.57% de la consommation de ces produits, plus particulièrement des garnitures de freins d'automobiles.

Le tableau 2 donne les émissions dans les provinces et la figure 1, leurs sources. La province de Québec comptant ses principaux centres de production d'amiante dans les Cantons de l'Est, elle a le plus haut total, soit 81.5% du total pour le Canada.

Deux points sont importants dans les résultats de cette étude. D'abord, les émissions sont indiquées en tonnes courtes. Les dangers pour la santé sont toutefois beaucoup plus reliés au nombre de fibres d'amiante dans l'air qu'à leur poids total.

Malheureusement, comme l'amiante peut se présenter en fibres autant macroscopiques que microscopiques ainsi qu'en masses contenant plusieurs fibres, il est impossible de relier poids et fibres en termes de dégagements. Un dégagement dont le poids semble négligeable peut tout de même constituer un danger important pour la santé.

Le deuxième point concerne les dangers de l'exposition à l'amiante. Même si la plupart des liens de cause à effet entre la dose et les dommages occasionnés restent encore incertains et controversés, il a été établi que le danger varie selon le type d'amiante. La crocidolite ou amiante bleue est la variété la plus cancérigène et un dégagement de crocidolite doit donc être considéré comme plus important qu'un dégagement de tout autre type d'amiante. Presque tous les dégagements d'amiante au Canada sont du type chrysotile.

TABLE 1 1970 ASBESTOS EMISSIONS IN CANADA

Source	Emissions		Emission factor (lb/ton asbestos)	
	Tons	Percent	Present study	U.S. (45)
PRODUCTION				
Asbestos mining	6 620	40.4	8	9
Asbestos milling	9 673	59.0	11.7	84
Production total	16 293	99.4		
MANUFACTURING				
Asbestos-cement products	1.88	0.01	0.15	1
Floor tile industry	0.75	*	0.15	1
Paving	0.44	*	0.15	–
Coating, caulks, sealants	0.42	*	0.15	1
Insulation	0.57	*	0.30	–
Friction materials	0.99	*	0.90	6
Plastics	0.09	*	0.15	–
Textiles	0.11	*	0.30	2
Paper	0.05	*	0.15	1
Miscellaneous	0.13	*	0.15	1
Manufacturing total	5.43	0.03		
CONSUMPTION				
Construction industry	0.90	*	0.15	–
Sprayed insulation	2.18	0.02	10.00	10
Brake linings				
Installation	18.00	0.11	10	10
Wear	72.00	0.44	40	–
Consumption total	93.08	0.57		
TOTAL	16 391.51	100.00		

* Negligible (less than 0.01%).
– Nonexistent.

TABLE 2 PROVINCIAL ASBESTOS EMISSIONS (1970)

Province	Emissions (tons)					Percent
	Production[a]	Manufacturing[b]	Construction[c]	Brake linings[d]	Total	
Newfoundland	653	–	0.09	1.26	654.3	4.0
P.E.I.	–	–	0.01	0.45	0.5	*
Nova Scotia	–	–	0.11	2.88	3.0	*
New Brunswick	–	*	0.07	2.43	2.5	*
Quebec	13 325	2.92	0.62	23.76	13 352.3	81.5
Ontario	375	2.42	1.11	34.28	412.8	2.5
Manitoba	–	0.02	0.16	3.78	4.0	*
Saskatchewan	–	*	0.11	3.87	4.0	*
Alberta	–	0.02	0.39	7.74	8.1	*
British Columbia	880	0.05	0.41	9.54	890.0	5.4
Yukon and N.W.T.	1 060	–	*	*	1 060.0	6.5
TOTAL	16 293	5.43	3.08	89.99	16 391.5	100.0

[a] Table 5 and sections 4.1, 4.2.

[b] Table 9.

[c] Sections 6.1, 6.2, and Table 11.

[d] Table 13.

* Negligible.

– Nonexistent.

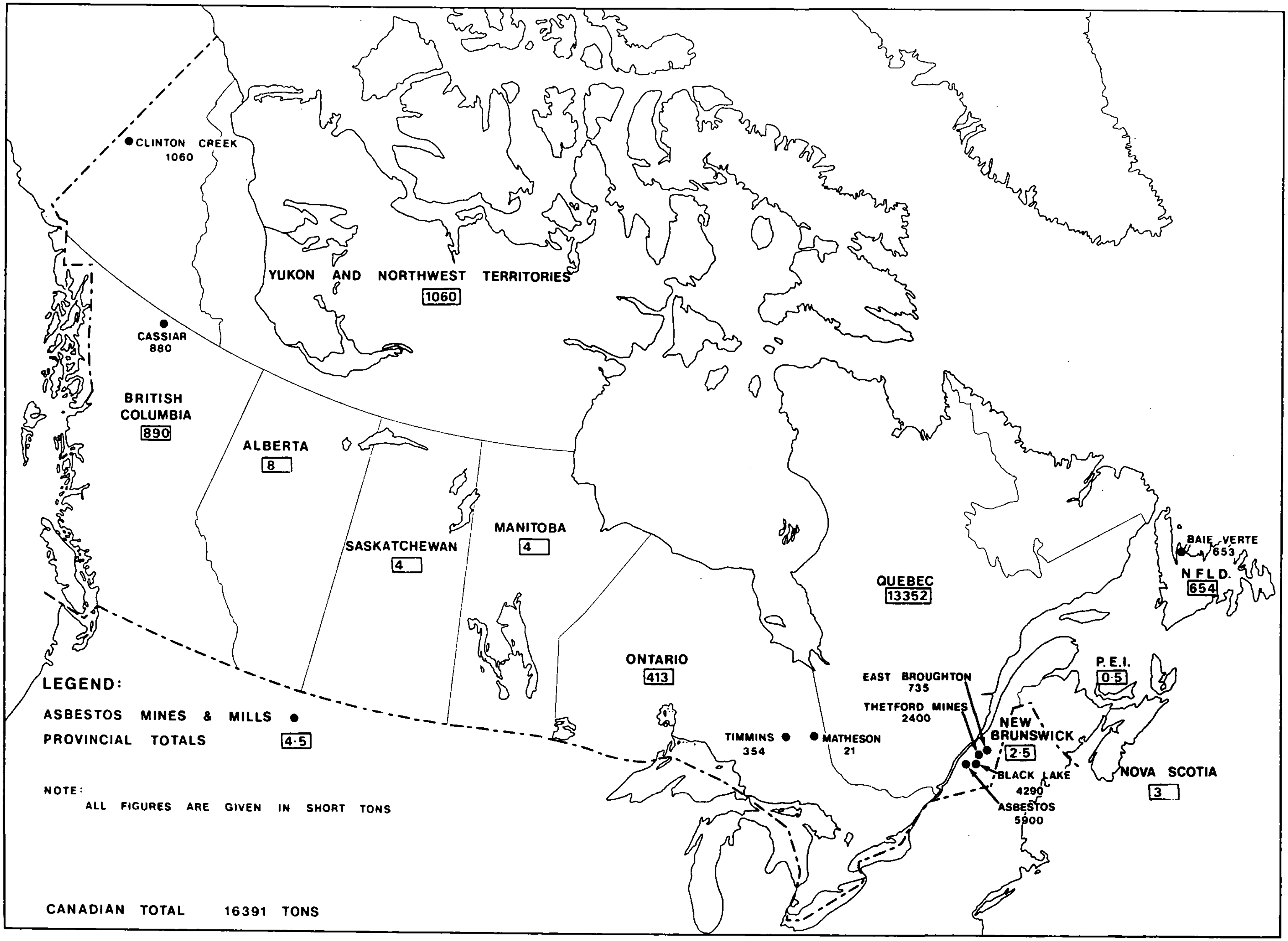

FIGURE 1 1970 ASBESTOS EMISSIONS IN CANADA

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1 INTRODUCTION

1.1 Scope

The purpose of this report is to identify and quantify the sources of airborne asbestos in Canada for the year 1970. Data were gathered from government reports and statistics, scientific publications, and questionnaire replies returned by asbestos producers and consumers. It is believed that the majority of industrial sources of asbestos emissions in Canada were contacted during the study.

In most cases, emission data could not be supplied by the companies involved. Estimates based on process descriptions, control equipment, and other pertinent information had to be made for these sources. Particle size information on asbestos dust was also found to be completely lacking, both in scientific publications and in industrial emission data.

An additional point worth noting is that attention in this report is confined to the use of those materials commonly called 'asbestos'. Cralley (22) has pointed out that there are numerous other minerals such as plaster of Paris, talc, pyrophyllite, soapstone, and gypsum that contain fibres. In talc, these fibres are believed to be tremolite asbestos (20, 23), although in other materials other respirable animal, vegetable, and mineral fibres have been identified (22). Although the fibre content of Canadian talcose rock is unknown, since 75 000 tons of talc, soapstone, and pyrophyllite were mined in 1970 (23), talcose rock mining may be a source of atmospheric emissions worth attention in the future. Further emissions may result from the use of talcose materials in cosmetics and pesticides (24). Compared with the 1 654 000 tons of chrysotile fibre produced in 1970, however, the 75 000 tons of talc mined, of which only a fraction is fibrous, represent a relatively small source.

1.2 Properties of Asbestos and its Compounds

Asbestos is the name given to a group of approximately 30 hydrous silicate minerals. Its fibrous physical structure combined with such properties as nonflammability, good flexing and tensile strength, good heat and electrical insulating ability, and good resistance to acids and alkalies has made asbestos one of the most useful industrial materials.

Although over 3000 uses have been recorded (1), the seven major ones are summarized in Table 3. Its application as a binding agent is its most important single use. The dispersal of tiny asbestos 'reinforcing rods' through a material gives that material increased strength and durability (2).

On the basis of crystalline structure, two asbestos groups can be defined: pyroxene and amphibole. The pyroxene group contains chrysotile, a hydrous magnesium silicate related

TABLE 3 WORLD CONSUMPTION OF ASBESTOS (1963) (2)

Industry	Consumption (1000 tons)	Consumption (%)	Dollar value (million dollars)	Use	Asbestos grade
Asbestos cement	2190	68.0	328.5	Reinforcing; binder	#4 – #7
Floor tile	307	9.5	13.2	Reinforcing; binder	#7
Asbestos paper	220	6.8	19.8	Heat, chemical resistance; electrical insulation	#3 – #6
Friction materials and gaskets	111	3.5	11.1	Reinforcing; binder; heat resistance	#3 – #7
Paints, roof coatings, caulks	85	2.6	3.7	Reinforcing; binder	#7
Textiles	66	2.0	26.4	Nonflammability	#1 – #3
Plastics	21	0.7	0.9	Reinforcing; binder	#7
Miscellaneous	221	6.9	19.7		
TOTAL	3221	100.0	423.3		

to the mineral serpentine. Chrysotile asbestos accounts for over 90% of the world's asbestos consumption (3, 7) and is the only variety mined in Canada. The amphibole group contains several types of asbestos, the major ones being crocidolite (blue asbestos), which is related to the mineral riebeckite, and amosite, which is related to the mineral grunerite (4). Lesser amounts of anthophyllite, tremolite, and actinolite are also mined. Although amphibole asbestos deposits in Canada are known, none is mined (1, 4, 8).

The properties of the various asbestos types are summarized in Table 4. The major difference between chrysotile and the amphibole asbestos materials lies in the fibre structure. Whereas chrysotile fibres are flexible, soft, hollow cylinders with an outer diameter of 0.02–0.025 μm, an inner diameter of 0.002–0.005 μm, and a length varying from 5 to 100 μm, amphibole fibres are hard, springy, flat sheets approximately 1 μm in width (5). This size range of asbestos fibres is orders of magnitude smaller than other industrial fibres such as glass wool and cotton (6).

With asbestos materials, fiberization is a cleavage property; that is, the mineral tends to split in a well-defined direction, forming fibrils of decreasing diameter. Although splitting can be continued down to the molecular dimensions given previously, a balance between fiberization and fibre length must be obtained during the milling process. The extra value of the longer fibre used in textiles can be seen in Table 3. Although the textile industry rates sixth in tonnage consumed, it rates second in dollar value.

Canadian asbestos is graded according to length. Crude #1 contains fibres of 3/4 in. or longer, crude #2 contains fibres 3/8 to 3/4 in. long, and so on down to group #7. Prices on January 1, 1970, varied from $1525/ton for crude #1 to $50.50/ton for group #7 (7). Typical grades used by major consumers are given in Table 3.

The nonflammability of asbestos results from molecular changes that occur under the action of heat. For chrysotile, absorbed water is driven off at about 570 °F, and the water of crystallization is lost between 1020 °F and 1110 °F. As dehydration takes place, the fibres start to deteriorate. Deterioration begins at approximately 750 °F. The fibres are completely destroyed, and the fibrous chrysotile changes into the nonfibrous mineral fosterite (Mg_2SiO_4) above 1020 °F (4, 5). Amphibole asbestos behaves similarly, but will withstand slightly higher temperatures without deterioration.

1.3 Asbestos Health Hazards

The relationship between asbestos exposure and severe respiratory illness was established many years ago. The first recorded case of asbestosis or asbestotic pneumoconiosis occurred in 1907 (9), and the causal effect of asbestos on this disease has been demonstrated

TABLE 4 PROPERTIES OF ASBESTOS (2, 5, 6)

Type	Chemical formula	Colour	Flexibility	Length	Spinn-ability	Acid resist-ance	Tensile strength (1000 psi)
Chrysotile	$Mg_6Si_4O_{10}(OH)_8$	White, grey, green, yellow	Excellent	Short to long	Best	Poor	824
Anthophyllite	$(Mg, Fe)_7Si_8O_{22}(OH)_2$	Greyish-white, brown, green	Very poor	Short	Poor	Good	4
Amosite	$Fe_5Mg_2Si_8O_{22}(OH)_2$	Ash-grey, green, brown	Good	2–11 in.	Fair	Good	287
Crocidolite	$Na_2Fe_5Si_8O_{22}(OH)_2$	Lavender, blue, green	Fair to good	Short to long	Fair	Good	876
Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$	Grey-white, green, yellow, blue	Poor	Short to long	Poor	Good	1–3
Actinolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$	Green	Poor	Short to long	Poor	Best	1

since then (10, 11). It has been shown, however, that asbestosis can be prevented by reducing asbestos dust concentrations to levels that are still well above those that might occur in ambient air (9).

A second lung disorder that has been related to asbestos is the formation of pleural calcification and plaques. Selikoff regards bilateral pleural calcification involving the diaphragm, a disease that can be identified through chest X-rays, as diagnostic of asbestosis (3). Other studies have shown a definite link between pleural plaques and asbestos exposure (12, 13).

Of more recent concern is the apparent carcinogenic effect of asbestos (14). Although it appears clear that asbestos exposure can, after a latent period of perhaps as long as 40 years, result in cancer of the lung and mesothelioma of the respiratory and gastrointestinal tract, the actual causal mechanism and amount of exposure required remain controversial. Cancer in other areas of the body has also been related to asbestos in some cases (3, 9). Crocidolite is thought to be the most carcinogenic of all asbestos materials, although none of the varieties of asbestos is considered non-carcinogenic (1, 15). Whether asbestos itself or trace amounts of carcinogens contained in asbestos produce cancer is not known (3). Further, the modes of ingestion of fibres that can lead to cancer and synergistic effects remain controversial (9). A definite synergism between asbestos and cigarette smoking in lung cancers of asbestos workers has been demonstrated by Selikoff (16).

Nonoccupational exposure of city dwellers to asbestos is believed to occur through the consumption of products containing asbestos. Urban air concentrations of 600–6000 fibres per cubic metre have been estimated (3) but measurements in New York City have indicated a 10–100 ng/m^3 level (17). The low hazard first suggested by these nanogram per cubic metre levels must be tempered with the realization that one nanogram per cubic metre could be fragmented into a million fibres producing a one fibre per cubic centimetre concentration. Without microscopic counting, however, the fibre concentration represented by these weight measurements cannot be established.

On the basis of accumulated industrial experience, asbestos exposure standards have been set (1). The American Conference of Governmental Industrial Hygienists and American Industrial Hygiene Association recommended a threshold limit value of 5 million particles per cubic foot (5 Mp/ft^3) based on a total dust count and an 8 h day. In 1970 American federal agencies specified 5 Mp/ft^3 where ordinary fillers were used in manufacturing but this was also to be limited to 2 Mp/ft^3 when asbestos was used in processes.

The British Occupational Hygiene Society recommended a maximum accumulated exposure of 2.8 Mp/ft^3-years (10^8 particle-years per cubic metre) in 1968. Only fibres above

5 μm in length and with a length to diameter ratio of at least 3:1 were to be counted (3). In 1970, the British standard was amended to a threshold limit value over an 8 h day of two fibres per cubic centimetre of air, a standard now accepted by many authorities. Ontario has proposed a highly tentative ambient air standard of 0.04 fibre per cubic centimetre of air (19).

Although the two fibres per cubic centimetre level is believed sufficient to prevent asbestosis, whether or not it also prevents cancer is unknown. Selikoff suggests it does not, since pleural and peritoneal mesotheliomas have occurred in workers with little or no evidence of asbestosis (17). It has been suggested that for the most carcinogenic asbestos material, crocidolite, the threshold limit value should be set at zero (1). The carcinogenic potential of even the few 'ferruginous bodies' that can be found in the lungs of most urban dwellers is therefore undetermined (20).

One of the problems of establishing asbestos limits has been that of quantitative measurement. A relatively small number of asbestos fibres must be identified in the midst of the large numbers of other dust particles collected. Also, since asbestos materials usually occur in clumps containing many individual fibrils, the question of what constitutes a single fibre must be answered. Measurement techniques and difficulties are outlined in References 1, 3, 19, and 21.

2 NATURAL ASBESTOS BACKGROUND

Approximately 30 varieties of asbestos are widely distributed in rocks occurring at or near the surface of the earth (9). Natural erosion processes, which are estimated to weather approximately 10^{10} tons of rock annually on a worldwide basis (25), will accordingly release asbestos fibres into the air, water, and soil. Deposition of airborne asbestos onto land and into water will be increased by rainfall and snow.

At present, no figures are available on the natural background levels of asbestos. It is hoped that this information might be available in the near future from studies of the fibre content of glacial and polar ice (9). Present measurements, which indicate 600–6000 particles per cubic metre of urban air (3), include the effects of industrial emissions as well as natural emissions.

Until this background figure has been established, the impact of human activities on a global scale is impossible to evaluate. If, for example, the overall asbestos abundance in the earth's crust is 100 ppb, natural processes would release 1000 tons of asbestos annually. The buildup of this material in the soils and oceans would also have to be evaluated to gauge the effect of industrial asbestos emissions.

Whatever the average natural background might be, significant deviations from the average will be found. Near large asbestos deposits, larger emissions and higher background concentrations will naturally occur. Lung disease among farmers in Bulgaria and Finland, for example, has been related to the high asbestos content of rock outcroppings. Farmers in these areas not only till soils high in asbestos content but also build their houses with asbestos-bearing rock. Background levels are sufficient in this case to cause pleural calcification (17).

3 FLOW OF ASBESTOS THROUGH THE CANADIAN ECONOMY IN 1970

Canadian production of asbestos fibre in 1970 totalled 1 654 000 tons. Provincial statistics, which are given in Table 5, indicate that the companies operating in Quebec accounted for 82% of production (7).

The majority of Canadian asbestos is exported as fibre after milling. In 1970 approximately 94.5% of production, or 1 562 000 tons of fibre, was required for the export market. Over 80 countries, including the United States, Britain, Japan, and West Germany, as principal customers paid a total of $227 million for this raw material ($145/ton on average) (7).

The remaining 5.5% fraction was split between consumption by Canadian industry, which required 50 743 tons or 3% of domestic production (26, 27), and inventory stock-piles by asbestos producers, which absorbed 38 495 tons or 2.5% of production (26). Canadian industry also consumed 4784 tons of amosite asbestos imported from South Africa, 909 tons from Venezuela, and 140 tons from Britain (28). Questionnaire replies suggest that the bulk of the 5833 tons of imported fibre was used in the manufacture of pipe insulation.

TABLE 5 CANADIAN ASBESTOS PRODUCTION IN 1970 (7)

Province	Quantity (1000 tons)	Percent
Quebec	1 353	81.8
Yukon	108	6.5
British Columbia	89	5.4
Newfoundland	66	4.0
Ontario	38	2.3
TOTAL	1 654	100.0

In Figure 2 the consumption of asbestos in Canada in 1970 was estimated from information supplied in References 7, 8, 26, 27, and 28 and by industry replies to our questionnaire. Approximately 62% of the total Canadian usage was accounted for by two industries: the manufacturers of asbestos-cement building products required 25 000 tons (44.3% of consumption), and the manufacturers of floor tile required 10 000 tons (17.7% of consumption). Asbestos manufactured goods produced in Canada are both consumed domestically and exported.

Only dollar values of exports were available from Statistics Canada, and information on quantities and amounts of asbestos contained was not available. As an alternative, an indication of export sales versus domestic sales of various asbestos goods manufactured by a large Canadian company was applied. These figures suggest that approximately 10% of the 56 576 tons used by Canadian industry was exported as manufactured goods, whereas 90% was sold domestically. In Figure 2 exports are shown both in dollar value and in asbestos content, estimated from the 10% figure broken down in proportion to dollar value.

Canada also imports asbestos manufactured goods. Once again, only dollar values were available, and not quantities. In Figure 2 the order of magnitude of the quantities involved has been estimated in the same fashion as for manufactured products. Canada had a net deficit of $3.84 million, adding an estimated additional domestic asbestos consumption of 3400 tons to the 56 576 tons indicated previously.

4 EMISSIONS FROM ASBESTOS PRODUCTION

4.1 Asbestos Mining

Canada is the Western world's largest producer of asbestos, producing approximately 35% of the world's supply. Table 6 summarizes 1970 data for Canadian asbestos mines. Seven companies operating in a strip 70 miles long and 6 miles wide in the Eastern Townships of Quebec accounted for over 80% of production. The extensive chrysotile asbestos deposits in this area have been mined continuously since 1878. In total, approximately 7000 acres of land are involved in the production of chrysotile asbestos in Canada (29).

A typical asbestos operation is shown schematically in Figure 3. Holes are drilled into the deposit with compressed air or electric drills, and blasting then loosens the ore. Rough separation of ore and barren rock in the pit is followed by power shovel loading of trucks and transportation of ore to the mill. The asbestos content of the ore varies from 3% to 10%. As is evident in Table 6 most Canadian mines are open pit operations.

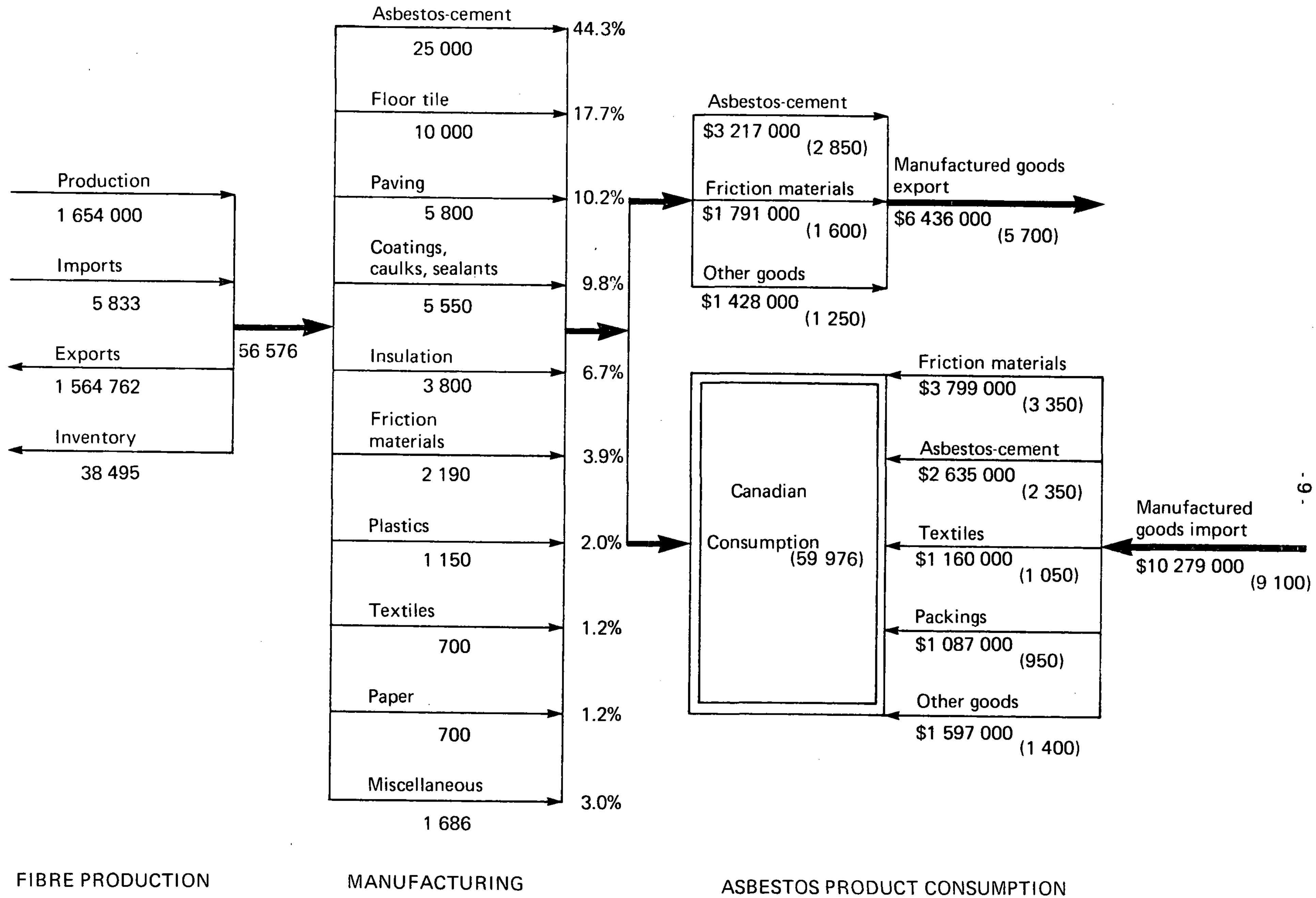

FIGURE 2 CANADIAN ASBESTOS FLOW IN 1970 (SHORT TONS)

TABLE 6 CANADIAN ASBESTOS PRODUCERS IN 1970 (7)

Location	Mine description	Mill capacity (tons ore/day)
Asbestos, Que.	Open pit	32 000
Black Lake, Que.	Open pit	11 200
	Open pit	6 000
	Open pit	6 000
Thetford Mines, Que.	Open pit; underground	8 000
	Underground	3 000
	Open pit	2 000
East Broughton, Que.	Open pit	4 000
Baie Verte, Nfld.	Open pit	6 000
Cassiar, B.C.	Open pit	2 400
Clinton Creek, Yukon	Open pit	3 000
Timmins, Ont.	Open pit	5 000
Matheson, Ont.	Open pit	300

Emissions from the mining of asbestos are in the form of asbestos dust from the drilling, blasting, loading, hauling, and unloading operations. Questionnaire replies indicate that dust is suppressed somewhat by bag filters on primary drills and by wetting travelled areas during dry weather. Despite these efforts, dust remains a problem. Vehicles are accordingly supplied with sealed, pressurized cabins, and the mill is usually located some distance from the pit (30).

Questionnaire replies were received from all asbestos producers except one. Accordingly, 98% of domestic production was accounted for. None of these companies, however, could supply emission data for their mining operations. In the absence of such information, emission factors compiled by EPA in the United States have been applied (31). The EPA handling loss figure of 2 lb/ton has been applied to loading and unloading operations. An additional 4 lb/ton has been added to allow for dust losses during drilling, blasting, and transporting. On the basis of this 8 lb/ton emission factor, atmospheric emissions from asbestos mines in 1970 are summarized as follows.

Source	Emission factor (lb/ton asbestos produced)	Emissions in 1970 (tons)
Asbestos mining	8	6620

4.2 Asbestos Milling

The asbestos milling process, which is carried out at the locations listed in Table 6, is described in detail in Reference 4. The milling process is outlined in Figure 3 although it should be noted that a rotary dryer is normally used and not the tower dryer shown. Ore from the mine is transported to a jaw crusher where initial crushing into 4–6 in. diameter rocks takes place. The material is crushed further, passed through rotary dryers, and stored in a dry ore storage bin. To separate the fibrous material from background rock of similar physical and chemical characteristics, steps of crushing, fiberization (rock breakage in high speed hammer mills), and removal of fibre by air suction are employed. The fluffy cotton-like fibres thus released are removed from the air stream by cyclones and graded according to fibre length by screening.

Care is taken during milling to minimize fibre breakage as the longer fibres are of more commercial value. Accordingly, air aspiration of longer fibres takes place before fiberization. In some cases, longer fibres are hand cobbled, and are not mechanically milled. Eventually, fibres of various grades are deposited into hoppers, from which they are pressure packed into 100-lb bags, approximately 2 ft^3 in volume, for shipment.

During the milling process, asbestos dust is released into the atmosphere from several areas:

(a) The principal area of concern to the asbestos industry has been the atmospheric emissions from the dryer stack (30). In our questionnaire replies, these are the only emission data that could be supplied by the companies involved in asbestos milling. Emission factors for the 11 mills supplying data varied from 0.34 to 3.10 lb asbestos/ton asbestos produced, with an average figure weighted by the amount of asbestos produced of 1.4 lb/ton. In this case, a straight arithmetic average also leads to a figure of 1.4 lb/ton. In all cases, cyclones with reported efficiencies of 80–90% were used for control in 1970. One company, however, indicated that a bag filter with an efficiency above 99% had been installed in 1972 and other plants have apparently also installed similar equipment.

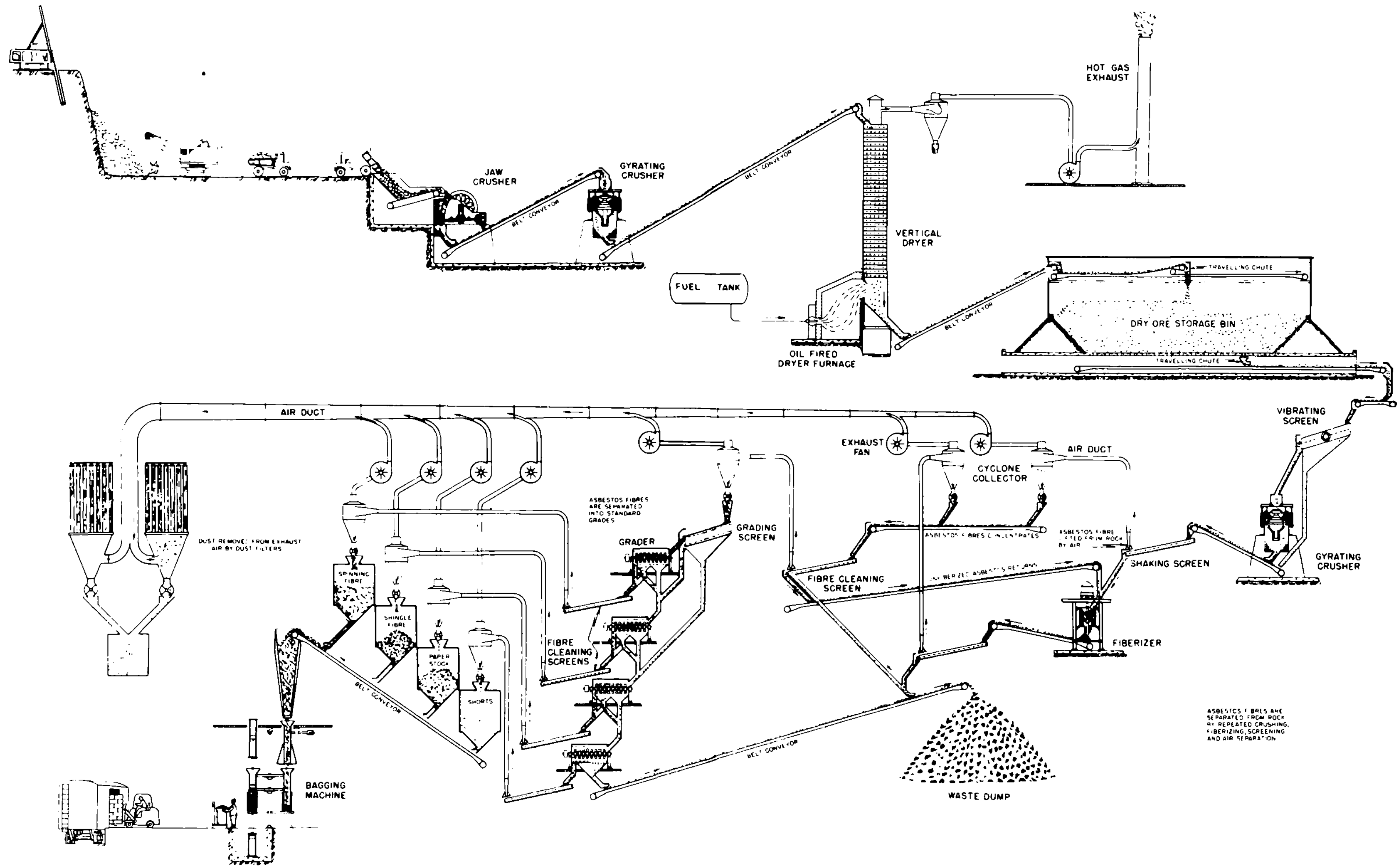

FIGURE 3 FLOWSHEET OF TYPICAL ASBESTOS MINE AND MILL

(b) Substantial emissions are produced from the actual milling process. The air aspiration process used for beneficiation results in all the asbestos that is eventually produced being airborne during milling. The dust created will therefore be very high in asbestos content whereas dust created during mining, for example, may only contain about 5% asbestos. Although no emission figures were supplied, seven companies indicated that they used bag filters with reported efficiencies of 99–99.5% on the mill exhaust.

Referring to Figure 3 a lower limit on mill exhaust losses can be established by assuming that 20% of the asbestos produced escapes the cyclone separators, and 1% of this figure escapes the baghouse to enter the atmosphere. The overall loss indicated is therefore 0.2% of production, or 4 lb asbestos/ton produced.

An upper limit can be established by assuming that only a baghouse filter is used to remove asbestos dust from the mill exhaust. Assuming that 1% of production enters the atmosphere, an emission factor of 20 lb/ton is indicated.

It is felt that a realistic emission factor will lie somewhere between 4 and 20 lb/ton. For the purposes of this study, a 10 lb/ton factor has been used.

(c) Additional asbestos dust is created during crushing and conveying of asbestos ore. In the absence of data from the companies involved, EPA emission factors have again been applied (31). These suggest a total of 11.2 lb/ton suspended emissions from the various crushing and screening operations plus an additional 2 lb/ton for conveying and handling losses. Assuming the use of a bag filter with 99% efficiency leads to an additional emission factor of 13.2 x 0.01 = 0.1 lb/ton asbestos milled.

(d) A fourth source of asbestos emission is the dust released from the disposal of tailings. The EPA storage pile emission factor is 10 lb/ton (31).

Assuming a 0.1% asbestos content in the waste rock, an emission of 0.01 lb asbestos/ton tailings is estimated. Further, assuming a 5% asbestos content in the ore mined, the amount of tailings generated in 1970 is calculated to be 1 654 000 x (0.95/0.05) = 31 500 000 tons. The indicated emission is therefore approximately 160 tons and the emission factor becomes 0.2 lb asbestos/ton asbestos produced.

Based on the foregoing analysis, emissions from asbestos milling in 1970 are summarized as follows.

Source	Emission factor (lb/ton asbestos produced)	Emissions in 1970 (tons)
Dryer stack	1.4	1160
Mill exhaust air	10.0	8270
Rock handling	0.1	83
Tailings disposal	0.2	160
TOTAL	11.7	9673

5 EMISSIONS FROM THE MANUFACTURING OF ASBESTOS PRODUCTS

During the study, approximately 44 plants manufacturing products containing asbestos were contacted. In most manufacturing areas, a few large companies were found to account for the bulk of production. Consumption figures supplied in questionnaire returns, along with production information and the data given in Figure 2, suggest that the seven companies identified by asterisks in Table 7 accounted for over 80% of 1970 Canadian asbestos usage. A more exact figure is not available because of the lack of precise consumption information from a few companies. Asbestos purchased by most of the other companies listed was relatively small, varying from a fraction of a ton annually to about 200 tons annually. In some cases, particularly in packing and gasket manufacture, asbestos was purchased in cloth or paper form and not as raw fibre.

5.1 Manufacturing Process Descriptions

Asbestos fibre is used in a similar fashion by most manufacturing industries. The fibre is received from domestic or foreign supplies in 100-lb bags, and is mixed with other materials for processing into finished goods. Features of specific industries are covered in this section.

5.1.1 Asbestos-Cement Industry. Asbestos fibres, usually #4 to #7 grade, are used as a reinforcing additive in the manufacture of asbestos-cement building products. Asbestos-cement pipe, for example, is widely used in water mains and sewers because of its low cost and excellent corrosion resistance. These properties, plus those of fire resistance and heat insulating ability, have similarly led to the widespread use of flat and corrugated asbestos-cement sheets and shingles in building.

TABLE 7 ASBESTOS GOODS MANUFACTURERS CONTACTED DURING THE STUDY

Province	Product
New Brunswick	Wallboard
Quebec	* Friction materials, textiles, sealants, papers, packings, caulks
	Sealants
	Furnace cement
	Sealants
	Sealants
	* Asbestos-cement products, insulation, plastics
	Wallboard
	Sealants
	* Floor tile
	* Floor tile
	Packings
	Friction materials
	* Floor tile
Ontario	Sealants
	Sealants
	Bituminous pipe
	Wallboard, plaster
	Floor tile
	Packings
	Asbestos-cement products
Ontario (Cont'd)	Sealants
	Friction materials
	Automobile hoses
	Insulation
	Gaskets
	Packings
	Friction materials
	Sealants
	Sealants
	Sealants
	* Paving
	Paving
	Floor tile
	Packings
	Refractory materials
	Rubber belting
	* Asbestos-cement pipe
Manitoba	Sealants, caulks
Saskatchewan	Sealants
Alberta	Sealants, caulks
British Columbia	Sealants
	Insulation
	Sealants

* Seven companies accounted for over 80% of 1970 Canadian asbestos usage.

To manufacture asbestos-cement pipe, a water slurry is made from 50% Portland cement, 15–25% asbestos, and 25–35% silica. Thin layers of slurry are transferred to a moving belt where some water may be removed by suction, and wound around a steel mandrel. When the desired wall thickness is obtained, the mandrel is removed, and the pipe is steam cured. Cutting, trimming, and grooving operations are carried out before shipment (32). Similar processes are used to make shingles and sheeting.

A related industry, which we have included under asbestos-cement manufacturers, is the use of asbestos in gypsum wallboard and plaster. Small amounts of asbestos, approximately 0.5% by weight, are added to gypsum stucco to produce gypsum wallboard and some types of plaster. Gypsum stucco is prepared by mining, grinding, and calcining gypsum rock (33). One company also reported the use of about 1% by weight asbestos in mortar mix formulations (34).

The rate of growth of demand for asbestos-cement products in Canada is expected to decline in the next few years because of competition from other materials. Small diameter plastic pipe, for example, has already replaced asbestos-cement pipe in many applications (8).

5.1.2 Floor Tile Industry. Short asbestos fibres, usually of group #7, are employed as a binder and filler in the manufacture of floor tile. Vinyl-asbestos tiles consist of 14–17% vinyl resins, 6–10% esters, 50–75% limestone, 7–15% asbestos, 1–5% colouring pigments, and 1–3% stabilizers. The materials are mixed in a blender, formed into sheets by calenders, and cut into tiles (35, 36).

Asphalt-asbestos tiles are made in the same way from a mixture of gilsonite, oxidized petroleum asphalt, pigments, oils, and about 25% by weight asbestos. Demand for asphalt tiles is decreasing, and it was stated that they are no longer produced in Canada (35, 36).

The asbestos content of floor tiles makes them extremely durable, giving long wear and resisting attack by oils, greases, and alkalies. Due to competition from carpets and other floor coverings, however, the future outlook for the industry is stable, with no rapid growth anticipated (37).

5.1.3 Paving. Although short asbestos fibres have been used in asphalt paving since about 1920, the full advantages of using asbestos have become apparent only recently (38). A 1.5–2% by weight asbestos content in asphalt leads to increased strength, durability, flexibility, and improved crack and indentation resistance of the paving. The binding qualities of asbestos fibre also prevent slippery asphalt pools from forming during hot weather, and allow more asphalt to be used in the mix.

In an asphalt plant, the gravel filler materials are dumped into a hopper. They are then transported on a conveyer belt through a hot air drier, through gravel grading screens, and into a mixer, where hot asphalt is added. Typically asphalt makes up about 10% by weight of the mixture. Asbestos may be added on the conveyer or in the mixer. Asphalt mix is next transferred to trucks and transported to the paving site.

At present, asphalt containing asbestos is used mainly in a thin layer forming the finished surface of a city street. It is expected that asbestos use will grow in the future, since asbestos-asphalts may be used in base layers, in bridge surfaces, and in other applications (39, 40).

5.1.4 Coatings, Caulks, Sealants. Short asbestos fibres are used as an extender pigment or filler in the manufacture of paints and as an additive in putty, caulkings, and coatings. Caulkings and mastics containing asbestos retain their pliability, and are therefore able to weather-seal joints in building exteriors. The binding qualities of asbestos find widespread application in asphalt coatings, which are employed as roof sealants, driveway sealants, basement waterproofing, and car rustproofing formulations. Estimated consumption by categories within this group are given in Table 8.

Manufacturing operations simply involve mixing the powdered asbestos with other materials, and packaging.

TABLE 8 ASBESTOS USE IN COATINGS, CAULKS, AND SEALANTS (1970)

Use	Amount (tons)
Roof coatings	2500
Wallboard joint cement	1700
Auto undercoating	500
Adhesives	80
Caulks, putty	40
Paints	30
Other sealants, cement	700
TOTAL	5550

5.1.5 Insulation. Asbestos fibre is mixed with such materials as perlite, bentonite, and sodium silicate in the production of insulating materials (41). Preformed pipe coverings containing about 60% by weight amosite asbestos, and insulating blocks containing about 6% amosite asbestos are available. Sprayed materials containing asbestos are also employed for fireproofing steel buildings. The use of an asbestos spray eliminates the need to encase steel beams in concrete to prevent buckling. This use is further discussed in section 6.2.

5.1.6 Friction Materials. The durability and heat resistance required by clutch facings and brake linings are obtained through the use of #3 to #7 asbestos fibres. Questionnaire replies indicate that two types of friction materials are made in Canada. The most common type is molded from a mixture of asbestos fibre, organic resins, rubber binders, metal chips, and fillers. After oven curing, machining and grinding operations are performed. The second process involves weaving an asbestos yarn, saturating the tape with organic binders, and curing and machining the cured product as before (42, 43). Brake linings are further discussed in section 6.3.

5.1.7 Plastics. Asbestos fibres are used in the reinforcement and filling of reinforced plastics. The fibres may be incorporated into a resin matrix in a random mix, a woven cloth, or a nonwoven mat form. Increased strength, opacity, erosion resistance, corrosion resistance, and flexibility are produced. Polyester-asbestos, phenolic-asbestos, and silicone-asbestos reinforced plastics are available (5).

5.1.8 Asbestos Textiles. The longer grades of asbestos fibre are used in the manufacture of asbestos textile products, which find application in numerous situations requiring incombustibility, thermal stability, heat and electrical insulating ability, and corrosion resistance. Processing involves opening the fibres received from the mill; blending and mixing asbestos fibre with such organic fibres as cotton and rayon; carding the fibres, a step in which thousands of thin wires comb the fibres into a relatively parallel arrangement and after which rovings are formed by separating the carded sliver into ribbons or untwisted strands; spinning, twisting, and forming operations which produce asbestos yarns; and weaving of asbestos yarn into such items as asbestos cord, cloth, tubing, tape, and rope (6).

Other products of the textile mill include carded asbestos fibre, used in the filtration of such liquids as soft drinks, beers, wines, oils, and chemicals; asbestos lap, a form of carded fibre, used in electrical insulation; asbestos wick, formed by loosely twisting strands of roving, used as a packing material; and nonwoven asbestos felts, produced by adding binders to carded fibre, used in the reinforcing of plastics and as thermal insulation.

5.1.9 Asbestos Paper Products. Asbestos paper finds application in heat and electrical insulations, gaskets, roofing, felts, wicks, pipe coverings, etc.

Paper is formed by drying a slurry of asbestos, sodium silicate, starch, and size that has been formed into a sheet by Fourdrinier machines. The process parallels that of producing paper from wood pulp.

5.2 Manufacturing Industry Emissions

The industries manufacturing various asbestos goods have several similarities. Asbestos fibre is received from domestic or foreign suppliers in 100-lb bags. Some dust is created when the bags are opened and the fibre is dumped into a hopper, mixer, or similar piece of equipment. Several manufacturers noted, however, that the dust produced fell within the United States Occupational Safety and Health Administration (OSHA) asbestos regulations (44), which consider an average concentration of five fibres per cubic centimetre of air acceptable for an 8 h day. (In 1976, the standard will be lowered to two fibres per cubic centimetre.) Measurement techniques and required ventilation, tools, and work practices for handling asbestos are also specified in the OSHA regulations, which have been adopted by most Canadian regulatory bodies.

Questionnaire replies suggest that emissions are considered small and well-controlled in general. Wet processes used in many plants tend to minimize dust production. In addition, hoods and associated bag filters of 95–99% efficiency were reported in the majority of cases.

Information on asbestos emissions was supplied by only three of the plants contacted, and, for these three, only estimates of atmospheric emissions were available. Knowledge on the particle size range of asbestos dust was lacking.

Using scanty emission data supplied, asbestos manufacturing losses have been estimated as follows.

(a) The emission data supplied by the three companies mentioned previously were used to calculate emission factors. One of these companies manufactured asbestos-cement products, one manufactured insulation, reinforced plastics, and asbestos-cement products, and one manufactured a variety of asbestos products. Emission factors were computed to be 0.06 lb asbestos/ton used, 0.13 lb/ton, and under 0.25 lb/ton.

(b) On the basis of the similarity of processes and controls in the manufacturing industries contacted, as is evidenced by the similarity of the emission factor estimated above, an emission factor of 0.15 lb/ton is considered to be representative of most asbestos manufacturing plants. This number is approximately the average of the figures presented above, weighted by the amounts of asbestos consumed.

(c) The figures leading to the 0.15 lb/ton factor were computed from data supplied by plants engaged predominantly in wet processes. It is expected that relatively more dust will be created during dry process operations. Three industry segments listed in section 5.1 will therefore have relatively high emission factors.

(i) In the manufacture of friction materials, substantial dry grinding is done to shape the finished product. Davis accordingly estimates an emission factor for friction product manufacture six times that of other industries (45). In the absence of other information, we have also used this multiplier to estimate an emission factor of 0.15 x 6 = 0.90 lb/ton.

(ii) Similarly, the dry nature of the asbestos textile industry will tend to create higher dust levels. Again following Davis (45), we have doubled the 0.15 lb/ton figure for textile production.

(iii) The manufacture of insulation has been considered to be similar to the manufacture of textiles, and a 0.3 lb/ton figure has accordingly been used.

Emission factors and emissions calculated using these factors and the data of Figure 2 are summarized by industry in Table 9. To calculate emissions by province, asbestos consumption reported in questionnaire returns has been compiled. These results, along with corresponding emissions, are given in Table 10.

6 EMISSIONS FROM THE CONSUMPTION OF ASBESTOS PRODUCTS

Atmospheric emissions are also produced during the consumption of asbestos manufactured goods. Fibres in urban air are thought to result largely from these consumptive emissions produced by asbestos mines, mills, and production plants (17).

6.1 Construction Industry

All asbestos-cement products, floor tiles, and insulation products, and many of the asbestos papers, textiles, paints, caulks, and coatings, are used by the construction industry.

TABLE 9 EMISSIONS FROM THE MANUFACTURE OF ASBESTOS GOODS (1970)

Industry	Asbestos consumption (1000 tons)	Emission factor (lb/ton)	Emissions tons	Emissions %
Asbestos-cement products	25.0	0.15	1.88	34.7
Floor tile	10.0	0.15	0.75	13.8
Paving	5.8	0.15	0.44	8.1
Coatings, caulks, sealants	5.6	0.15	0.42	7.7
Insulation	3.8	0.3	0.57	10.5
Friction materials	2.2	0.9	0.99	18.2
Plastics	1.2	0.15	0.09	1.7
Textiles	0.7	0.30	0.11	2.0
Papers	0.7	0.15	0.05	0.9
Miscellaneous	1.7	0.15	0.13	2.4
TOTAL	56.7		5.43	100.0

Although in such products as sewer pipe, floor tile, and asphalt coatings the asbestos fibre is completely bound, other products contain fibres that can be released to the atmosphere. Electricians, for example, create asbestos dust when stripping insulation from wiring. Plumbers can release fibres when installing asbestos valve packings and pipe coverings, and when cutting small diameter asbestos-cement pipe. Carpenters create dust in cutting, fitting, and nailing asbestos sheets, shingles, and wallboard. As well as subjecting construction workers to asbestos fibres, the use of building materials containing asbestos is therefore a source of ambient air pollution. The nature of this source makes control difficult.

Emissions are also difficult to assess. Although the lack of controls would tend to give a relatively high emission factor, the small amounts of dust involved relative to the manufacturing and mining processes would tend to decrease the emission factor. Lacking definitive information, it has been assumed that approximately 20% of asbestos consumption in Canada, that is, about 12 000 tons in 1970, enters the construction industry in a form that could produce emissions. Further, the 0.15 lb/ton factor found previously has again been applied. This approach leads to the following emission estimate.

Source	Emission factor (lb/ton)	Emissions in 1970 (tons)
Construction industry	0.15	0.9

6.2 Steel Fireproofing

A specific area of the construction industry considered separately here is the use of sprayed asbestos materials on steel beams for fireproofing, acoustical damping, condensation control, and decorative finishing. Many buildings are fireproofed in this way.

TABLE 10 PROVINCIAL ASBESTOS EMISSIONS FROM MANUFACTURING

Province	Asbestos consumption[a] (percent of total)	Emissions (tons)
New Brunswick	*	*
Quebec	53.8	2.92
Ontario	44.7	2.42
Manitoba	0.3	0.02
Saskatchewan	*	*
Alberta	0.3	0.02
British Columbia	0.9	0.05
TOTAL	100.0	5.43

a Asbestos consumption by industries contacted, including estimates made from Figure 2 for some plants, was 57 030 tons. This total suggests that Table 7 contains almost all Canadian users. Reported consumption may be slightly higher than the fibre consumption of Figure 2 since some companies, although reporting asbestos use, purchased paper or cloth, and not raw fibre.

* Negligible.

The hazard to construction workers and the general population through ambient air pollution and through the contamination of building ventilation air has been noted in several articles (17, 19). Such cities as New York (46) and Philadelphia (47) have accordingly banned the use of asbestos spray materials. In Canada, however, these materials can still be used if occupational health procedures, such as supplying workers with respirators, are met (19, 50).

The most common fireproofing material starts with a dry mixture of 5–30% asbestos, mineral wool, bentonite, synthetic resins, oils, and adhesives. This mixture is forced through a hose and mixed with water in a nozzle as it is sprayed onto steel beams. A cementitious spray made up of a wet slurry of asbestos, gypsum, and vermiculite is also used, although it is more expensive. Control of emissions is attempted by enclosing the spraying operation, and outfitting workmen with respirators; however, these measures are apparently ineffective in general (46, 47).

Future demolition of these buildings will likely release asbestos dust into urban air. At this time, however, demolition losses are expected to be negligible since asbestos spray insulation has only been applied since the 1950's. In 1970, well over half of all multi-storey construction in the United States used asbestos spray insulation. Approximately 40 000 tons of insulation were required, containing between 2000 and 12 000 tons of asbestos (46).

Figures on Canadian consumption were not available. Davis has estimated an emission of 15 tons in the United States, based on an emission factor of 10 lb/ton and an estimated usage of 3000 tons of asbestos (45). According to the figures of Statistics Canada (59) and the United States Department of Commerce (60), the value of Canadian construction in 1970 was 14.5% of that in the United States. It is therefore assumed that asbestos emissions from fireproofing operations in Canada were 14.5% of emissions in the United States. Provincial totals are estimated according to construction values in Table 11 and emissions are summarized as follows.

Source	Emission factor (lb/ton asbestos applied)	Emissions in 1970 (tons)
Asbestos fireproofing	10	2.18

6.3 Brake Linings

The role of automobile brake linings in asbestos air pollution has been frequently discussed. During the two or three years' life of a set of linings, the lining components summarized in Table 12 are emitted as dust through wear. It has been shown, however, that this dust is primarily nonfibrous and therefore relatively harmless. The heat of friction is apparently sufficient to destroy most fibres, and only about 1% of the dust emitted is in the form of asbestos (48). This indicates that approximately 2% of the asbestos content of brake linings becomes an atmospheric emission through wear.

To estimate the magnitude of this emission source, data on miles driven in Canada in 1970 (49), listed in Table 13, are used in conjunction with an estimated brake lining life of 27 500 miles (45). A consumption equivalent to $78\ 970 \times 10^6 / 27\ 500 = 2.87 \times 10^6$ sets of brake linings containing approximately 3600 tons of asbestos is indicated. Wear therefore produces an atmospheric emission of $0.02 \times 3600 = 72$ tons.

An additional emission is produced during installation of replacement linings, where grinding is used to fit the linings to the drums. Following Davis (45), a 0.5% loss of the contained asbestos is assumed for this operation. Brake lining emissions are accordingly summarized as follows.

Source	Emission factor (lb/ton contained asbestos)	Emissions in 1970 (tons)
Lining installation	10	18
Lining wear	40	72
TOTAL		90

6.4 Waste Disposal, Demolition, and Other Sources

Figures on asbestos emissions from the disposal of wastes are not available. In most asbestos products, however, the fibre is effectively trapped and will not be emitted to the atmosphere. Incineration will also not lead to any emissions, since heat reduces asbestos to a nonfibrous material. It is accordingly concluded that asbestos emissions from the disposal of wastes will be negligible.

Similarly, in brake lining recovery, the old linings are removed from the brake shoes by heat. Accordingly, little or no fibrous dust will be created (51).

TABLE 11 ASBESTOS EMISSIONS FROM FIREPROOFING (1970)

Province	Construction value (59) (million dollars)	Percent	Asbestos emissions (tons)
Newfoundland	440.8	3.2	0.07
P.E.I.	43.4	0.3	–
Nova Scotia	471.7	3.5	0.08
New Brunswick	326.7	2.4	0.06
Quebec	2 741.5	20.1	0.44
Ontario	4 912.3	36.0	0.79
Manitoba	702.0	5.2	0.11
Saskatchewan	480.0	3.5	0.07
Alberta	1 697.9	12.5	0.27
British Columbia, Yukon, and N.W.T.	1 806.5	13.3	0.29
TOTAL	13 622.8	100.0	2.18

TABLE 12 BRAKE LINING COMPOSITION (48)[a]

	Percent by weight	
	Automobile	Truck
Asbestos	55	33
Resins, polymers	28	48
Oxides, pigments	9	16
Metals,	3	2
Carbon graphite	5	1
TOTAL	100	100

[a] It is estimated that 2.5 lb asbestos are contained in a set of brake linings.

TABLE 13 ASBESTOS EMISSIONS FROM BRAKE LININGS

Province	Vehicles miles (49) (million miles)	Percent	Asbestos emissions (tons)
Newfoundland	1 112	1.4	1.26
P.E.I.	372	0.5	0.45
Nova Scotia	2 506	3.2	2.88
New Brunswick	2 121	2.7	2.43
Quebec	20 863	26.4	23.76
Ontario	30 073	38.1	34.28
Manitoba	3 338	4.2	3.78
Saskatchewan	3 369	4.3	3.87
Alberta	6 792	8.6	7.74
British Columbia	8 423	10.6	9.54
TOTAL	78 970	100.0	90.00

Wrecking companies (52, 53) indicate that very little asbestos insulation is encountered during demolition of old buildings. This seems reasonable since asbestos sprays have only been used for the last 20 years (46). The handling of the asbestos insulation encountered is the same as that for fibre glass insulation. Material is removed with as little breakage as possible, and recovered for resale. One wrecker commented, however, that the soft asbestos materials usually break easily and must be disposed of as garbage (53).

The occupational hazards of removing old asbestos insulation have been noted in shipyards (54). Atmospheric emissions from demolition in 1970, however, are believed to be negligible.

One potential source of asbestos emissions on which no data could be found was the release through wear of asphalt paving containing asbestos. Whether or not abrasive wear of pavement will produce fibrous dust has not been established. If asbestos fibres are released, this emission source may be significant; assuming that the asbestos used in paving in 1970 is lost to the atmosphere over a 10–20 year period, for instance, leads to an annual emission of 29–58 tons. Wear of paving applied before 1970 would also contribute to produce an even higher 1970 paving loss figure. The paving source has not been included in this report because of the lack of quantitative emission data.

A final source of asbestos emissions worth noting is the use of asbestos-carded fibre or felt pads in the filtration of liquids. One chemical plant (55) and numerous wineries, distilleries, and similar plants use asbestos in this way (56–58). One winery (56), for example, reported an annual use of 25 000 asbestos pads, each roughly 16 in. x 16 in. x 0.5 in. Although atmospheric losses from this source may be considered negligible, tests have shown the presence of asbestos fibres in beers, wines, and other drinks (18). Whether these fibres come from the asbestos filters or whether they are already contained in the water is uncertain. The hazards of oral ingestion of fibres are also unknown (18).

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