OECD015

Control of Toxic Substances in the

oecd015

Control of Toxic Substances in the

General Distribution

OECD ENVIRONMENT MONOGRAPHS

No 20

CONTROL OF TOXIC SUBSTANCES IN THE ATMOSPHERE

- ASBESTOS -

April 1989

OCDE
OECD

GENERAL DIFFUSION

ENVIRONMENT MONOGRAPHS

This series is designed to make available to a wide readership selected technical reports prepared by the OECD Environment Committee and Directorate. Additional copies of Monographs on a limited basis can be forwarded on request.

This Monograph is also available in French.

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

20442

CONTROL OF TOXIC SUBSTANCES IN THE ATMOSPHERE

- ASBESTOS -

Under the guidance of the OECD Environment Committee, the Air Management Policy Group is responsible, inter alia, for "identifying and developing essential elements of an overall air management policy which would meet both environmental protection and economic objectives". In 1979, the Group responded to these concerns and developed a work programme on selected toxic substances emitted into the atmosphere.

This report presents an assessment of previously developed literature addressing the environmental impact of asbestos. It is intended to provide a basis for possible control policies in OECD Member countries for asbestos as an ambient air pollutant. It was derestricted by the OECD Council in 1989.

TABLE OF CONTENTS

1. INTRODUCTION

An important task of environmental protection is to identify, and subsequently prevent, the hazards to human health and the entire environment posed through anthropogenic pollutants. A number of pollutants have been well studied over the years, their environmental impacts are quite well established, and legislative action has been initiated on the various levels of government, including national and international action.

Many of the known serious and controversial environmental contamination problems, however, have been related to unconventional pollutants, and researchers have increasingly associated chronic health effects observed in humans with toxic pollutants. As a result, public interest has also increased concerning possible and probable consequences that accompany the emission of man-made pollutants into the environment. To date, prime concern is expressed about toxic substances which may exhibit carcinogenic and/or mutagenic action, and which have not been studied extensively enough in order to develop regulations that definitively eliminate the associated risk to human health.

Prevention of the recurrence of such environmental contamination problems requires close cooperation between industry and regulatory agencies and a streamlined, coordinated approach by regulatory agencies, local, state and national governments. The OECD Environment Committee, as a forum for international exchange of information and experience in Member countries, has responded to this concern with respect to the problem of air emissions. Within its Air Management Policy Group, in 1979, the Committee launched a programme on the "Control of Specific Toxic Substances in the Atmosphere". This programme will assess selected toxic substances which currently seem of greatest concern to OECD Member countries, and will through a "New Pollutant Awareness System", offer the possibility to signal new suspected toxic air pollutants which should require consideration.

The pollutants so far chosen for study are characterised by their chronic intoxicaton effects, currently the main challenge to environmental toxicologists. Initial damage to the mitotic system may be induced after a short, one-time exposure, however, the actual tumor may then only develop after long latency periods. Characteristic of all carcinogens is the irreversibility of effects and the difficulty to relate their exposure levels to actual tumors observed in humans.

Among the variety of environmental carcinogens, the cancer inducing fibres are relevant; and asbestos fibres were, thus, chosen for study by the OECD Air Management Policy Group. Asbestos is the generic name for a group of naturally occurring mineral silicates characterised by their extremely fine fibrous structure.

Asbestos has been known for over 4000 years because of its main chemical and physical characteristics, in particular its incombustibility and excellent tensile strength. It has its origin in different industrial and natural sources, and is present in all environmental media, including air, water, soil, food, beverages, drugs, etc.

To date, it is well established that asbestos poses a health risk to humans and prolonged exposure to high airborne levels in the occupational environment has caused lung fibrosis (asbestosis) and/or bronchial carcinoma, mesothelioma of the peritoneum and/or pleura, as well as laryngeal cancer and possibly malignant tumors in the gastro-intestinal tract.

Since 1960, the presence of asbestos fibres in the environment and their health effects have been discussed; in 1973, the WHO and CEC decided that asbestos was one of the priority pollutants to be studied (Zielhuis, 1976). Although asbestos is considered in most countries to be mainly an occupational risk, some countries consider it currently one of the most hazardous environmental substances and thus, it is the focal point of many scientific and ecological studies that try to assess, and then reduce, its environmental impact.

This report presents an assessment of previously developed literature addressing the environmental impact of asbestos(*). It is not intended to present a new edition of all those studies, neither is it attempting to present a complete review of all material available since that would exceed the scope of the study. However, the authors carefully reviewed the extensive material available to them, including primary as well as secondary literature, and made an effort to describe the current state-of-the-art, highlight controversial opinions, include critical evaluations where they felt these were appropriate and/or necessary, and discuss the possibility of reasonable limitations of asbestos fibres in the air, considering technically available and economically feasible control measures. In addition to published reports and literature, country responses to a questionnaire prepared by the Air Management Policy Group [ENV/AIR/78.10] were utilised.

The report is intended to provide a basis for possible control policies in Member countries for asbestos as an ambient air pollutant. The report includes, in particular in Chapter 6 on health effects, but also in several other places, information and data from the workplace because these were considered relevant for the ambient air environment. In Chapter 6, for example, almost no quantitative data would be available if epidemiological studies in the workplace were not included; they are intended to aid in any risk estimation to human health in the general environment. In the chapter on emissions, concentrations, regulations, and controls, only those data are included which would have a direct effect on emissions and concentrations of asbestos in ambient air. The information on the workplace included in this report is, therefore, not intended to present any judgment on the degree of asbestos pollution and associated risk to human health in the work environment.

(*) It should be understood that when referring to asbestos in connection with risk or scientific studies, it should be expressed as "respirable fibrous dust".

The report begins with the mineralogy of asbestos (Chapter 2); a description of analytical methods follows in Chapter 3; in Chapter 4, emissions sources are identified and emissions quantified as far as possible; Chapter 5 presents resulting ambient concentration levels. A discussion of asbestos-associated health effects is presented in Chapter 6; Chapter 7 lists currently existing national standards; available control technologies and associated costs are described in Chapter 8. The report ends with a summary and conclusions (Chapter 9).

References to Chapter 1

Zielhuis, R. L. (1976); Public Health Risk of Exposure to Asbestos, ECE Directorate Social Affairs, Rep. 18-6.

2. MINERALOGY

This Chapter presents a brief discussion about the terminology of fibres, in general, and asbestos in particular; mineralogical terms and concepts are explained as they will be used throughout the report. In addition, geological formation, chrystallography, as well as physical and chemical properties of asbestos will be described.

2.1 Definition and Discussion of Mineralogical Terms and Concepts

Fibres are defined as elongated particles with a length to width ratio of at least 3:1; they can be classified according to their chemical composition, their physical structure, and/or their formation (natural versus synthetic).

As for asbestos, various definitions have been introduced which, according to their purpose, differ widely in approach and scope. This has led to considerable ambiguity and inconsistency of terminology.

(1) According to the Glossary of Geology, the term asbestos is "... a commercial term applied to a group of highly fibrous silicate minerals that readily separate into long, thin, strong fibres of sufficient flexibility to be woven, ..."

This definition would exclude amphiboles such as crocidolite, because of their insufficient flexibility, as well as most commercial grades of chrysotile, which are far too short to be woven.

(2) The list of 6 minerals shown in Fig. 2.1, including 5 minerals from the group of amphiboles, and one from the group of serpentines, is often referred to as being the commercial varieties of asbestos, and is, on that basis, used as a definition of asbestos for regulatory purposes in many countries, including the recently adopted EEC asbestos regulations (Council Directives 83/477/EEC of 19 September 1983). Yet, this list includes actinolite, a variety which is not being used commercially and for which there are no human studies of any kind linking this fibre type to adverse health effects.

(3) OSHA, in its notice of proposed rulemaking for "Occupational Exposure to Asbestos", published in the Federal Register (October 9, 1975, p. 47652, 47660) goes a step further in saying that the naturally occuring minerals, chrysotile (of the serpentine group); amosite, crocidolite, tremolite, anthophyllite and actinolite (of the amphibole group) are classified as asbestos "if the individual crystallites or crystal fragments display a length greater than 5 micrometers, a maximum diameter less than 3 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".

(4) In Court, a still wider ranging meaning has been attributed to the term asbestos. In the Reserve Mining Co. case in 1974, Judge Miles Lord ruled, on behalf of the U.S. District Court for Minnesota, that

"Asbestos is a generic term for a number of hydrated silicates that, when crushed or processed, separate into flexible fibres made of fibrils" (498.F.2d 1073 (1974)).

The issue of definition is important when viewed in relation to health implications. The inclusion of actinolite in the list referred to under (2) above infers the view that all mineral fibres may be hazardous. The extension by OSHA of the definition of asbestos in the last sentence quoted under (3), and the far reaching definition by the U.S. District court for Minnesota mentioned under (4) imply that various issues, discussed further in this report, may not be seen as confined to what is traditionally called "the asbestos industry". They extend into many other industries and substances and this should be borne in mind in particular when discussing issues such as (a) sources of emissions and (b) the field of application of asbestos regulations.

It should be noted that many of these minerals may occur in a non-fibrous form, in which case they should not be classified as asbestos. On the other hand, the number of minerals other than asbestos that exhibit fibrous structure is impressive. Bank (1980), employing the mineralogic definition has identified 152 minerals as "asbestiform". Their presence in ambient air is described in a recent report by the U.S. National Academy of Sciences (1984).

The asbestiform minerals are characterised by their ability to separate into small fibres and ultimately, individual fibrils. Individual fibrils of chrysotile have diameters of the order of 0.02 um, but the largest dimension of a single crystal is 0.0009 um (9.2 A). Similarly an amphibole fibril of 0.1 um cross section is composed of single crystals of 0.0018 um (18 A) in the largest dimension.

Asbestiform minerals are an ubiquitous impurity in many deposits of commercially valuable, non-metallic minerals such as talc and mica (Speil and Leineweber, 1969). Anthophyllite and tremolite have been found to constitute minor or major fractions of commercial talc (Schulz and Williams; Merliss; Blejer and Arlon; Kleinfeld et al.). Rohl and Langer (1974) have discussed the geological coexistence of talc and many hydrated magnesium minerals, many of which are asbestos. Asbestos minerals are also associated with metallic mineral deposits. They frequently accompany ores of ferrous and non-ferrous metals, such as iron, nickel, chromium, copper and gold. In a 1974 U.S. EPA report, 16 specific large scale non-asbestos mining operations were identified as having asbestos. In addition, the study identified 6,000 mining operations (out of an approximate U.S. total of 15,000) which could theoretically have asbestos fibres in the ore or gangue rock.

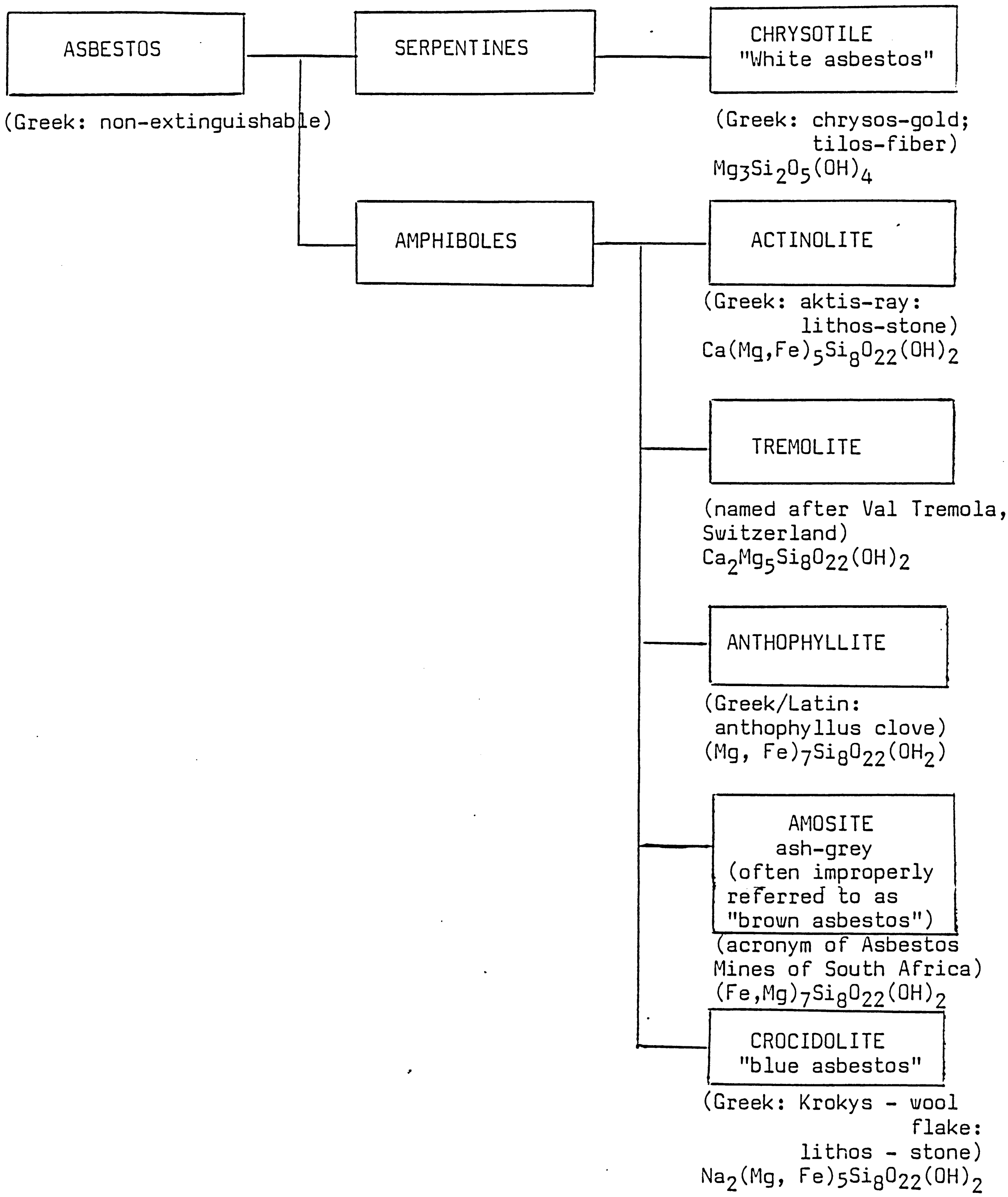


Figure 2: ASBESTOS MINERALS

2.2 Geological Formation

All forms of asbestos develop through several stages of geologic processes (paragenesis) from parent rock that is transformed into asbestos. Parent rocks of asbestos minerals include basic constituents normally found in ultramafic (Mg Fe rich), dolomitic, or limestone rocks. Transformation may occur under localised conditions of temperature and pressure which lead to recrystallization of other in-situ minerals (metamorphism). It may occur as a result of the action of hot mineral solutions that can dissolve or otherwise alter some minerals to form others (hydrothermal processes) (US Department of Health, Education and Welfare, 1978).

Serpentine asbestos (chrysotile) is formed through postmagmatic hydrothermal (temperatures $>360°C$) metamorphism of ultra-basic, magnesium (Mg) - and aluminium (Al) - containing rock, such as dunite, gabbro and basalt. These rocks consist almost entirely of olivine and sometimes, pyroxene and amphiboles (Lanting and den Boeft, 1979)

Technically important are those chrysotile fibre bundles which are found in veins of ultramafic belts (serpentine belts) and have been separated through a gel phase. It is differentiated between cross fibres which are perpendicular to the veins, and slip fibres which are approximately parallel to the veins (Wicks, 1979). The wide geological distribution of serpentine rock, for example in Alpine-type mountain chains, make chrysotile a very common mineral . Besides chrysotile, several ores are present in these belts (e.g. taconite, as already pointed out under 2.1) (Lanting and den Boeft, 1979).

Amosite and crocidolite are formed in thermally metamorphosed banded iron stones. Anthophyllite asbestos occurs in metamorphosed ultramafic rock and is sometimes associated with talc (compare 2.1). Tremolite asbestos is characteristic for metamorphosed dolomitic limestone; actinolite is found in low grade schists. All amphiboles account for only 5% of the commercially used asbestos (Lanting and den Boeft, 1979).

2.3 Crystallography

Mineralogically, asbestos fibres can be differentiated into serpentines and amphiboles according to their different crystal structure.

Similar to all natural silicates, chrysotile (serpentine asbestos) and the amphiboles have silicon-oxygen tetrahedra as their basic structural unit. The structural difference between the two classes is related to the arrangement of the tetrahedral units.

2.3.1 Serpentine Asbestos

In chrysotile, the tetrahedral units form silicon oxide (Si_2O_5) double layers, resulting in a laminar structure; these silica layers are held together by layers of brucite ($Mg(OH)_2$). The silica layers have a tighter spacing than the magnesium hydroxide (brucite) layers and as a result, they are contorted into hollow tubes with the $Mg(OH)_2$ layer on the outside (USEPA, 1975). A schematic diagram of the structure of a chrysotile fibre is shown in Figure 2.2 (Hodgson in USEPA, 1975).

The finest fibres (fibrils) can be considered the fundamental form of chrysotile and range from 150 to 400 A in diameter.

2.3.2 Amphibole Asbestos

The amphiboles differ in that they combine to produce silicon oxide (Si_4O_{11}) double chains, which are held together by cation linkages. The chains or strips are loosely bonded to each other along the edges and faces so that fibrous cleavages readily occur (USEPA, 1975). Amphiboles are characterised by a preferred crystallographic orientation of the fibrils and thus, tend to split parallel to the fibre axis. A schematic diagram of the crystal structure of an amphibole fibre is shown in Figure 2.3 (Hodgson in USEPA, 1975).

The smallest fibres of amphibole asbestos - usually between 800 and 1000 A in diameter - are coarser than chrysotile fibrils and do not exhibit the tubular structure, but are solid.

As will be pointed out in Chapter 3, it is not generally possible to differentiate between the various amphiboles by fibre morphology alone.

2.4 Physical and Chemical Properties

Chrysotile asbestos and the different types of amphiboles can be distinguished by their chemical compositions as already indicated in Figure 2.1, and they possess different physical and chemical properties.

The main characteristics which give all asbestos its commercial value are incombustibility, tensile strength, and its effectiveness as a reinforcing and/or binding agent. The different types are also, in different degrees, resistant to high temperatures, electric current, and alkalis, and may be efficient in absorbing sound; in addition, the amphiboles are resistant to acids. Chrysotile and crocidolite fibres can be spun and woven into cloth. Detailed physical and chemical properties of the different asbestos types are summarised in Table 2.1.

The surface characteristics of the asbestiform minerals seem to be very important in relation to their interaction with whatever environment they may be exposed to. The external surface of chrysotile fibres consists of magnesium hydroxide. The pH of a suspension of chrysotile in distilled water is 10.3 comparable to a value of 10.4 for magnesium hydroxide suspension under the same conditions. This can be attributed to the removal of hydroxyl groups from the chrysotile surface. When suspending chrysotile in acid solutions the dissociation of the surface is more pronounced because of the interaction of surface hydroxyl groups with hydrogen ions and the surface charge is strongly positive. Below a pH of 3, the magnesium ions are removed and the silica surface exposed.

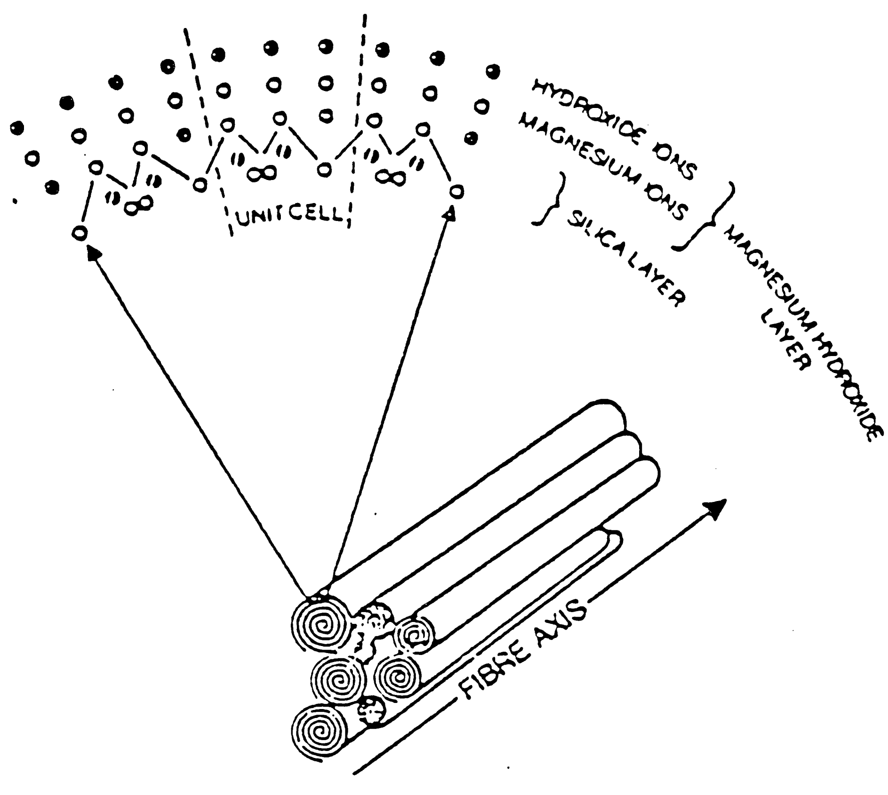


Figure 2.2 Schematic Diagram of a Chrysotile Fiber (Dr. A.A. Hodgson in USEPA, 1975).

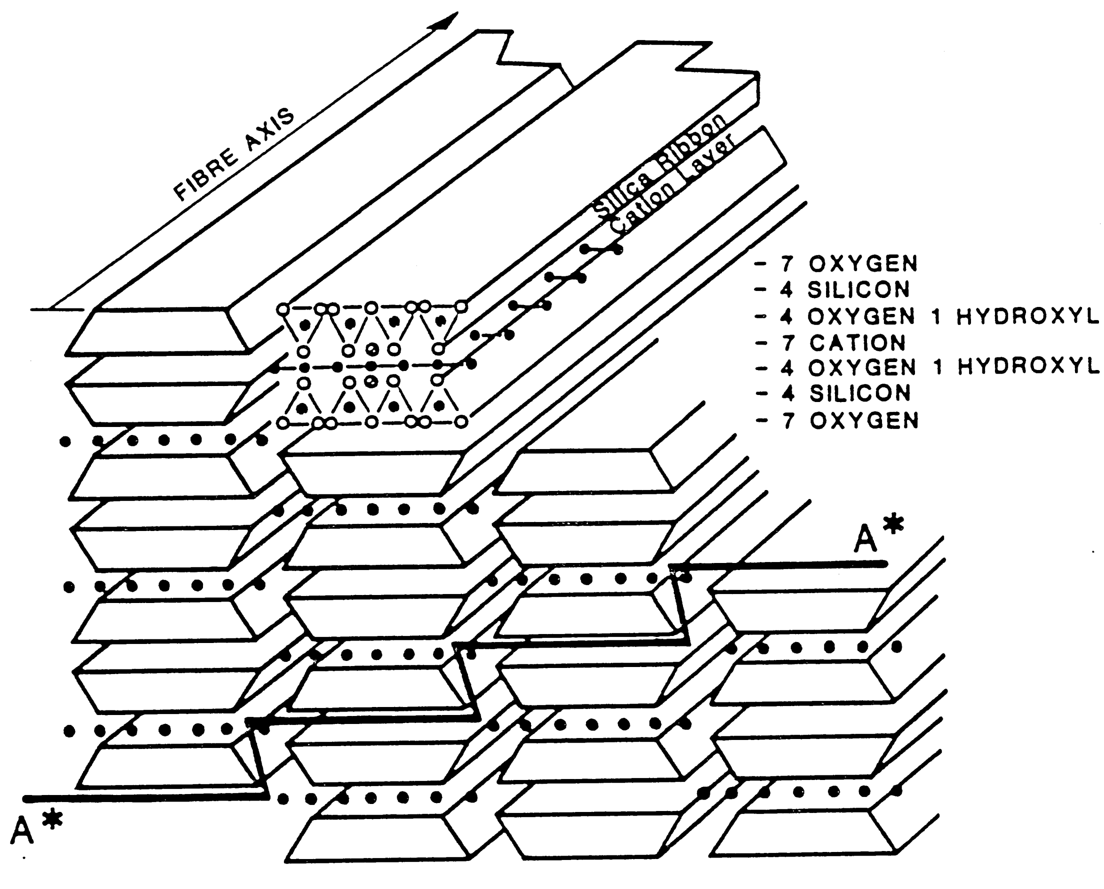


Figure 2.3 SCHEMATIC DIAGRAM OF AN AMPHIBOLE FIBER
(Dr. A. A. Hodgson in USEPA, 1975)

* A–A REPRESENTS THE EDGE OF THE PREFERRED CLEAVAGE PLANE ALONG WHICH THE FIBER WILL SPLIT TO FORM EVEN SMALLER FIBERS.

Chemically, the surface of amphiboles is similar to that of silica. It is polar in nature, the surface charge being weakly electronegative, whereas the surface charge of chrysotile is strongly electropositive.

The surface area of chrysotile is generally high, dependent on the degree of fibre bundle openess (up to 50 m^2/g for fiberized material). It has been shown that leaching of magnesium from chrysotile results in an increase of the surface area (to about 450 m^2/g). The surface area of amphibole asbestos is considerably lower than that of chrysotile (to 15 m^2/g) for fully fiberized material.

The adsorption of various materials on the surface of chrysotile has been studied from both the liquid and vapour states: nitrogen, argon, carbon monoxide, acetylene, n-butane, trimethyl amine, ammonia, water vapour, ethanol, benzene, hexane, human serum albumin, etc. The adsorption data show that the polar surface of chrysotile has a greater affinity for polar molecules than for non-polar ones. In liquids, the stability of asbestos fibres is pH dependant. In comparison with amphibole asbestos, chrysotile is rather chemically unstable in water solutions, in inorganic and organic acids, and also in human tissue. Leaching of magnesium from chrysotile fibres in human lung has been demonstrated by several researchers (Bignon et al., 1979).

TABLE 2.1

Physical and Chemical Properties of the Different Asbestos Types

Property	Chrysotile	Actinolite	Tremolite	Anthophyllite	Amosite	Crocidolite
Veining	cross and slip fibers	slip or mass fibers	slip or mass fibers	slip mass fibers unoriented and interlacing	cross fibers	cross fibers
Color	green, grey, amber to white	greenish	grey-white, greenish, yellowish, bluish	yellowish brown, greyish, white	ash-grey	blue
Texture	Soft to harsh, also silky	harsh	generally harsh, sometimes soft	harsh	coarse but somewhat pliable	soft to harsh
Luster	silky	silky	silky	vitreous to pearly	vitreous, somewhat pearly	silky to dull
Density [g/cm^3]	2.4-2.6	3.0-3.2	2.9-3.2	2.8-3.2	3.1-3.6	2.8-3.4
Hardness*)	2.5-4	6	5.5-6	5.5-6	5.5-6	5-6
Flexibility	very high	poor	poor	poor	good	good
Spinn-ability	very good	poor	poor	poor	poor	good
Morphology	fibrous and asbestiform	long and thin columnar to fibrous	long and thin columnar to fibrous	prismatic, lamellar to fibrous	prismatic, lamellar to fibrous	fibrous

TABLE 2.1 (Cont.

Property	Chrysotile	Actinolite	Tremolite	Anthophyllite	Amosite	Crocidolite
Crystal system	monoclinic and orthorombic	monoclinic	monoclinic	orthorhombic	monoclinic	monoclinic
Tensile strength $[10^3 N/mm^2]$	3.64-3.78	NDA**)	NDA**)	2.45	1.44-2.58	1.44-4.66
Modulus of elasticity $[10^3 N/mm^2]$	145	NDA**)	NDA**)	156	143	147-170
pH	9.2 - 9.8	neutral	neutral	neutral	neutral	neutral
Resistance to acids	poor	good	good	good	good	good
Electric charge	positive	negative	negative	negative	negative	negative
Dielectricity constant (220V/60Hz)	33.7	-	-	8.4	-	6.7
Specific resistance $[10^6 \Omega\ cm]$						
- dry	<1-2,100	NDA**)	NDA**)	190,000-900,000	8,000-30,000	48,000-109,000
- 50 % relative humidity	0.01-1.0	NDA**)	NDA**)	1,700-2,100	14-1,400	34-95
- 91 % relative humidity	<0.01-0.4	NDA**)	NDA**)	6-19	1-1,360	0.6-2.3

TABLE 2.1 (Cont.)

Property	Chrysotile	Actinolite	Tremolite	Anthophyllite	Amosite	Crocidolite
Insulating capacity [Ω /cm] (15 % relative humidity, 22°C, 100V/cm)	1.1 x 108	NDA**)	NDA**)	124 x 108	–	–
Optical properties	biaxial positive, extinction parallel	biaxial negative, extinction inclined	biaxial negative, extinction inclined	biaxial positive extinction parallel	biaxial positive, extinction parallel	biaxial +, extinction inclined
Refractive index	1.532-1.549	1.599-1.688	1.599-1.688	1.596-1.694	1.665-1.696	1.654-1.701
Specific heat [J /kg°K]	1,112	908	887	879	908	841
Fusion point [°C]	1,521	1,393	1,360	1,468	1,399	1,193
Temperature at ignition loss [°C]	650-700	960-1080	950-1040	850-1000	800-900	400-600
Resistance to destruction by heat	good, brittle at high temperatures	–	fair to good	very good	good, brittle at high temperatures	poor, fuses
Filtration properties	slow	medium	medium	medium	fast	fast

* Working scale of hardness: 1. very easily scratched by fingernail, 2. easily scratched by fingernail, 3. scratched by brass pin or copper coin, 4. easily scratched by knife, 5. scratched with difficulty with knife, 6. easily scratched by file, 7. little touched by file, but will scratch window glass.

** NDA: no data available.

2.5 References to Chapter 2

Bank, W., (1980); Asbestiform and/or Fibrous Minerals in Mines, Mills and Quarries. Mines Safety and Health Administration Information REPORT IIII, U.S. Department of Labor.

Bignon, J., Sébastien, P., and Bientz, M. (1979); Use of Biological Specimens for the Assessment of Human Exposure to Environmental Pollutants, M. Nijhoff Publisher, The Hague, 73-108.

Blejer, H.P., and Arlon, R. (1973); Talc: A Possible Occupational and Environmental Carcinogen, J. Occup. Med., Vol. 15, No. 2.

Deere, W.A., Howie, R.A., and Zussman; Rock Forming Minerals, Vol. 2, 7th edition, Longmann Group Ltd., 1974.

Hodgson, A.A.; in USEPA-560/2 - 75-000.

Kleinfeld, M. (1973); Biologic Response to Kind and Amount of Asbestos, J. of Occup. Med., 15, 296-300.

Lanting, R.W., and den Boeft, J.; Atmospheric Pollution by Asbestos Fibers, EC Report EUR 6768 EN, IMG-TNO Report G908, November 1979.

Merliss, R.R. (1971); Talc Treated Rice and Japanese Stomach Cancer, Science, 173, 1141.

Rohl, A.N. and Langer, A.M. (1974); Identification and Quantification of Asbestos in Talc, Environmental Health Perspectives, 9, 95-109.

Schulz, R.Z., and Williams, C.R. (1942); Commercial Talc - Animal and Mineralogical Studies, J. Ind. Hyg. and Toxic., 24, No. 4, 24.

Speil, S. and Leineweber, J.P. (1969); Asbestos Minerals in Modern Technology, Environ. Res. J., 2, 166-208.

Umweltbundesamt (UBA); Luftqualitätskriterien - Umweltbelastung durch Asbest und andere faserige Feinstäube, Kapitel 3 - Stoffbeschreibung, Berichte 7/80, Berlin, 1980.

US Department of Health, Education and Welfare; Asbestos: An Information Resource, DHEW Publ. No. (NIH) 79-1681, May 1978.

USEPA; Asbestos: A Review of Selected Literature through 1973 Relating to Environmental Exposure and Health Effects, Report EPA 560/2-76-001, Office of Toxic Substances, Washington D.C., September 1975.

U.S. National Academy of Sciences (1984), Committee on Non-occupational Health Risks of Asbestiform Fibres, Washington (see ref. Chapter 6).

Wicks, F.J.; Serpentine Mineralogy, Petrology and Paragenesis, The Canadian Mineralogist 17 (1979), p. 637-904.

3. MEASURING METHODS

3.1 General

Methods for measuring concentrations of airbone asbestos are needed to characterize the situations in the following three settings.

-- the workplace, to monitor conditions at mines, mills and manufacturing plants;

-- exhaust emission control from dust filtering equipment used in the industry; and

-- the ambient atmosphere, to monitor conditions close to or away from sources emitting airborne asbestos.

The International Standards Organization (ISO) Technical Report 7708, dated 1983, recommended a definition to describe the particle size distribution of the inspirable fraction of the total airborne material available. This definition states that the fraction drawn into the nose or mouth with aerodynamic diameters (a.d.) smaller than 200 um (density 1) should be divided into extra thoracic (a.d. 200 to 5 um), tracheobronchial (a.d. 30 to 1 um) and alveolar (a.d. 10 and 7 respectively to smaller than 0.1 um) fractions (see Figures 3.1 and 3.2).

For example, in the USSR the total inspirable fraction is selected for measuring the concentration of airborne asbestos (ILO 1983). In the majority of countries however, only the biologically relevant alveolar fraction - termed "respirable dust" is selected for monitoring.

Concentrations of airborne asbestos in the workplace and/or the ambient atmosphere are expressed numerically either in fibres/ml or fibres/m^3 for measuring the alveolar fraction (EEC 1983, ILO 1983). Units expressed in milligrams/m^3 are used for measuring the combined presence of fibrous and non-fibrous dust in the workplace and for exhaust emission control. In both instances, all of the inspirable fraction or just the alveolar fraction may be considered. Units expressed in nanograms/m^3 may be used to measure concentrations of the alveolar fraction in the ambient atmosphere.

A measurement of mass concentration on the basis of density may be calculated from detailed information on the concentration of respirable asbestos fibre defined in numerical terms (EEC 1983, ILO 1983). Necessary details would include available data in fibres/ml, fibres/l or fibres/m^3, with particle aspect ratios (length to diameter) greater than 3:1. The particle length is defined as being not less than 5 um with a geometric diameter less than 3 um. This latter dimension is equivalent to an aerodynamic diameter less than 10 um or 7 um, depending on the standard used to define the alveolar fraction.

The sampling procedure in all three settings is basically the same for determining numerical fibre concentration or the gravimetric concentration (mg/m^3). A given air volume is sucked onto a filter (membrane or Nuclepore) during a given interval with suitable pumps and the concentration of the dust deposited on the filter is subsequently determined.

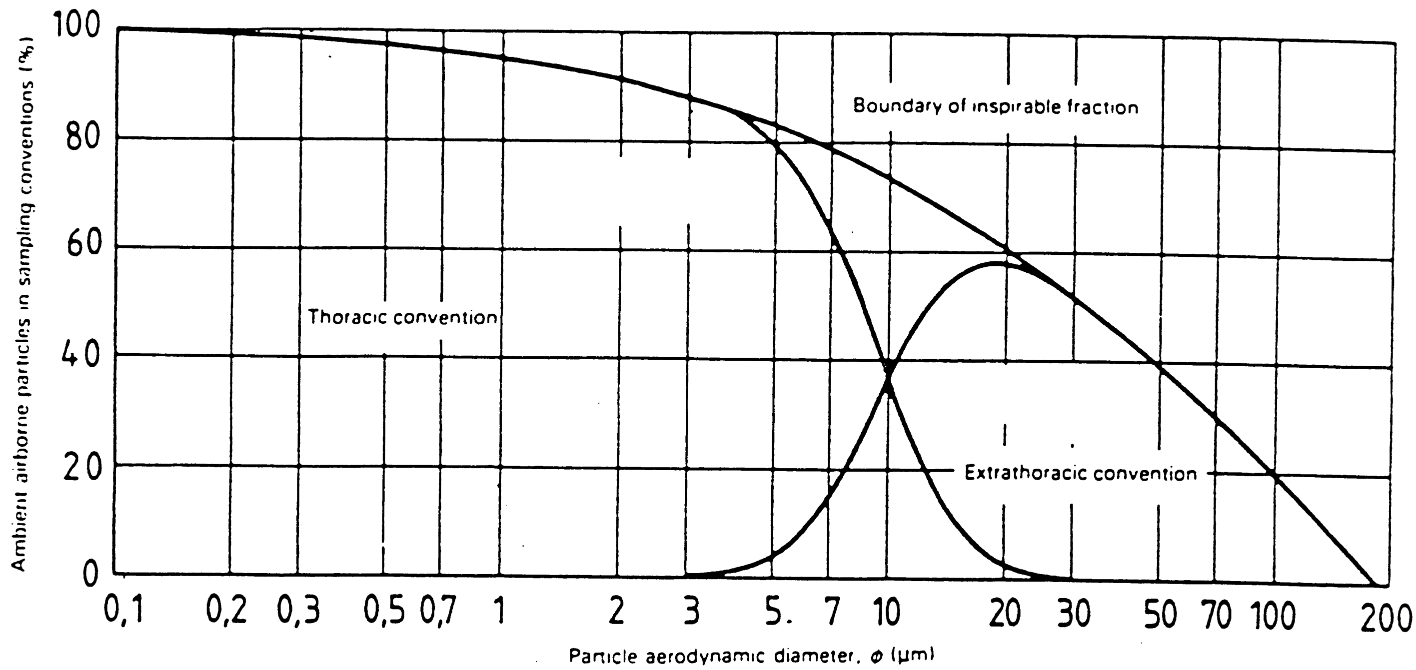


Figure 3.1 – The inspirability ξ(φ) and the sampling conventions corresponding to the extrathoracic fraction and to the thoracic fraction

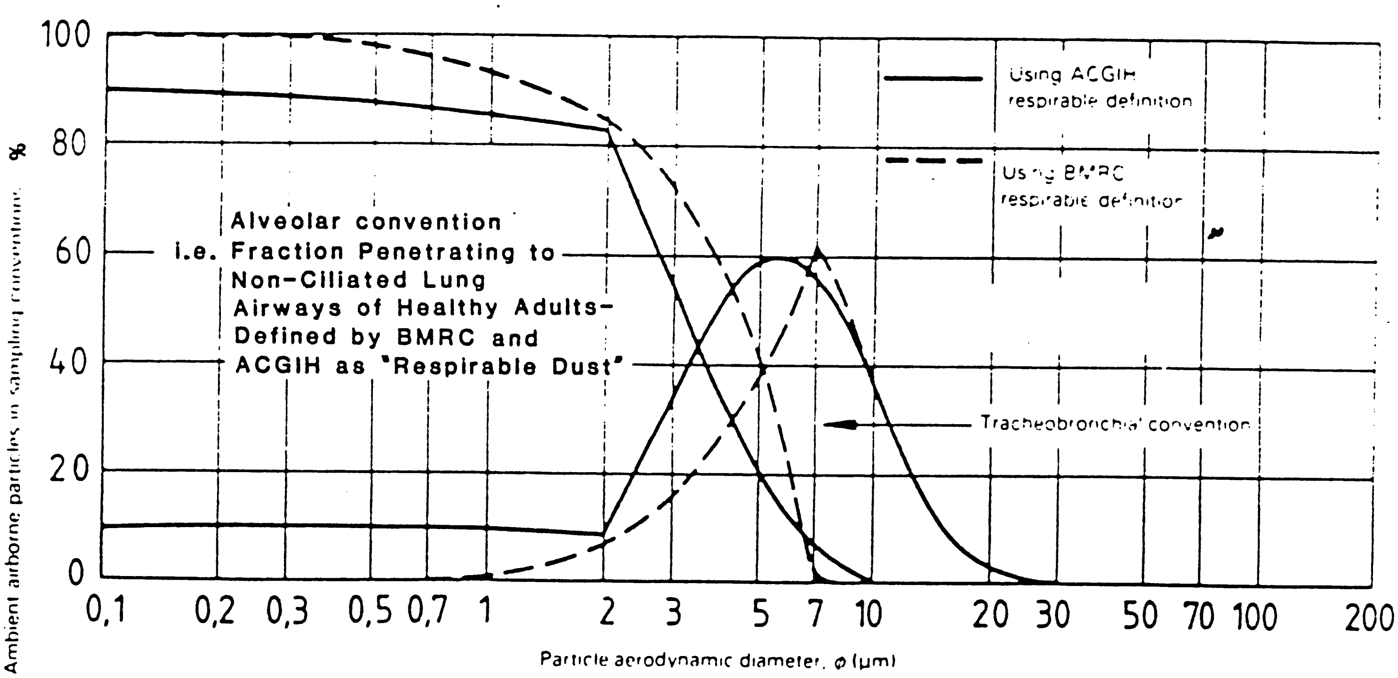


Figure 3.2 – Division of the thoracic convention of figure 1 into the alveolar convention and the tracheobronchial convention, where the target population is healthy adults

For determining gravimetric concentrations in the alveolar fraction, sampling instruments must be equipped with a preseparator for the extra thoracic and tracheobronchial fractions.

Sampling time is dependent on the concentration of airborne asbestos, as well as other dust particles, and can vary from less than 1 h for workplace conditions, to 24 h for the ambient atmosphere.

Sampling strategy differentiates between static sampling at fixed locations and personal sampling within the workers' breathing zone (ILO 1983). Static sampling is done for engineering control in the workplace setting and for exhaust emission control, as well as for monitoring the ambient atmosphere. The purpose of personal sampling in the workplace is to assess compliance with regulations.

Evaluation and/or analysis of dust-laden filters is different for the three settings considered in this industry. For determining the numerical concentration of fibres at the workplace, light microscopy is applied and all fibres conforming to the given size criteria are counted. Reliable identification of fibre type is not possible with light microscopy, however, most fibres present in the workplace and exhaust emission settings in particular are asbestos. For evaluation of filter samples from the ambient atmosphere analytical electron microscopy is used because individual fibres must be identified and analyzed quantitatively. Asbestos generally constitutes only a small proportion of the total fibrous content of ambient air.

Furthermore, long fibres (more than 5 um) with smaller diameters (less than 0.2 um) can occur in the ambient atmosphere but may not be apparent because they are not visible in the light microscope. For gravimetric evaluation of filter samples (mg/m^3) from the workplace and exhaust emissions, various common methods are available. These include weighing the filter with and without dust and/or measuring absorption of energy from radioactive material dependent on the mass of dust deposited. Also, a qualitative and quantitative infrared spectroscopy or x-ray diffraction analysis with regard to composition of filter dust can be carried out on these samples of relatively large quantities of dust resulting from a required long period of collection.

Direct-reading instruments such as particle counters and dust photometers are only used for static monitoring, engineering control and exhaust control. For reliable evaluation of workplace conditions, these instruments need to be calibrated carefully to properly characterize the dust in the workplace.

To obtain comparable results, there is a need for an international agreement on a Common Reference Method, or better Standard Methods for all three settings.

3.2 Workplace Atmosphere

3.2.1. Light Microscopy

Several versions of a method for counting respirable fibres on filters (cellulose ester membrane filters of 1.2 um pore size) have been developed (Asbestos Research Council 1971, Leidel et al. 1979, Asbestos International

Association 1979, U.S. Public Health Service/National Institute for Occupational Safety and Health 1979, U.S. National Institute for Occupational Safety and Health 1984), all of which are based on phase contrast light microscopy. The principles of this method, based on the AIA/RIM1 method, were adopted by the European Economic Communities (EEC 1983) and the International Labour Office (ILO 1983) and details need not be described here. The same principles are now under discussion for acceptance by the International Standards Organization (ISO).

Using phase contrast light microscopy, asbestos fibres down to about 0.25 um in diameter (lower for amphiboles than for chrysotile) are visible and countable. The detection limit of this method is defined as the minimum fibre concentration which can be detected above the background fibre count and is usually 0.01 fibre/ml. Theoretically, the detection limit can be lowered by increased sampling time, but this cannot normally be achieved in industrial situations because dust levels can lead to overloading the filter.

Evaluation of one sample takes about half an hour.

Faster counting of fibres may be effected by automatic evaluation of filter samples. In principle, such evaluations can be conducted by image analyzing systems (Dixon and Taylor 1979, Burdett et al. 1982) or based on magnetic alignment combined with scattered light measurements (Gale and Timbrell 1980). The main advantage of such evaluation procedures is that the human factor can be eliminated. An image analysis system is at present used by the United Kingdom Health and Safety Executive for screening its filter samples collected in the asbestos textile, cement, and friction material industries. The relationship between machine count and manual count is reported to be generally as good as between different manual laboratories. The machine, where it is used, has reduced manual counting in the laboratory by about two thirds (Kenny 1984). The instrument by Gale and Timbrell yields results which require individual calibration for each size distribution, consequently, interpretation is difficult.

In common with other microscopic methods, the light microscopy method for asbestos can display large interlaboratory differences in results, and systematic quality control by regular exchanges of samples is an essential adjunct to the method. An informal exchange scheme, AFRICA (Asbestos Fibre Regular Informal Counting Arrangement) covering seventeen laboratories in twelve countries, is run from the United Kingdom. In addition, some overseas laboratories participate in the PAT (Proficiency Analytical Testing) Scheme run by the United States National Institute for Occupational Safety and Health.

Finally, it must be stressed that in recent years the development, improvement and refinement of the Membrane Filter Method by Light Microscopy in phase contrast has led to higher sensitivity and thus to stricter assessment of conditions in the workplace. Accordingly, more rigid control has in fact resulted in lower concentration levels being achieved than a comparison of numerical data would indicate.

3.2.2. Other Methods

Other methods for measuring concentrations, namely gravimetric and optical, can be used especially for engineering control. These methods may provide supportive information to numerical fibre data from individual work places, providing accurate conversion factors relating to the Membrane Filter Method can be established. The disadvantage of these other methods is that they do not permit discrimination of fibrous from non-fibrous dust particles. Also, they have not been shown to provide a better index of the hazards to health.

To determine the total mass of respirable dust, fibrous and non-fibrous material alike, gravimetric instruments such as the MRD, MPG or VC 25 can be used. In these instruments, only the alveolar fraction is measured. A disadvantage of this approach, if concentrations of dust are low, is that a very long sampling period of 4 h or more is required to collect a sample of adequate size for analysis.

To measure concentrations of dust by the scattered light principle, optical instruments such as the Tyndallometer, the Royco Particle Counter or the Fibrous Aerosol Monitor (FAM) are used. These represent direct-reading instruments to which a recorder can be connected. The advantage of this approach is that it is possible to:

-- locate dust sources immediately,

-- determine instantly the efficiency of dust suppression measures,

-- record variations of dust concentrations, and

-- determine short-time peak concentrations.

Attention should, however, be paid to the fact that the optical method is a relative method and that the measured concentration of airborne dust, apart from the actual quantity available, is also dependent on the size distribution of the fibrous and non-fibrous particles alike.

For special research purposes, application of electron microscope methods may be meaningful. However, evaluation would have to be releated to the Membrane Filter Method by Light Microscopy in phase contrast using procedures for counting fibres of the same dimensions. For this, numerical fibre concentrations would have to be distinguished for fibres with lengths greater than and less than 5 um and diameters greater than and less than 0.25 um. Clearly, for routine measurement of conditions in the workplace, the application of electron microscopy is neither feasible nor necessary.

3.3 Exhaust Emission

Measurements of exhaust emissions from filtering equipment used in the asbestos industry have the following objectives:

-- testing efficiency of the equipment,

-- periodic check-ups on the overall performance of equipment and particularly,

-- confirming the equipment's compliance with established limit values.

These steps, properly taken, should ensure that the emission of asbestos dust from the workplace into the ambient air will be as low as technically feasible.

In principle, two methods can be applied:

1. Measurement of numerical fibre concentration in fibres/ml and,

2. Measurement of mass concentration in mg/m^3.

Both methods have advantages and disadvantages which should be considered.

Measurement of fibre concentrations is important if it is necessary to know the amount of fibres escaping into the atmosphere. However, the measurement technique is not easy and if too long a sampling time is employed at higher concentrations it is possible to overload the filter. In many instances a sampling time of 5 to 15 minutes will be satisfactory.

The advantages of measuring mass concentrations are:

-- that the total dust emitted is known, and

-- that if required, this approach allows analysis of components of the dust (not only asbestos) by means of infrared spectroscopy or x-ray diffractometry.

The disadvantage of the mass concentration method is that it is necessary to sample for 1 hour and 8 hours depending on the concentration present and the sampling equipment used to ensure that sufficient material is captured for weighing. Also sampling should be conducted isokinetically at four or more sampling points in the sampling plane.

For achieving the objective of reducing emissions as much as technically possible, procedures should involve regular sampling of emissions, in addition to having planned maintenance programmes and good operator training.

A biologically relevant evaluation of the fibres emitted, along with their concentration, is not necessary and would probably only fulfil parts of the control objectives desired.

With proper filter material and appropriate cleaning and maintenance using high capacity units, total dust concentrations of less than 1 mg/m^3 and asbestos concentrations of less than 0.1 mg/m^3 could be achieved. Measurement and analysis respectively, should confirm that adequate control is in place.

The duration of sampling for gravimetric evaluation takes 2 hours on average. Evaluation (measurement of concentration) including analysis, can be carried out in less than 1 hour, on average.

Until now, published results for concentrations of fibrous particles and/or asbestos particles measured by electron microscopy, were often published only for an aspect ratio (length to diameter) greater than 3:1, irrespective of actual length and diameter.

This general approach does not allow meaningful comparisons to measurements taken in the workplace because no data was provided on the lower visibility limits (based on magnification) and on a division based on diameter.

For continuous but more costly control of the effectiveness of filtration equipment, optical dust-measuring instruments can be used. In this case, the objective is not precise measurement of dust concentration or composition, but only determination if a certain total concentration of dust is exceeded (e.g. 1 mg/m^3), as in the case of a leakage in the filtering system.

The Asbestos International Association over the past three years developed a "Method for the Determination of Airborne Asbestos Fibres and other Inorganic Fibres by Scanning Electron Microscopy" (RTN2). This work was concluded in 1984. A similar study using the same method is available in draft form from the VDI (1984), Germany, "Messen anorganischer faserförmiger Partikeln in der Aussenluft - Rasterelektronenmikroskopisches Verfahren" (Measuring of inorganic fibrous particles in ambient air - scanning electron method) and is presently under final discussion. In March 1984, a document entitled "Proposed Analytical Method for Determination of Asbestos Fibres in Air", was submitted to the International Standards Organization (ISO) for discussion). This deals in particular with transmission electron microscopy (ISO 1984).

A directive on controlling emissions from filtering equipment, including measurement techniques, is presently being compiled by Directorate-General XI of the EEC.

3.4 Ambient Atmosphere

In the ambient atmosphere, airborne asbestos fibres comprise a very small minority of the total number of particles present. Moreover, the types of fibres which may be present are unknown. Also, the diameters of asbestos fibres found in the ambient atmosphere are usually smaller than in the workplace environment, perhaps below the minimum which can be detected by phase contrast light microscopy. Normally, the lengths of the fibres in the ambient environment are shorter than 5 um. Therefore, evaluating these samples requires another method, so-called analytical electron microscopy (AEM). This includes either scanning electron microscopy/SEM or transmission electron microscopy/TEM (STEM) with energy dispersive x-ray analyzer (EDXA) and selected area electron diffraction (SAED).

For purposes of correlating these AEM measurements with those in the workplace taken by routine measurements (Membrane Filter by Light Microscopy) AEM-based size data must be divided into two groups as follows:

-- for fibres longer than 5 um and diameters greater than and less than 0.25 um;

-- for fibres shorter than 5 um and diameters greater than and less than 0.25 um.

Sampling in the ambient environment may take a long period of time because of low concentrations of fibre. However, a minimum sample volume of 0.5 m^3 is necessary and technically the time required for collecting is less important. Evaluation and analysis takes about one day per sample because each fibre must be sized, counted and analyzed qualitatively. The detection limit for the concentrations is between 1 000 fibres/m^3 and 100 fibres/m^3 (0.001 to 0.0001 fibres/ml), depending on the volume sampled and filter area examined. For comparison, it should be noted here that the equivalent single fibre criteria, as applicable to workplace conditions, are: diameter, 0.2-0.3 um; length greater than 5 um and length/diameter ratio greater than 3.

3.4.1 Scanning Electron Microscopy

Scanning electron microscopy (SEM) in reflexion can qualitatively directly analyze fibres on a Nuclepore filter (polycarbonate of 0.8 um pore size) down to a diameter between 0.1 and 0.2 um and thus distinguish asbestos fibres from others by energy dispersive x-ray analysis (EDXA). The visibility of fibres depends on magnification and is possible with smaller diameters down to 30-40 nm.

3.4.2 Transmission Electron Microscopy

A modern transmission electron microscope (TEM) has a resolution of about 0.2 nm (SEM; 5 nm; 1 nm = 10^{-9}m), which is more than adequate for resolving unit fibrils of chrysotile. In the TEM, fibres can qualitatively be analyzed down to a diameter of 0.01 um by energy dispersive x-ray analysis (EDXA). Additionally, the selected area electron diffraction (SAED) has some characteristic features for determining the crystal structure of a fibre or a particle. The detection limit for the concentration is the same as for the SEM as described. A complete evaluation and/or analysis whilst applying the EDXA and SAED, however, takes up to 4 days for a sample. Two types of specimen preparations are possible: direct and indirect. The direct transfer procedure transfers particles from a particular area of the filter onto the same area required for a TEM specimen. In the indirect methods, used particularly when concentration or dilution of the sample is required, the filter is ashed and the residual material is resuspended in water. The water suspension can be prepared by a number of methods for TEM examination. Some of these techniques incur large and unreproducible losses of fibres, and others are sensitive to low levels of contamination sometimes present in the sample collection filters. It is also claimed that some techniques cause high fibre counts to be reported bacause particular steps in the specimen preparation fragment large fibres into greater numbers of smaller ones.

The application of the TEM is very advantageous because of lattice-structure analysis via electron diffraction and also because of a higher probability of identifying unknown fibres. However, the significance of the improved resolution of very thin and very short fibres is not clear.

In a few laboratories in some countries, numerical fibre concentrations, as measured by TEM, are converted into units of mass concentration (ng/m^3). However, it is doubtful what this conversion represents a better index for quantifying the biological effects of fibres.

3.5 Cost Considerations

Average costs for measurements in the workplace atmosphere amount to:

$US 20 000 for equipment of a laboratory (light microscope with phase contrast and 5 pumps plus accessories, evaluation, installation);

$US 500 for the sampling per day (max. 10 samples);

$US 30 for the evaluation per sample.

Average costs for measuring exhaust emissions amount to:

$US 50 000 for the apparative equipment (sampling instrument, scales, infrared spectrometer, Tyndallometer)

$US 500 for the sampling per day (2 samples)

$US 500 for the evaluation per day (weighing, IR-analysis) (6 samples)

For measuring the ambient atmosphere the average costs amount to:

Scanning Electron Microscopy

$US 200 000 for the apparative installations

$US 500 per day for the sampling (4 samples)

$US 500 per sample for the evaluation (1 day)

Transmission Electron Microscopy

$US 500 000 for the apparative installations

$US 500 per day for the sampling (4 samples)

$US 500 per sample for the evaluation (4 days)

3.6 References to Chapter 3

Asbestos International Association (AIA), Reference Method for the Determination of Airborne Asbestos Fibre Concentrations at Workplaces by Light Microscopy (Membrane Filter Method). AIA Health and Safety Publication, Recommended Technical Method N° 1 (RTM1), Asbestos International Association, 68, Gloucester Place, London, W1H 3HL, England.

Asbestos International Association (1984), Method for the Determination of Airborne Asbestos Fibres and other Inorganic Fibres by Scanning Electron Microscopy. AIA Health and Safety Publication, Recommended Technical Method N° 2 (RTM2). Asbestos International Association, 68, Gloucester Place, London, W1H 3HL, England.

Asbestos Research Council (1971), The Measurement of Airborne Asbestos Dust by the Membrane Filter Method. Technical Note 1, Asbestosis Research Council, P.O. Box 40, Rochdale, Lancashire, England.

Burdett, G.J. et al. (1982)
Problems of fibre counting and its automation (to be published).

Dixon, R.N. and Taylor, C.J. (1979)
Asbestos Fibre Counting by Automatic Image Analysis.
Scanning Electron Microscopy /T/1979
(Johari, O., Ed.) SEM Inc., AMF O'Hare,
JL 60666, 361-366.

European Economic Communities (1983)
Council Directive on the protection of workers from the risks related to exposure to asbestos at work, Brussels, September 1983.

Gale, R.W. and Timbrell, V. (1980)
Practical application of magnetic alignment of mineral fibres for hazard evaluation.
In: Biological Effects of Mineral Fibres (Wagner, J.C., Ed.), International Agency for Research on Cancer, Lyon, 53-60.

International Labour Office (1983),
Code of Practice on Safety in the Use of Asbestos,
International Labour Office, Geneva, 1983.

International Standards Organization (1981)
Size Definitions for Particle Sampling,
Report of ad hoc Working Group to Technical Committee 146 - Air Quality of the International Standards Organization, Am. Ind.Hyg. Assoc. J. (42), A-64 / A-68, 1981.

International Standards Organization (1984),
Proposed Analytical Method for Determination of Asbestos Fibres in Air.
Document for Joint Working Group ISO/TC147/SC2/WG18 - ISO/TC146/SC3/WGI, March 1984.

Kenny, L.C. (1984) Asbestos fibre counting by image analysis - the performance of the Manchester Asbestos Program on Magiscan, Ann Occup Hyg. (in Press).

Leidel, N.A. et al. (1979), USPHS/NIOSH membrane filter method for evaluation airborne asbestos fibres. U.S. Department of Health, Education and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, 4676 Columbia Parkway, Cincinnati, Ohio 45226, USA.

National Institute for Occupational Safety and Health (1984), Revised NIOSH asbestos counting method. In; NIOSH Manual of Analytical Methods, May 1984. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, USA.

Verein Deutscher Ingenieure (1984)
Messen anorganischer faserförmiger Partikeln in the Aussenluft - Rasterelektronenmikroskopisches Verfahren (Measuring of inorganic fibrous particles in ambient air - scanning electron microscopical method).
(in draft form; presently under final discussion)
Verein Deutscher Ingenieure, Postfach 1139, D-4000 Dusseldorf.

4. ASBESTOS EMISSIONS

This chapter presents emission data from known man-made and natural sources of asbestos into the atmosphere. The emission sources are divided into 6 groups as follows: (1) mining and milling of asbestos ores; (2) manufacture of products containing asbestos; (3) end uses of products containing asbestos; (4) disposal of asbestos waste materials, and (5) emissions from mining, milling, transport, use and disposal of non-asbestos minerals containing asbestos fibres, and (6) natural sources.

The chapter concludes with a summary which presents a tentative assessment of the relative magnitude of emissions contributed by the most important of these sources.

Major problems in assessing emissions are:

- the difficulty in measuring asbestos emissions
- the uncertainty in the engineering estimates of emission rates presented in literature, and
- the paucity of data from actual source sampling.

Gravimetric emission measurement results which have become available in recent years indicate that, in general, emission rates published in the past and based on engineering estimates, have considerably overestimated reality and are, at any rate, no longer representative for present day operating conditions in industry. Dramatic improvements have been recorded over the last 10 years in control of emissions, as a direct consequence of the introduction of emission standards in various countries, but also, indirectly as a consequence of the introduction of occupational exposure standards and regulations. For this reason, emission factors based on engineering estimates from the past, rather than on source sampling, have not been taken into account in this report except, in a few cases, for the sake of comparison with actual measurement results.

4.1 Mining and Milling of Asbestos Ores

In 1982, the worldwide asbestos industry mined and processed approximately 4.7 x 10^6t* asbestos. About 60% of this was mined in the USSR, 17% in Canada and 9% in Southern Africa. (Source: Asbestos, by R.A. Clifton, reprint from the 1982 Bureau of Mines Yearbook, U.S. Dept. of the Interior). Of the total world production in 1982, approximately 95% was chrysotile, 3% was crocidolite, and 2% amosite. Yearly production rates for different countries from 1977 till 1981 are given in Table 4.1. The production of South Africa is particularly important since most of the amphibole asbestos (amosite and crocidolite) is mined here; South Africa is the only commercial source of amosite. It should also be noted that chrysotile from Zimbabwe is of spinning grade and thus, in high demand.

In general, asbestos ores mined contain an average of 6% saleable fibre; it should be noted that Table 4.1 gives production rates, and not the quantities of ore mined.

Asbestos ore is partially mined in open pit and partially in underground operations; possible sources of particulate (asbestos) emissions include: drilling, blasting, loading broken rock, and transporting ore to primary crusher or waste to dump. Subsequently, the ore is crushed including the following steps and emission sources: unloading ore from open pit, primary crushing, screening, secondary crushing, conveying and stockpiling wet ore. Then, a drying step follows, which involves conveying ore to dryer building, screening, drying, tertiary crushing, conveying ore to dry-rock storage building, and dry-rock storage. The following step is milling of the ore which is confined to the mill building and does not present any direct emissions to the air because the mill air is collected and, usually, ducted through some particulate matter control device. Figure 4.1 presents a detailed flow diagram of the asbestos mining and milling processes and also indicates possible asbestos emission sources.

Few attempts have been made to quantify fibre emissions from mining and milling operations. Uncontrolled and controlled emission factors based on pre-1975 engineering estimates (published in 1978 by Rajhans & Bragg) are shown in Table 4.2 together with emission factors based on actual sampling of point source emissions from the Quebec asbestos mining and milling industries in 1983. On the basis of these measurements, Lebel has shown that in 1983 the overall emission factor for the Quebec asbestos mining and milling industries amounted to 0.0058 kg/t of asbestos produced. This is more than 1000 times lower than the estimates published in 1978 by Rajhans & Bragg for controlled mining and milling operations. The total emission in 1983 from all the point sources in the Quebec region was about 4 metric tons. For Germany, total national asbestos emissions from asbestos milling were reported by UBA in 1980 as 0.17 t/year for 1975.

---

*Metric tons

TABLE 4.1

World Asbestos Production

Country	1977	1978	1979	1980	1981
Italy	149 327	135 401	143 931	157 794	137 086
Bulgaria	500	700	600	650	400
Czechoslovakia		575	564	617	388
Soviet Union	1 900 000	1 945 000	2 020 000	2 150 000	2 220 000
Turkey	3 975	13 380	38 967	8 882	2 833
Yugoslavia	9 036	10 304	9 959	10 468	12 206
Egypt	478	349	238	316	325
Mozambique	-	-	789	800	800
South Africa					
Amosite	66 983	40 526	39 058	51 646	56 834
Anthophyllite	550	-	-	-	-
Crocidolite	200 966	137 171	118 301	119 148	102 337
Chrysotile	111 575	79 511	91 828	106 940	76 772
Swaziland					
Chrysotile	38 046	36 951	34 294	32 833	35 264
Zimbabwe					
Chrysotile	273 194	248 861	259 891	250 949	247 503
Canada					
Chrysotile	1 517 360	1 421 808	1 492 719	1 323 053	1 120 523
USA (a)	92 256	93 097	93 354	80 079	75 618
Argentina	686	1 069	1 371	1 261	1 400
Brazil	92 773	122 815	138 457	170 403	180 000
Afghanistan	13 000	13 000	4 000		
China	200 000	250 000	250 000	250 000	250 000
Cyprus					
Chrysotile	36 684	34 359	35 472	35 535	24 703
India					
Amphibole	22 177	24 623	32 094	32 468	24 515
Japan					
Chrysotile	6 307	5 476	3 362	3 897	3 500
Korea, Republic of	6 180	13 616	14 804	9 854	14 084
Taiwan	673	2 031	2 957	683	2 317
Australia					
Chrysotile	50 601	62 744	79 721	92 418	44 647
World total	4 800 000	4 700 000	4 900 000	4 900 000	4 600 000

Note: In addition to the countries listed, Democratic P.R. of Korea and Romania are also believed to produce asbestos.

(a) Sold or used by producers.

Source: World Mineral Statistics, 1977-81.

SCHEMATIC FLOW DIAGRAM FOR TYPICAL ASBESTOS MINING /MILLING

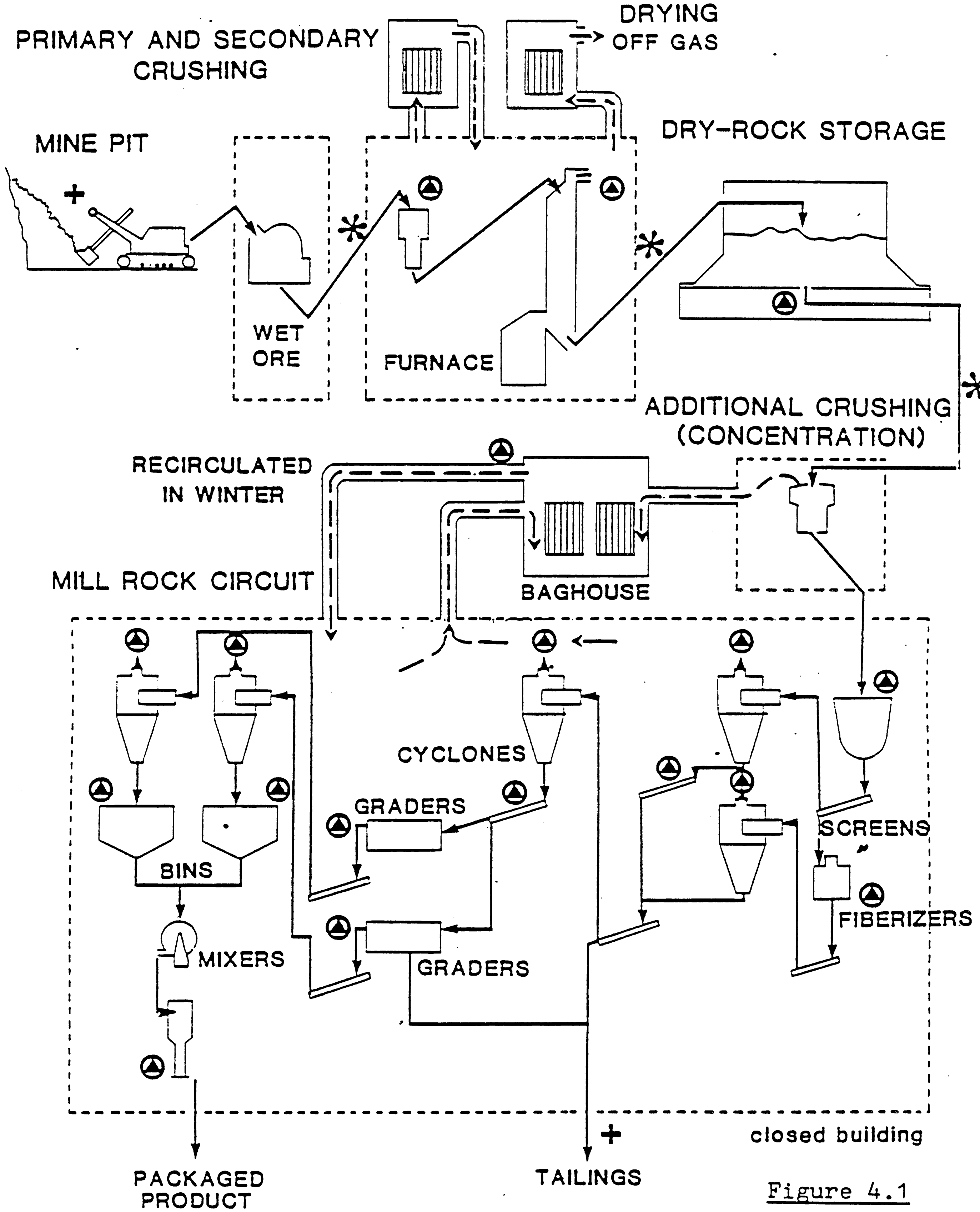


Figure 4.1

+ – emissions limited by wetting and shrouding where possible

Ⓐ – connected to exhaust and air cleaning system (air returned in winter)

* – closed conveyor

TABLE 4.2

Emission Factors for Asbestos Mining and Milling

Source	Emission Factor [kg/t asbestos produced]	
	Based on Engineering Estimates[a]	Based on Actual Source Sampling[b]
Mining (total uncontrolled)	4-5	X
Mining	1.5	X
Loading	1	X
Handling	1	X
Unloading	1	X
Mining (total, 50% controlled)	2.5	X
Mining (controlled)		
Drilling		0.0003
Underground		0.005
Milling (uncontrolled)	50	XX
Milling (50% controlled)	40	XX
Milling (80% controlled)	10	XX
Milling (high-efficiency fabric filter)	6	0.0055

a - From: Rajhans & Bragg (1978).

b - From: Lebel (1984) Quebec, Canada (in press).

X - Source sampling not applicable - diffused emissions.

XX - Not applicable - 100 % control required since 1978.

In countries where asbestos ores are mined and milled, these processes generally constitute the major emission source of asbestos into the atmosphere; in the USA, in 1972 it was estimated that mining and milling accounted for 48% of the total asbestos emissions into the air (Archer and Blackwood, 1979).

4.2 Manufacture of Products Containing Asbestos

Asbestos was already known to the Greeks and Romans because of its main chemical and physical characteristics, i.e. its incombustibility and excellent tensile strength. However, it only gained widespread commercial use in the early twentieth century when many new applications were developed. About 30 years ago, there were approximately 400 commercial uses for asbestos, while to date, due to industrial expansion and development of new products, there are over 3000 industrial applications (National Cancer Institute, Canada, 1978). The major categories are listed in Table 4.3; with an approximate breakdown based on the particular product consumption pattern existing in the U.S.A. In most other OECD countries, vinyl asbestos flooring constitutes a smaller, and asbestos cement a larger percentage of total asbestos consumption than in the case for the U.S.A.

It should be noted that for some of the categories listed, emissions result during end use rather than during manufacture and thus, will be treated under section 4.3.

Total national asbestos consumption rates for different countries are represented in Table 4.4.

In the following subsections, the major known asbestos emission sources during product manufacture will be described and their emissions will be quantified.

4.2.1 Asbestos Cement Products

The asbestos cement industry is the largest user of asbestos fibres in the manufacture of composites (E.C., Directorate Social Affairs, 1976; Archer and Blackwood, 1979). Asbestos cement products contain from less than 10% to over 30% of asbestos. Standard asbestos cement sheets usually contain between 9 and 12%, where as special products may contain from 15% to 33% of asbestos, mostly in the form of chrysotile, although limited amounts of crocidolite and amosite may be used in large-size asbestos cement pipes to give the required strength. The most important products are asbestos cement pipes and sheets; products are primarily manufactured in wet processes. Total national consumption rates, as well as relative consumption of total national asbestos in these products, are presented in Table 4.5.

TABLE 4.3

Major Commercial Application Categories for Asbestos

Asbestos cement products	70%
Vinyl asbestos flooring	10%
Friction materials	7%
Asbestos paper and felt	5%
Gaskets and packings	3%
Paints, roof coatings, caulks etc.	2%
Asbestos textiles products	1 %
Asbestos asphalt paving compounds	
Asbestos reinforced synthetic resins	
Filter media	2%
Sprayed asbestos and other forms of asbestos insulation and fire protection*	
Other	

* Major application in the past, now prohibited or abandoned in most OECD countries

TABLE 4.4

Total National Asbestos Consumption Rates

Country	Consumption Rate (10^3 x t)	Year	Remarks	Reference
Belgium/ Luxembourg	31	1982		Comité d'Information de l'Amiante, Benelux
Denmark	16	1983		Danish Asbestos Information Group
France	90	1982		Association Française de l'Amiante France, 1980
Germany	90	1982		Wirtschaftsverband Asbest. e.V.
Greece	12.7	1982		Hellenic Asbestos and Asbestos Cement Association
Ireland	5.7	1982		Irish Asbestos Council
Italy	112.6	1983		Centro Nazionale Amianto
Netherlands	6.7	1983		Comité d'Information de l'Amiante, Benelux
U.K.	45	1983		Asbestos Information Centre
Western Europe	460	1982		Asbestos by R.A. Clifton reprint from 1982 Bureau of Mines Yearbook, U.S. Dept. of the Interior.
U.S.A.	240	1982		"
Canada	40	1982		"

TABLE 4.5

Total National Consumption Rates for the Production of Asbestos Cement Products

Country	Consumption Rate [10^3 x t/yr]	Relative consumption of total national asbestos [%]	Year	Remarks	Reference
Belgium/ Luxembourg	29	93	1982		Comité d'Information de l'Amiante Benelux
Denmark	13.3	83	1983		Danish Asbestos Information Group
France	76	84	1982		Association Française de l'Amiante
Germany	60	66	1982		Wirtschaftsverband Asbest e.V
Greece	12	94	1982		Hellenic Asbestos and Asbestos Cement Association
Ireland	5.6	98	1982		Irish Asbestos Council
Italy	74.5	66	1983		Centro Nazionale Amianto
Netherlands	5.4	83	1983		Comité d'information de l'Amiante Benelux
U.K.	23	51	1983		Asbestos Information Centre
Western Europe	240	40	1981		Economics of Asbestos, 1983
North America	362	45	1981		Economics of Asbestos 1983

Possible emission sources are: (1) feeding asbestos fibre to dry mix; (2) blending the dry mix; and (3) cutting or machining end products. In addition, emissions can occur from sources other than processing operations, such as handling and/or shipment of dry materials containing asbestos. As regards operations (1) and (2), the use of wet processes has been introduced in the vast majority of asbestos cement manufacturing plants, which allow elimination of two important potential sources of emission. For Germany, an emission factor of 0.016 kg/t is given by Lanting and den Boeft based on total consumption and total emissions. This figure, published in 1980 and referring to the situation in the late seventies, compares favourably to the emission factors of 2 kg/t for uncontrolled sources and of 0.5 kg/t for controlled sources, published a few years earlier by Rajhans and Bragg in 1978 and relating to the estimated situation in the early seventies.

As for France, Bouije has pointed out that the total capacity of air filtering devices in place in 1982 in the French asbestos cement industry amounted to a flow rate of 1.11 x 10^6 m^3/hour. Assuming a 24 h/day operation and stack emission levels equal to the maximum allowed 0.1 mg/m^3 of asbestos dust, and assuming that no recycling of the filtered air takes place, this would amount to a total of 0.6 t/year of asbestos emissions for the whole of the French asbestos cement industry.

4.2.2. Vinyl Asbestos Floor Tile

In the U.S.A., the second largest user of asbestos fibres is the flooring products industry which includes vinyl-asbestos floor tile and sheet vinyl flooring with asbestos backing (Krussell and Cogley, 1982). Only a very small quantity of asphalt-asbestos floor tiles are produced.

Vinyl-asbestos flooring products have found increased use in some OECD countries during the last decade, because of long-term durability, impermeability to water, resistance to moisture and good wearing qualities (UBA, Germany, 1980).

In other OECD countries such as France and Belgium, use of asbestos for vinyl asbestos floor tile has declined considerably over the last few years and has become insignificant or non-existent.

Asbestos floor tiles contain approximately 10 to 30% (by weight) asbestos fibres within a polymer, formed largely from vinyl chloride and/or vinyl acetate. There has been a trend in recent years to lower the asbestos content in fibre reinforced vinyl floor tile. In the U.K., where the manufacturers traditionally incorporated 20% of asbestos in the polymer, the content is now only 5%, if asbestos is used at all.

TABLE 4.6

Total National Consumption Rates for the Production of Asbestos Floor Tiles

Country	Consumption [10^3 x t/yr]	Relative Consumption of total national asbestos [%]	Year	Remarks	Reference
Denmark	0.3	2	1978		Lanting and den Boeft, 1979
France	4.6	4.2	1979		Ministère de l'Environnement France, 1980
Germany (Federal Republic of)	4	3	1978	does not include cushion vinyls	Lanting and den Boeft, 1979
Germany (Federal Republic of)	4	3	1978	does not include cushion vinyls	Lanting and den Boeft, 1979
Italy	15	9	1978		"
Netherlands	0		1980		Comité d'information de l'amiante Benelux
U.K.	13	11	1978		"
U.S.A.	36	10	1980		Krusell and Cogley, 1982

The raw material is usually dry-mixed and passed through hot rollers which reduce it to sheet form, and coloured granules are added to produce the required pattern. The sheet is then passed through calender rollers to bring it to required thickness. Finishing processes involve cutting the tiles to size and shredding wastes and trimmings. Waste material from these processes is broken up in a hammer mill and is added to the raw material for reuse.

4.2.3. Asbestos Paper and Felt

Types of products classified as asbestos papers and felts range from thin varieties for gasket paper and pipe wrapping, through roofing and flooring felts up to and including one-half-inch thick millboard which contains up to 97% asbestos. The feed for paper machines is prepared by mixing short chrysotile fibres with appropriate binders such as starch, glue, water, glass, resins, latex, or gypsum. Since papermaking is a wet process, little asbestos dust is generated during the manufacture. However, finishing operations, like slitting and calendering, needed to prepare final paper sheets may be sources of elevated asbestos dust levels.

National asbestos consumption rates in the asbestos paper and felt manufacturing industry are presented in Table 4.7.

4.2.4. Brake Linings (Friction Materials)

Woven brake linings and clutch facings for heavy use are made from high-strength asbestos fabric reinforced with wire; this material is dried and impregnated with resin. However of greater importance are press-formed pads for disk brakes and moulded linings for drum type automotive brakes. In the dry-mix moulding process, the asbestos fibres and other constituents are combined with resin that is thermosetting when fully cured. Final treatment involves curing by baking and grinding to customer specification. The asbestos content in friction products ranges from 10% to 80%, with average contents of 30% in Germany and 60% in U.S.A. High emission levels in the manufacture of friction products result from the dry mixing process as well as during finishing operations.

Table 4.8 presents national asbestos consumption rates for the friction products industry. Meylan et al. give an emission factor for baghouse controlled sources in the USA of 0.009 kg/t, and Fowler gives an overall emission factor from an entire friction material manufacturing plant of 0.25 kg/t. In Germany, an emission factor of 0.16 kg/t was calculated and seems to be representative of the European situation (Lanting and den Boeft, 1979).

Emissions have been reduced substantially in Germany since 1975 (UBA, Germany, 1980) and further reduction is bound to result from the introduction in 1983 of the 0.1 mg/Nm^3 asbestos fine dust emission limit. In France, emissions up to 17 mg/Nm^3 from bag filters (and close to 1 g/Nm^3 from cyclones) have been recorded in 1976 in a particular friction materials manufacturing plant (Secretariat d'Etat chargé de l'Environnement, 1983). In 1981, the average emission level of the same plant had fallen to

TABLE 4.7

National Asbestos Consumption Rates for the Asbestos Paper and Felt Manufacturing Industry

Country	Consumption [10^3 x t/yr]	Relative Consumption of Total National Asbestos [%]	Year	Remarks	Reference
France	5.2	4.8	1979	asbestos board	Ministère de l'Environnement, France, 1980
Germany (Federal Republic of)	6	4	1978		Lanting and den Boeft, 1979
Italy	5	3	1978		"
Netherlands	0.5	49	1983		Comité d'information de l'Amiante Benelux
U.K.	28.5	20	1976	fillers and reinforcements, inc: paper, felts, millboard, filter pads, underseals, mastics, coatings and adhesives	Health and Safety Commission, Great Britain, 1979
U.S.A.	90	25	1980	felts, gaskets pipe-wrap, millboard electrical insulation commercial paper speciality papers	Krusell and Cogley, 1982

TABLE 4.8

National Asbestos Consumption Rates for the Friction Products Manufacturing Industry

Country	Consumption [10^3xt/yr]	Relative Consumption of Total National Asbestos [%]	Year	Remarks	Reference
Belgium/ Luxembourg	0.5	1	1978		Lanting and den Boeft, 1979
Denmark	1	5	1978		Lanting and den Boeft, 1979
France	5	4.7	1979		Ministère de l'Environnement, France, 1980
Germany (Federal Republic of)	11	7	1978		Lanting and den Boeft, 1979
Ireland	1	11	1978		"
Italy	4.3	3	1978		"
Netherlands	0.3		1983		Comité d'information de l'Amiante Benelux
U.K.	15.6	10.9	1976		Health and Safety Commission, Great Britain, 1979
U.S.A.	43.7	12	1980		Krusell and Cogley, 1982

0.17 mg/Nm^3, representing a 100 fold improvement of filter efficiency over a 5 year period. In 1983, the average emission level was 0.12 mg/Nm^3, or 166 times less than 7 years before. The improvement was partially due to the use of high efficiency filter media, but also to the introduction of a rigorous scheme for inspection of operating conditions and for periodic maintenance of the air cleaning devices.

4.2.5. Asbestos Textiles

Asbestos textile is the oldest application of asbestos fibres; commercial production started in Italy between 1850 and 1870 (Lanting and den Boeft, 1979). Asbestos textiles are used directly as finished article in fire-resistant garments, filters, sealing materials, wicks, and thermal insulation, or as intermediate product in brake lining, clutch facings, insulation and gaskets.

The asbestos textile manufacture used to be one of the dustiest operations of all asbestos product manufactures. However, during the past decade, emissions have been reduced substantially due to the implementation of occupational exposure limitations.

Asbestos textiles contain on the average 90% asbestos fibres (UBA, Germany, 1980) which gives them high resistance to heat, fire, acids, and abrasion, while the remainder is organic fibres of cotton or synthetics which impart strength. The first step in the manufacture is generally loosening of the fibres before they are blended with rayon, etc.

National asbestos consumption rates for the asbestos textiles production industry are shown in Table 4.9. It should be noted that in all countries for which total annual emission rates are available for the asbestos textiles industry, current emissions are controlled by fabric filters.

As was the case for other asbestos industry branches, emissions from the asbestos textile industry have considerably decreased in recent years. Whereas Archer and Blackwood reported emissions as high as 7 t/year for the U.S.A. in 1972, German figures published in 1980, but related to 1975, show emissions of 0.14 t/year for the same industry branch. Ullmann et al., reported in 1978 an emission factor of 0.022 kg/t asbestos consumed for the German asbestos textile industry.

In France, after having regulated emissions from the asbestos cement and friction materials industry since 1980 via sectoral agreements, the Secretariat d'Etat chargé de l'environnement et de la qualité de la vie has published in early 1984, Technical Instructions aiming at the prevention of pollution of the atmosphere and of the acquatic environment in general, and at the reduction of emissions of airborne asbestos in particular. They address most of the remaining asbestos industry branches, among which the asbestos textile industry. Particulate emissions may not exceed 0.1 mg/m^3 if containing more than 50% (by weight) of asbestos, and must be kept below 0.5 mg/m^3 if the asbestos content is less than 50%.

The 0.1 mg/m^3 emission limit for asbestos fine dust, which is in force in Germany since 1983, also applies to the German asbestos textile industry.

TABLE 4.9

Total National Asbestos Consumption Rates for the Production of Asbestos Textiles

Country	Consumption [10^3xt/yr]	Relative Consumption of Total National Asbestos [%]	Year	Remarks	Reference
Belgium/ Luxembourg	0.5	1	1978		Lanting and den Boeft, 1979
France	3.3	3	1978		Lanting and den Boeft, 1979
Germany (Federal Republic of)	6.5	4	1975		UBA, Germany, 1980.
Italy	4.2	2.6	1978		Lanting and den Boeft, 1979
Netherlands	0	-	1983		Comité d'information de l'amiante Benelux
U.K.	4.0	10.0	1983	not including textiles used in friction materials and jointings and packings	Health and Safety Commission, Great Britain,
U.S.A.	1.9	0.5	1980		Krusell and Cogley, 1982

4.2.6. Other Sources in Asbestos-Product Manufacture

Additional sources of asbestos fibre emissions can be the following:

-- asbestos asphalt paving compounds manufacture ($\sim$ 1% asbestos fibre content);

-- thermal and electrical insulation material manufacture;

-- moulding compounds manufacture ($\sim$ 36% asbestos fibre content);

-- asbestos plastics industry; and

-- coating calking manufacture.

These industries, however, almost never consume more than 1% of the total national asbestos, are usually well-controlled, and thus constitute minor sources when considering total national emissions.

4.3 End Uses of Products Containing Asbestos

The uses of asbestos-containing products have long been potential sources of asbestos emissions. The most recognised ones are spraying of asbestos insulation materials, the use of friction products, fire-proofing materials in construction, and the use of asbestos asphalt pavements. The emissions created by these uses are more noticeable in urban areas than elsewhere (Rajhans and Bragg, 1978).

The asbestos fibres used in asbestos cement products, shingles, and floor tiles are bound within the product and usually undergo little abrasion before being discarded. It has been found, however, that dust adhering to newly fabricated asbestos cement sheets from sawing at the manufacturing plant, or dust produced during field fabrication of these products, can constitute a temporary emission source at the building site.

To date, only very few attempts have been made to quantify the fibre emissions from product use; in the subsequent sections, available emission quantities are presented and discussed.

4.3.1 Sprayed and other forms of asbestos containing insulation materials

The high thermal stability and large volume to mass ratio make asbestos, particularly the amphiboles, a perfect material for fire-proofing, thermal and acoustical insulation.

A common application of asbestos insulations was the spraying of a mix of asbestos and water-setting binder. The asbestos content in the sprayed coating is not usually less than 55%, and the asbestos types most often used were amosite and crocidolite (U.K. Health and Safety Commission, 1981). This technique has been widely used in the period between world war II and 1975 in buildings for the fire-protection of structural steel work, for fire breaks in service ducts, as well as for fire protection and thermal insulation of power stations, of ships, and of some rolling stock.

Another technique which has been widely used in the same period is thermal insulation of pipework, boilers etc. with asbestos rope lagging or with sectional insulation material of high asbestos content.

The application of asbestos by spraying has decreased drastically since 1975. In its Industry Viewpoint concerning Asbestos (1979), the Asbestos International Association expressed the view that uses of asbestos in which adequate dust control cannot be achieved, such as spraying, should be abandoned on a voluntary basis if not prohibited by law. Application of asbestos by spraying has been prohibited since in several OECD countries and by the EEC' Authorities, and the use of this technique, though still common for other mineral fibres, has virtually stopped for asbestos. However, previously installed asbestos insulation will continue to constitute a potential source of asbestos release into the environment because the asbestos content is high, and fibres are generally loosely bonded.

Sprayed asbestos has mainly been used in large public buildings such as offices, schools, indoor swimming pools, libraries, warehouses, etc. The following mechanism of fibre release is assumed: erosion and/or damage cause fall-out of fibres which impact on the floor and are further dispersed by human activity (Sébastien et al., 1971; Lumley et al., 1971). Repair of heating units and boilers often requires the stripping of asbestos-containing insulation materials, thus causing high fibre concentrations. It should be noted that in many cases, these emission sources cause indoor air pollution problems rather than contamination of the ambient outdoor air; this leads to much higher human exposure since almost no dispersion takes place indoors.

The extent to which asbestos spraying has been applied in the past differs from country to country. Its use has apparently been very widespread in some countries such as the U.K. and U.S.A., whereas in other countries relatively few applications of this technique took place. In Holland, about 200 buildings were identified as containing spray asbestos in a recent survey (1983), among which about 100 were public buildings. A similar survey was started in 1983 in Belgium.

In France, much attention has been paid, in particular since 1980, to the presence of sprayed asbestos in public buildings, and a guidance note (Guide Methodologique pour le Diagnostic et Traitement des revêtements réalisés par Flocage contenant de l'Amiante) was published in January 1984.

Similar documents already exist in a number of OECD countries (U.K., U.S.A., Australia, Canada ...) or are under preparation (EEC, Holland, Belgium ...), and the Asbestos International Association has published in 1982 a Recommended Code of Practice for Repair and Removal of Asbestos Insulation.

These documents, in general, agree in the view that encapsulation of sprayed asbestos is often preferable to removal, but that in many cases measures are required to limit fibre release from these coatings.

4.3.2. Friction Products

In stationary sources, such as brake service stations and garages, dust is blown from the brake drums and occasionally, old brake linings are roughened or brake shoes are relined. The use of compressed air for brake drum cleaning during servicing is prohibited now in several countries and suitable equipment is available on the market for either wet cleaning, or dry cleaning with dust extraction. Almost no emission data are available.

Data concerning the asbestos content of dust originating from brake lining wear vary considerably. An important observation, however, by all researchers is the considerable reduction of asbestos content in the dust compared to the original composition of the brake lining. This is a function largely of two factors:

(1) chrysotile is thermally decomposed to an amorphous phase at high temperatures (> 500°C), which are produced locally at the surface of the brake lining during braking; and

(2) chrysotile is micromilled by mechano-chemical processes to a non-fibrous product (Lanting and den Boeft; UBA, Germany).

The emission quantities will, thus, depend on the initial asbestos content of the brake lining and on the driving speed. In the USA, generally higher asbestos concentrations are found in the brake drum dust (Rohl et al., 1977) because American brake linings contain approximately 50 to 60% asbestos while European and Japanese cars contain only about 10 to 30%, and they are usually driven at lower speeds resulting in lower heat loading during braking.

Values of asbestos content in brake drum dust range from below 0.001% (UBA, Germany, 1980) to 2 to 15% (Rohl et al., 1977). The only study, however, which presents data on emissions into the air during typical driving conditions was made by Jacko et al (1973). It was measured, for all types of traffic, that 85.6% of the total dust released from brake lining wear is deposited on the road surface (drop-out), 11.2% is retained in the brake drum, and 3.2% gets airborne immediately. It is not known how much of the drop-out is redispersed into the air.

In the study by Jacko, the average asbestos content was 0.23%, and resulting emission factors amount to 17.7 ug/km for passenger cars and 54.3 ug/km for light trucks. No differences were observed between disc and drum brakes.

Lanting and den Boeft give an emission factor of 20 kg/t asbestos (used in the brake lining) for wear and 5 kg/t for installation operations (1980).

TABLE 4.10

Total National Asbestos Emissions from Brake Linings

Country	Emissions [t/yr]	Year	Remarks	Reference
Germany	20	-	yearly average	Ullmann et al., 1978
	13	-	total from automotive traffic: including drop-out, air and water emissions	UBA, Germany, 1980
	10	1982	based on 11×10^3 t/yr consumption	Lohrer, 1982
U.S.A.	64		drop-out	Lanting and den Boeft, 1979
	2.3		directly to the atmosphere	
	129	1972	to the atmosphere	Archer and Blackwood, 1979

4.3.3. Field Fabrication and Abrasion of Products Containing Asbestos

Table 4.11 depicts fibrous dust concentrations generated by various ways of processing asbestos cement end products. It should be noted that these are occupational concentrations and exposure levels which are usually only encountered on construction sites. The figures also indicate that emissions can be significantly reduced when adequately designed tools and dust control equipment, and appropriate working methods are used.

Figures published by UBA, Germany, in 1980 indicated concentration levels beyond the countability limit when high speed disc grinders, without dust extraction equipment were being used, and still in excess of 100 f/ml when attempts were made to fit dust extraction devices to these tools.

Other measures taken to reduce generation of respirable dust at the building site, apart from the use of slow running, coarse dust producing power tools or hand tools, include pre-drilling and cutting to size in the plant, and providing the products with notches so that they can be broken to size rather sawn to size.

In Germany, it has been estimated that approximately 10t/yr asbestos are released into the atmosphere from abrasion of asphalt road coverings. This figure is based on the presumptions that between 1968 and 1980, 14 x $10^6 m^2$ road surface has been covered with asbestos asphalt and that the annual abrasion is 75 g/m^2.

For road pavement applications, asbestos is not an essential substance, while manufacturers of paints and coatings consider it a critical ingredient.

4.3.4. Other Products Containing Asbestos

Other asbestos-containing products which have been of concern because of associated emissions during usage include: hair-dryers, air-conditioning equipment, and filter media for beverages, the latter resulting in high asbestos concentrations in the beverages rather than presenting an air pollution problem. Both emissions from hair-dryers and air-conditioning equipment present an indoor rather than general outdoor air pollution problems. No emission data are available and resulting indoor concentrations will be discussed in Chapter 5.

4.4. Demolition and Disposal of Asbestos Waste Materials

Although many countries have already implemented legislation on the various uses of asbestos, demolition and disposal of waste materials will continue to be a significant source of airborne asbestos due to its very extensive use until recently.

TABLE 4.11

Asbestos Fibrous Dust[1] Emission during Processing Asbestos Cement End Products with Approved Tools[2] - 1984

Tools/Process	Emissions [3] (Fibres/ml air) min.	max.
1) Standard asbestos-cement sheets (flat and corrugated)		
a) Tools without dust extraction equipment		
Hand Clipper	0.04	0.11
Scriber	0.14	0.28
Parallel Shears	0.06	0.20
Jig Saw	0.14	1.12
Slow Speed Slitting Saw	0.07	0.64
Hand-guided Band Saw	0.08	0.38
b) Tools with dust extraction equipment		
Slow Speed Circular Saw (AXT 50 LA)	0.09	0.20
2) Sanitary asbestos-cement pipes		
Tools without dust extraction equipment		
Hand Cutter	0.03	0.30
Electric Power Cutter	0.15	0.18
Hand-guided Band Saw	0.08	0.38
Jig Saw (A Stx 649)	0.05	0.09

1) Fibres with a diameter smaller 3 um, a length greater 5 um and an aspect ration l:d greater 3.

2) Officially approved by Berufsgenossenschaftliches Institut für Arbeitssicherheit (BIA) in compliance with present-day legislation (1 F/ml) in Germany (ZH 1/616).

3) Membrane Filter Method (light microscopy). Personal sampling. Sampling time 30 minutes under test conditions which represent the normal daily application time of the tools on site.

Individual activities which are included in this source category are:

(1) demolition of entire structures;

(2) maintenance, repair, and replacement, in particular of insulation material;

(3) replacement and destruction of vinyl asbestos floor tiles; and

(4) disposal of all asbestos waste materials in landfills, etc., or their incineration.

Human exposure from these emission sources may be particularly high because fibre bundles are broken up into smaller fibres and fibrils.

In the USA, building demolition is considered a major source of asbestos emissions, amounting to a yearly average of 2000 t (Roberts, 1976). No emission data are available from asbestos-containing waste disposal; resulting ambient air concentrations have been measured and will be discussed in Chapter 5. Emission factors are not available for any of the diffuse sources; in the USA, an emission factor of 450 g/t asbestos waste has been estimated for uncontrolled incineration (Carlin, 1977).

4.5 Natural Sources

Natural asbestos emissions originate mainly from quarries of asbestos-containing rock; first measurements of natural emissions were carried out in the USA (Carter, 1977; Rohl et al., 1977) and particularly high concentrations were found around Rockville, Maryland, and in different areas in California. No total national emissions have been estimated for any country, nor have emission factors been determined for diffuse natural souces. Some researchers estimate that the contribution from natural sources to ambient asbestos concentrations is greater than from anthropogenic sources (Spurny et al., 1979; Rohl et al., 1977; Carter, 1977; Hach et. al., 1977).

As mentioned earlier, a further emission source which is not linked to the asbestos industry nor to the use of asbestos products is the mining, treatment, transport, use and disposal of non-asbestos ores containing asbestos (such as some ores of iron, gold, chromium, nickel, copper and other).

In some countries, where asbestos is a natural constituent of the soil, farming and agriculture can constitute sources of pollution. (Romania, Finland, Austria ...).

4.6 Comparative Assessment of the Magnitude of Emissions from Each Source (Summary)

There are not enough data available to permit a comparative assessement for each of the above emission sources. Furthermore, for any country there is no information on the contribution of natural asbestos emissions to ambient air levels.

In the manufacturing industry, in the past, without air filtering measures, emissions constituted a major source. The application of stringent emission standards in some countries, e.g. France and Germany, reduced emissions to levels as low as 0.1 mg asbestos dust per m^3 of air. These standards can be met by the manufacturing industry with best available control technology. Their introduction and application in other countries would minimize the impact of these emission sources on the environment.

In the absence of appropriate control measures, construction activities are recognized as an important emission source. Application of appropriate work practices and tools can eliminate this source as a major concern.

Removal of friable asbestos insulation presents a major emission source if not conducted in accordance with the stringent procedures required for appropriate emission control.

4.7 References for Chapter 4

Archer, S. R. and T. R. Blackwood; Status Assessment of Toxic Chemicals - Asbestos, Report USEPA - 600/2-79-210c, December 1979.

Asbest-Institut für Arbeits- und Umweltschutz e.V. (1980), Mitteilungen, Schreiben an das Umweltbundesamt Ro/Oe vom 11 März.

Bouije, D.: Etat de la prévention technique dans l'industrie de l'amiante; In: l'amiante: où en est-on en France ? Paris (1983)

Carlin, A.P.; Hazardous Wastes: A Risk-Benefit Framework applied to Cadmium and Asbestos, Report USEPA 600/5-77-002, February 1977.

Carter, L.J.; Asbestos: Trouble in Air from Maryland Rock Quarry, Sci. 197(1977), 237-240.

EEC, Directorate Social Affairs; Air Quality Criteria for Asbestos - Preparatory Study Basic to the Setting-up of Guidelines for Asbestos Exposure, 1976.

Fowler, D.P.; Disposal and Emissions of Asbestos in the U.S.A., SRI International, Menlo Park, California (1977).

LeGuen, L.M. and G. Burdett: Asbestos concentrations in Public Buildings - A preliminary report. U.K., Ann. Occup. Hyg. Vol 24, N° 2, pp. 135-189 (1981).

Hack, J. T., A.N. Rohl, A. M. Langer and I.J. Selikoff; Asbestos Pollution, Sci 197(1977), 716-718.

Hamilton, D.J.: Asbestos Insulation in South Australian Buildings. Canberra (1980).

Jacko, M.G., R.T. DuCharme and J.H. Somers; How Much Asbestos do Vehicles Emit? Automotive Engineering Meeting, Detroit, Michigan (1973).

Lanting, R.W. and J. den Boeft; Environmental Pollution by the Asbestos Industries, Problems and Proposals for Solutions, EC Report EUR 7418,
IMG-TNO Report G953, November 1980.

Lanting, R.W. and J. den Boeft; Atmospheric Pollution by Asbestos Fibres, EC Report EUR 6768 EN,
IMG-TNO Report G908, November 1979.

Lebel, J., Point Source Emissions from the Quebec Asbestos Mining and Milling Industries in 1983. GAMA, Canada (1984) (In Press).

Lumley, F.P.S., P.G. Harries and F.J. O'Kelly; Buildings Insulated with Sprayed Asbestos: A Potential Hazards, Am. Occup. Hyg. 14 (1971) 255-257.

Meylan, W.M., P.H. Howard, S.S. Lande, and A. Hanchett; Chemical Market Input/Output Analysis of Selected Chemical Substances to Assess Sources of Environmental Contamination: Task III: Asbestos, Report USEPA 560/6-78-005, August 1978.

National Cancer Institute; Asbestos: An Information Resource, prepared for the US Department of Health, Education and Welfare, May 1978.

Pinchin, D.J., Asbestos in Buildings; Ontario (1982).

Rajhans, G.S. and G.M. Bragg; Engineering Aspects of Asbestos Dust Control, Publ. Ann Arbor Science, Ann Arbor, Michigan (1978).

Roberts, H.; Asbestos. An Appraisal of an Investigation into Problems due to its Presence in Local Authority Buildings, Environ. Health (1976) 249.

Rohl, A.N., A.M. Langer and I.J. Selikoff; Environmental Asbestos Pollution Related to Use of Quarried Serpentine Rock, Sci 196 (1977), 1319-1322.

Rohl, A.N., A.M. Langer, R. Klimentidis, M.S. Wolff and I.J. Selikoff; Asbestos Content of Dust Encountered in Brake Maintenance and Repair, Proc. Roy. Soc. Med., 70 (1977) 32-37.

Sébastien, P., A. Gaudichet, G. Dufour, G. Bonnaud, J. Bignon and J. Goni; Enquête métrologique sur la pollution atmosphérique intérieure des bâtiments isolés par projection d'amiante (1977), Rapport du Laboratoire des Particules Inhalées, Direction de l'Action Sanitaire et Sociale, Préfecture de Paris.

Sébastien, P., M.A. Billon, G. Dufour, A. Gaudichet, G. Bonnaud and J. Bignon; Levels of Asbestos Air Pollution in Some Environmental Circumstances, presented at the Conference of the New York Academy of Sciences: The Scientific Basis for the Public Control of Environmental Health Hazards, New York, June 1978.

Spurny, K., F. Pott, F. Huth, G. Weiss and H. Opiela; Identifizierung und krebserzeugende Wirkung von faserförmigen Aktinolith aus einem Steinbruch, Staub-Reinhalt. Luft 39 (1979), 386-389.

Ullmann, D., R. Eggersdorfer and R. König; Analyse der Asbestindustrie, Forschungsbericht 78-10403624, Umweltbundesamt, Berlin (1978).

Umweltbundesamt; Luftqualitätskriterien- Umweltbelastung durch Asbest und andere faserige Feinstäube, Kapitel 5 - Umweltbelastung, Berichte 7/80, Berlin, 1980.

5. ASBESTOS IN AIR

Asbestos is ubiquitous in the environment due to the extensive industrial use of this mineral and to dissemination of fibres from natural sources. In this chapter, the available data on asbestos concentrations in ambient and indoor air will be reviewed in an attempt to provide a basis for the assessment of health risks associated with inhalation of asbestos in the general environment.

5.1 Occupational Exposure

Over the years, introduction of engineering controls in most asbestos industries have effected large reductions in fibre concentrations in the occupational environment. Indeed, most countries today have a standard for occupational exposure of 2 fibres per mL (2000 f/L) or better. However, in order to place in perspective the health effects observed in populations exposed in the past to high airborne concentrations in the workplace, a brief review of historical data on occupational exposure will be presented here.

This discussion will be limited to data obtained by the membrane filter optical microscopic technique which has been in use since about 1968. Levels in the occupational environment have been monitored since about 1951; however the very early data were generally obtained by midget impinger methods and reported in units of millions of particles per cubic foot (mppcf). Conversion of these data for purposes of comparison with current levels is fraught with uncertainty.

A summary of ranges of levels observed in various industries in the 1960s and early 1970s is presented in Table 5.1. Levels as high as 490×10^3 fibres/L were recorded in some occupational environments during this period. Results of more recent (1972-1978) personal exposure measurements made at various operations involving the manufacture of asbestos-based products in the U.K. are presented in Table 5.2. It can be noted from comparison of the data in the two tables that occupational exposure levels have been dramatically reduced over the past ten years.

5.2 Exposure in the General Environment

Optical microscopy is inappropriate for the analysis of asbestos in ambient air due to the poor limit of resolution of the method. In fact, only about 0.3 per cent of the total airborne asbestos fibres present in the general environment can be detected by phase contrast optical microscopy (Chatfield, 1983). In addition, asbestos fibres cannot be distinguished from other inorganic and organic fibres by this method of analysis and non-asbestos fibres may constitute up to 99 per cent of the total fibre content of ambient air (Spurny and Stober, 1978). Transmission electron microscopy (T.E.M.) is the method of choice for such determinations. However, it is often difficult to make meaningful comparisons of airborne fibre levels determined by T.E.M.

due to the variations in procedures for sample preparation and analysis used in different laboratories. In addition, results are sometimes reported in terms of numbers of fibres and sometimes in terms of mass concentrations. It is difficult to compare values for mass and fibre concentrations since appropriate conversion factors will vary from sample to sample (see Table 5.3).

Results of the early monitoring studies conducted with T.E.M. (prior to 1976) should be viewed with considerable caution since the membrane filters used for air sampling may have been contaminated (Chatfield, 1975). In addition, indirect sampling techniques involving ashing of filters were used in many of the early studies (Rickards and Badani, 1971; Selikoff et al., 1972; Sebastien et al., 1976; Nicholson et al., 1980; Lanting and den Boeft, 1979; Bruckman and Rubino, 1978), and levels were reported in terms of mass concentrations. In addition to the potential for contamination during the ashing procedure, it has been well documented that numerical fibre concentrations do not necessarily corrrelate well with mass concentrations (Chatfield, 1983). Therefore the following discussion will be restricted primarily to asbestos levels determined by T.E.M. using the most accepted method of sample preparation involving direct transfer techniques. Data obtained by this method are generally reported as fibre concentrations. Since fibre number and size are important determinants in the pathogenesis of asbestos-related disease, data reported in terms of fibre concentration are most relevant for risk assessment.

5.2.1 Vicinity of Industrial Sources

Available data on levels of asbestos in air in the vicinity of industrial sources are summarised in Table 5.4. Asbestos levels in the air of mining towns in Québec have been determined recently*. Samples were collected in June 1983 at 11 sites in five mining communities located downwind from asbestos mines. Sampling was also conducted at a control site in Sherbrooke, Québec. The overall mean asbestos concentrations in the samples from the mining towns were 47.2 fibres/L (total) and 7.8 fibres/L ($>$ 5 um). Mean values for each of the sites sampled ranged up to 97.5 fibres/L (total) and 20.6 fibres/L ($>$ 5 um). For the control community, the mean values were lower -- 14.7 fibres/L (total) and 0.7 fibres/L ($>$ 5 um) (Lebel, 1984).

On the basis of the results of a study in which levels were reported as mass values (sample preparation involved ultrasonic treatment), it has been concluded that on average, concentrations in the vicinity of asbestos manufacturing plants (in ng/m^3) are 10-100 times greater than urban background concentrations, rising to values 1 000 to 10 000 times greater during plant filter cleaning. However, these values are several orders of magnitude lower than the hygiene control standard that applies within the plant (Burdett and Rood, 1983).

---

* It should be noted that an emission regulation of 2 f/c.c. for asbestos mines and mills was introduced in Canada in 1977.

5.2.2 Ambient Air

The few available data on levels of asbestos in ambient air determined by transmission electron microscopy using direct transfer sample preparation techniques are presented in Table 5.5. Concentrations at 12 locations in Metropolitan Toronto during 1980-81 ranged up to 45 fibres/L, of which several fibres (2-9) had lengths greater than 5 um (Chatfield, 1983). Airborne levels in three other smaller cities in Southern Ontario ranged from 0 to 14 fibres/L (total) and 0 to 11 fibres/L (> 5 um long). Concentrations at a remote rural location near Bracebridge, Ontario, were all below the detection limit of the analytical method (2 fibres/L). Although there were few fibres found, it was possible to discern a small difference between the fibre concentrations at the remote rural location and those in Metropolitan Toronto adjacent to a busy freeway.

Levels in samples from downtown locations in Stockholm, Sweden ranged from 7 to 85 fibres/L (total) and 1 to 3 fibres/L (> 5 um long). Concentrations in suburban locations were similar, ranging from 9 to 69 fibres/L (total) and 2 to 3 fibres/L (> 5 um).

Values for measurements made upwind of an asbestos plant in California ranged between 0.2 and 11 fibres/L (total) (John et al., 1976).

Levels of asbestos in ambient air determined by scanning electron microscopy (S.E.M.) using direct transfer sample preparation techniques are not strictly comparable to those obtained by T.E.M. However, available data indicate that for fibres greater than 5 um in length, fibre counts obtained by the two methods are somewhat similar. Levels of fibres greater than 5 u in length and less than 3 u in diameter, measured by S.E.M. in an urban area with high traffic density in Leoben, Austria averaged 0.5 fibres/L and ranged from 0 to 2.2 fibres/L. Concentrations in an "unaffected area" (presumably remote from asbestos sources) in Gahberg, Austria averaged less than 0.1 fibres/L and ranged from 0 to 0.1 fibres/L (Felbermayer and Ussar, 1980).

5.2.3 Indoor Air

Recently there has been concern about potential exposure to asbestos in the air of public buildings with friable surfaces of sprayed asbestos-containing insulation. Sprayed asbestos was used extensively between 1946 and 1973 on structural surfaces (to retard collapse during fire) and on ceilings (for purposes of acoustic and thermal insulation and decoration). The results of available studies in which asbestos levels in indoor air were determined by T.E.M. using direct sample preparation techniques are presented in Table 5.6.

A number of studies of airborne asbestos levels in buildings containing friable asbestos-containing insulation in Québec and Ontario have been reported. In general, the fibre concentrations in such buildings were not significantly higher than those in ambient air (Chatfield, 1983). For example, in a large building insulated with a friable mixture of chrysolite and mineral wool, no values above 17 fibres/L were found and levels were below the detection limit (approximately 3 fibres/L) in 12 of the 15 samples. These results were similar to those reported in a study conducted in the U.K. (Leguen and Burdett, 1981).

These results contradict observations in earlier studies in which mass concentrations of asbestos fibres determined by T.E.M. were elevated in buildings with sprayed asbestos-containing insulation compared to those in outside air (Nicholson et al., 1976; Nicholson et al., 1980; Sebastien et al., 1979). However, these results may be a function of the effect of the inclusion of several thick fibres from the indoor environment in the mass concentrations.

Levels in some subway systems may be elevated due to emission of fibres from the brakes of the trains and from damaged friable asbestos-containing insulation materials. In a recent study in which T.E.M. samples were prepared by an ashing procedure designed not to break down the fibres, levels in the Stockholm subway ranged up to 21,000 fibres/L (total) and 120 fibres/L (>5 um) (Chatfield, 1983). Levels recorded in the Toronto subway (which is closer to the surface and has a large number of ventilation shafts) ranged from 13 to 140 fibres/L. (Ontario Ministries of Labour and Environment, 1980).

The fibres in the majority of the asbestos-containing construction materials and consumer products used in homes are effectively bound in a solid matrix and are not expected to be released under conditions of normal use (e.g. asbestos vinyl floor tiles (*) and vinyl sheet flooring). However, elevated levels have been observed during renovations or alterations which disturb the integrity of asbestos-containing construction materials (Meek, in press).

Prior to 1979, asbestos liners were used in some hand-held hairdryers to protect the plastic of the barrel from the heating coils. Analysis for asbestos in ambient air resulting from the operation of 16 brands of asbestos-containing hairdryers commercially available in Canada indicated that levels in a 1 cubic metre chamber after operation of the hairdryers for 30 minutes were at or near the limit of sensitivity of the T.E.M. method of analysis (Environmental Health Directorate, 1979). These concentrations were similar to those for asbestos-free hairdryers.

It has been suggested that asbestos fibres in tap water could become airborne as a result of home humidification. However, the transfer of chrysotile fibres from water to air via home humidification using a conventional drum-type home humidifier in a laboratory study was found to be negligible even when the concentration of asbestos in the water was as high as 400 million fibres/L (Meranger et al., 1979).

(*) Recently it has been suggested that weathering of such tiles during normal use may be an important source of asbestos exposure, since an elevated concentration of airborne chyrsotile (170 ng/m^3) was observed in one out of four samples in a commercial building where no other source of chrysotile could be identified (Sebastien et al., 1982). However, these results have not been confirmed elsewhere.

5.3 Summary

The method of choice for the determination of asbestos in ambient air is transmission electron microscopy using direct transfer sample preparation techniques. The results of early analyses involving other methods of sample preparation must be interpreted with caution.

Available data obtained by the most accepted methods of sample preparation and analysis indicate that concentrations of asbestos in ambient air in remote rural locations are generally less than 2 fibres/L (total). Levels in urban air range up to 85 fibres/L (total) and 9 fibres/L (> 5 um). Although few data are available, concentrations in the vicinity of industrial sources are only slightly higher than those at the upper end of the range of concentrations observed in urban locations: 24.4 to 97.5 f/L (total) and 1.4 to 19.3 f/L (> 5 um).

Table 5.1 - Asbestos Concentrations in Various Industries (1964-1973)

Process	Levels f/L (x 10^3; > 5 μ)	Reference
Mining (Canadian)	1.1 - 18.9	Gibbs and Du Toit, 1973
Textile Manufacture (1964-65)	1.1 - 51.4	Lynch and Ayer, 1966
Application and Removal of Insulation in Shipyards	0.1 - 20.2	Cooper and Balzer, 1968, cited in Selikoff and Lee, 1978
Application and Removal of Insulation in Shipyards	0.1 - 490	Harries, 1971
*Spraying of Asbestos Insulation	10 - 70 (range of means)	Reitzer *et al.*, 1972

* process now banned in most countries

Table 5.2 - Asbestos Concentrations in Different Manufacturing Industries in the U.K. (1972-1978)*

Industry	Number of Samples	Median Levels f/L ($\times 10^3 > 5\ \mu$)	Percentage of Results below 2×10^3 f/L
Asbestos-cement	845	0.10 (0.01-6.20)	98.5
Millboard/paper	135	0.14 (0.01-2.63)	99.6
Friction Materials	900	0.2 (0.01-10.22)	95.0
Textiles	1304	0.4 (0.01-6.65)	95.0
Insulation Board	545	0.45 (0.01-13.66)	88.6

* Modified from Advisory Committee on Asbestos, 1979.

Table 5.3 - Observed Ratios Between Fibre and Mass Concentrations Determined by T.E.M.

Location	Fibres per Nanogram	Reference
Urban air	35	Murchio *et al.*, 1973
Ambient air	10 - 20 (> 5 μm)	Spurny *et al.*, 1979
Air near asbestos plants	1,000 - 100,000	Lanting and den Boeft,
Ambient air	1,000 - 10,000	1979
Subway system	10,000 - 60,000	Chatfield, 1983

Table 5.4 - Asbestos Concentrations in Air in the Vicinity of Industrial Sources[a]

Location	N	Concentration Total (f/L)[b]	Concentration > 5 µ (f/L)[b]	Reference
Asbestos, Québec-downwind of an asbestos mine (1983)	1 sample in each of 3 locations	37.2(24.4-48.3)	11.6(1.4-19.3)	Lebel, 1984
Thetford Mines, Québec downwind of an asbestos mine (1983)	1 sample in each of 3 locations	63.4(39.5-97.5)	16.0(7.9-22.0)	Lebel, 1984
Black Lake, Québec-downwind of an asbestos mine (1983)	1 sample in each of 2 locations	49.0(32.7-65.3)	5.0(1.4-8.5)	Lebel, 1984
Robertsonville, Québec downwind of an asbestos mine (1983)	1 sample	71.1	8.6	Lebel, 1984
Tring Junction, Québec downwind of an asbestos mine	1 sample in each of 2 locations	15.1	N.D.	Lebel, 1984
California-downwind of an asbestos plant	-	-	-	John *et al.* 1976
U.K. - downwind of amosite board manufacturing	3 samples	1300 ng/m^3 (500-2000)[c] (amosite; reported as mass concentrations)		Burdett *et al.*, 1984
U.K. - downwind of waste tip	3 samples	2200 ng/m^3 (900-4700)[c] (amosite; reported as mass concentrations)		Burdett *et al.*, 1984
U.K. - downwind of asbestos waste tip	8 samples	200 ng/m^3 (12-800)[c] (reported as mass concentrations)		Burdett *et al.*, 1984
U.K. - manufacturing plant, downwind perimeter	5 samples	28 ng/m^3 (10-50)[c] (reported as mass concentrations)		Burdett and Rood, 1983
as above, but samples taken during filter cleaning	5 samples	166 ng/m^3 (40-350)[c] (reported as mass concentrations)		Burdett and Rood, 1983

a: T.E.M. analyses using direct transfer sample preparation techniques (unless otherwise specified).

b: unless otherwise stated.

c: sample preparation involved ultrasonic treatment.

Table 5.5 - Asbestos Concentrations in Ambient Air[a]

Location	N	Concentration Total (f/L)[b]	Concentration >5 u (f/L)[b]	Reference
Metropolitan Toronto (1980-81)	1 sample in each of 12 locations	< 2-45	< 2-9	Chatfield, 1983
Southern Ontario (1980-81)	1 sample in each of 12 locations	< 2-33	< 2-4	Chatfield, 1983
Toronto - busy intersection (1983)	12 samples	0-24 (95% confidence intervals)	0-13	Chatfield, 1983
Mississauga, Ont. (1983)	8 samples	0-11 (95% confidence intervals)	0-11	Chatfield, 1983
Oakville, Ont. (1983)	13 samples	0-14 (95% confidence intervals)	0-8	Chatfield, 1983
Bracebridge Ont-remote rural location	10 samples	0-3 (95% confidence intervals)	0-2	Chatfield, 1983
Peterborough, Ont.	3 samples	0-7 (95% confidence intervals)	0-4	Chatfield, 1983
California-upwind of an asbestos plant (1974)	10 samples	<0.2-11		John et al., 1976
Sherbrooke, Québec	2(?) samples	14.7	0.7	Lebel, 1984
U.K. - rural and semi-rural (1979-1981)	total of 8 samples at 3 locations	mean <1-4 ng/m^{3}[c] (reported as mass concentration)		Burdett et al., 1984
U.K. - urban background (1979-1981)	total of 17 samples at 3 locations	mean <1-2 ng/m^{3}[c] (reported as mass concentrations)		Burdett et al., 1984
U.K. - background - 1 mi. upwind of asbestos manufacturing plant	3 samples	3 ng m^{3} (1-5)[c] (reported as mass concentrations		Burdett and Rood, 1983
U.K. - urban background	6 samples	1 ng/m^{3} (n.d.-6)[c] (reported as mass concentrations		Burdett and Rood, 1983

a: T.E.M. analyses using direct transfer sample preparation techniques (unless otherwise specified).

b: unless otherwise stated.

c: sample preparation involved ultrasonic treatment.

Table 5.6 - Airborne Asbestos Concentrations in Public Buildings Containing Friable Asbestos-Containing Material[a]

Location	N	Concentration Total (f/L)[b]	Concentration > 5 μ (f/L)[b]	Reference
19 buildings in Ontario	64	0.7-20.2	0.0-3	(Pinchin, 1982)
3 buildings in Ontario-amosite insulation	N.A.	means 2	< 2	(Chatfield, 1983)
7 buildings in Ontario-chrysotile insulation	N.A.	means 7-44	< 4-<9	(Chatfield, 1983)
3 buildings in U.K.	99(?)	$<10^{-9}$ g/m[3c]		(Leguen and Burdett, 1981)

a: T.E.M. analyses using direct transfer sample preparation techniques (unless otherwise specified).

b: unless otherwise stated.

c: sample preparation involved ultrasonic treatment.

5.4 References

Advisory Committee on Asbestos (1979), Final Report, Health and Safety Commission, Her Majesty's Stationery Office, London, U.K.

Bruckman, L. and R.A. Rubino (1978), Monitored asbestos concentrations in Connecticut, J. Air Poll. Cont. Assoc., 28, 12, 1221-1226.

Burdett, G.J., J.M.M. Le Guen and A.P. Rood (1984), Mass concentrations of airborne asbestos in the non-occupational environment -- a preliminary report of U.K. measurements, Ann. Occ. Hyg., 28, 31-38.

Burdett, G. and A. Rood (1983), Sample preparation for monitoring asbestos in air by transmission electron microscopy, Anal. Chem., 55, 1642.

Chatfield, E.J. (1975), Asbestos background levels in three filter media used for environmental monitoring, In: Proceedings, 33rd Annual Meeting Electron Microscopy Society of America, Las Vegas, Nevada; Arceneaux, C.J. (Ed.). Claitor's Publishing Division, Baton Rouge, Louisiana, 276-277.

Chatfield, E.J. (1983), Measurement of Asbestos Fibre Concentrations in Ambient Atmospheres, Report prepared for the Royal Commission on Matters of Health and Safety Arising from the Use of Asbestos in Ontario, Toronto, Ontario.

Cooper, W.C. and J.L. Balzer (1968), Evaluation and control of asbestos exposures in the insulating trades, In: Internationale Konferenzen der biologische Wirkunger Asbestos, Dresden, Dtsch. Zentralinst. Arbeitsmed, Berlin, DDR.

Den Boeft, J. and B.W. Lanting (1981), Asbest en andere minerale vezels in de buitenlucht (orienterende metingen von concentratieniveaus in Nederland) Organisatie voor Toegepast-natuurwetenschappelijk Onderzoek, The Netherlands (English summary, only).

Environmental Health Directorate (1979), Preliminary Study on the Possible Release of Asbestos Fibres During the Operation of Hand-Held Hair Dryers, Department of National Health and Welfare, Ottawa.

Felbermayer, W. and M.B. Ussar (1980), Environmental Pollution by Weathering of Asbestos Cement Sheets, Ministry of Health and Environmental Protection, Austria.

Friedrichs, K.M. (1982), Monitoring fibres in ambient air, Presentation to a Delegation of Canadian Scientists, February 10, 1982.

Gibbs, G.W. and R.S.J. Du Toit (1973), Environmental data in mining, In: Biological Effects of Asbestos, IARC Scientific Publication No. 8, IARC, Lyon.

Gibbs, G.W., N. Rowlands and R. Brulotte (1982), A pilot study of the measurement of airborne asbestos fibre concentrations in ambient air. Presented at the 73rd APCA Annual Meeting and Exhibition, June, 1980, Montreal, Quebec, Paper Number 80-27.3.

Harries, P.G. (1979), A comparison of mass and fiber concentrations of asbestos dust in shipyard insulation processes, Ann. Occup. Hyg., 14, 234.

John, W., A. Berner, G. Smith and J.J. Wesolowki (1976), Experimental Determination of the Number and Size of Asbestos Fibres in Ambient Air, NTIS, Springfield, Virginia.

Lanting, R.W. and J. den Boeft (1979), Atmospheric pollution by asbestos fibres. Report No. G908, Instituut voor Milieuhygiene en gezondheidstechniek, T.N.O., postbus 214, 2600 AE, Delft, Holland.

Lebel, J. (1984), Review of Fibre Concentrations in Québec Asbestos Mining Towns, Québec Asbestos Mining Association, Québec.

Leguen, J.M. and G. Burdett (1981), Asbestos concentrations in public buildings - a preliminary report, Ann. Occup. Hyg., 24, 185-189.

Lynch, J.R. and H.E. Ayer (1966), Measurement of dust exposures in the asbestos textile industry, Am. Ind. Hyg. Assoc. J., 27, 431.

Meek, M.E. (in press), Asbestos.Report to the Federal Provincial Working Group on Indoor Air Quality, Department of National Health and Welfare, Ottawa.

Méranger, J.C., W.W. Reid and A.B.C. Davey (1979), The transfer of asbestos from water to air via a portable drum-type home humidifier, Can. J. Public Health, 70, 276.

Murchio, J.C., W.C. Cooper, and A. DeLeon (1973), Asbestos Fibers in Ambient Air of California, California Air Resources Board, Berkley, California.

Nicholson, W.J., A.N. Rohl, I. Weisman, and I.J. Selikoff (1980), Environmental Asbestos Concentrations in the United States. In: Biological Effects of Mineral Fibres, Vol. 2; Wagner, J.C. (Ed.) IARC Scientific Publications No. 30, International Agency for Research on Cancer, Lyon, France, 834-827.

Ontario Ministries of Labour and Environment (1980), The 1980 Follow-up on Air Quality in the Toronto Subway System, Report ARB-TDA-63-80, Toronto.

Pinchin, D.J. (1982), Asbestos in Buildings, Report Prepared for the Royal Commission on Matters of Health and Safety Arising from the Use of Asbestos in Ontario, Toronto.

Reitze, W.B., W.J. Nicholson, D.A. Holaday and I.J. Selikoff (1972), Application of sprayed inorganic fiber containing asbestos: occupational health hazards, Am. Ind. Hyg. Assoc. J., 33, 178.

Rickards, A.L. and D.V. Badami (1971), Chrysotile Asbestos in Urban Air, Nature, 234, 93-94.

Sebastien, P., J. Bignon, A. Gaudichet, G. Dufour and G. Bonnaud (1976), Les pollutions atmospheriques urbains par l'asbeste, Rev. Franc. Mal. Resp., 4 (Suppl. 2), 51-62.

Sebastien, P., J. Bignon and M. Martin (1982), Indoor airborne asbestos pollution: from the ceiling and the floor, Science, 216, 1410.

Selikoff, I.J. and D.H.K. Lee (1978), Asbestos and Disease, Academic Press, N.Y.

Selikoff, I.J., W.J. Nicholson and A.M. Langer (1972), Asbestos air pollution, Arch. Environ. Health, 25, 1-13.

Spurny, K.R. and W. Stober (1978), Asbestos measurements in remote ambient air, In: Clean Air, The Continuing Challenge, Ann Arbor Science Publishers Inc., Ann Arbor, Michigan.

Spurny, K.R., W. Stober, H. Opiela and G. Weiss (1979), On the evaluation of fibrous particles in remote ambient air, The Science of the Total Environment, 11, 1-40.

6. HEALTH EFFECTS

6.1 General

The health hazards associated with exposure to high airborne levels of asbestos in the occupational environment have long been recognised. Prolonged exposure to elevated concentrations causes asbestosis, which is a slowly progressive, persistent and often disabling fibrosis of the lungs. Often associated with asbestosis are pleural abnormalities such as thickening, calcification and effusion. Bronchial carcinomas (lung cancer), mesotheliomas of the pleura and peritoneum (rare tumours of the lining of the chest and abdominal cavities) and possibly laryngeal cancer and malignancies of the gastrointestinal tract have also been associated with occupational exposure to asbestos.

Increased risks of asbestos-related disease have been observed not only in occupationally exposed populations, but also in the families of workers and in the residents of neighbourhoods in the vicinity of asbestos industries. In this chapter, selected information will be discussed in an attempt to characterize the risks associated with exposure to asbestos in ambient air. More comprehensive analyses, beyond the scope of this document, are included in several reviews prepared recently by panels of experts such as the U.S. National Academy of Sciences (1988), the Royal Commission on Matters of Health and Safety Arising from the Use of Asbestos in Ontario (1984), the World Health Organization (1986), the U.S. Consumer Product Safety Commission (1983).

6.2 Epidemiological Studies

6.2.1 Health Effects in Occupationally Exposed Populations

There are few epidemiological data available concerning the health effects associated with exposure to asbestos in ambient air. Some relevant data can be obtained through examination of the results of epidemiological studies of occupationally-exposed populations.

6.2.1.1 Asbestosis

Asbestosis has been defined as "fibrosis of the lungs caused by asbestos dusts which may or may not be associated with fibrosis of the parietal or pulmonary layer of the pleura" (U.K. Health and Safety Commission, 1979). Asbestosis is a progressive and sometimes disabling disease which is characterised by clinical signs and symptoms such as breathlessness, pulmonary function changes, basal rales and small, mainly irregular, opacities on chest radiographs.

A relationship between exposure and the prevalence of symptoms or excess mortality due to asbestosis has been observed in epidemiological studies of workers exposed to all types of asbestos in most sectors of the asbestos industry (Becklake, 1982). Estimates of dose-response relationships for asbestosis are necessarily crude due to the fact that the clinical, radiological and other signs on which the diagnosis is based are non-sepcific and subject to wide variations in interpretation (Acheson and Gardner, 1980).

However, dose-response data from three recent studies (Berry et al., 1979; Finkelstein, 1982; British Occupational Hygiene Society, 1983) indicate that the prevalance and incidence of "certified" asbestosis may be directly proportional to the cumulative dose.

6.2.1.2 Non-malignant Pleural Effects

Pleural abnormalities such as thickening, calcification and effusion have also been associated with exposure to asbestos. However, the increased prevalence of pleural plaques observed in epidemiological studies of workers exposed to various types of asbestos has been related more to time since first exposure than to dust concentrations (U.S. Consumer Product Safety Commission, 1983). Plaques are a late manifestation and generally do not appear before 20 years after first asbestos exposure (Hillerdal, 1978). It has often been concluded on the basis of the available data, that pleural plaques in themselves do not give rise to clincial symptoms or functional impairment; changes in pulmonary function that have been observed in workers with pleural plaques in a few studies (Hedenstierna et al., 1981; Fridriksson et al., 1981) have largely been attributed to parenchymal involvement which was not radiologically apparent (Casey et al., 1981; U.S. Consumer Product Safety Commission, 1983). However, the long term significance of pleural plaques is unknown. Although it has often been concluded that their primary importance is simply as a marker of asbestos exposure, the results of some recent studies indicated that workers with pleural plaques are more likely to develop parenchymal fibrosis (Sheers, 1979) and neoplasia (Fletcher, 1972; Edge, 1979).

6.2.1.3 Bronchial Carcinoma

The first suggestion that asbestos might be a human carcinogen came in 1935 when Lynch and Smith (1935) in the U.S. and Gloyne in the U.K. (1935) independently observed lung cancer in three asbestos workers who had died of asbestosis. There were similar reports in the following years; however the first epidemiological studies that confirmed the association between occupational asbestos exposure and lung cancer were not conducted until the mid-1950s (Doll, 1955). This association has been repeatedly observed in numerous subsequent studies of occupationally exposed populations; these studies have further characterised the risk of developing asbestos-related lung cancer in relation to occupation, fibre-type and other factors such as cigarette smoking.

The risk appears to increase with both level and duration of exposure and based on the available evidence, it is generally assumed by most investigators that the relationship between mortality due to bronchial carcinoma and cumulative exposure to asbestos is linear. There is also some evidence that mortality from lung cancer increases with dose when lapsed period is held constant (Acheson and Gardner, 1980). Although the risk appears to be independent of age at first exposure, the relative risk decreases after 35 to 40 years from onset of exposure (Chronic Hazard Advisory Panel on Asbestos, 1983).

The risk is increased at least additively and in some cohorts, multiplicatively by cigarette smoking (McDonald, 1980); it has been reported that the risk of developing lung cancer for asbestos workers who are smokers is about 10 times that of non-smoking asbestos workers and 90 times that of non-smokers who are not occupationally exposed to asbestos (Selikoff and Hammond, 1979; McDonald, 1980).

Bronchial carcinoma has been associated with exposure to all three commercially produced varieties of asbestos. In one study, a greater excess of lung cancer was observed in asbestos cement workers with mixed fibre exposure (crocidolite and chrysotile) than in those exposed only to chrysotile (Hughes and Weill, 1980). In this study, a difference in risk was still apparent after the extent of fibre exposure was taken into account. however, the evidence concerning variations in risk of lung cancer associated with exposure to different types of asbestos must be considered to be incomplete.

6.2.1.4 Mesothelioma

Several cases of mesothelial tumours of the pleura and peritoneum associated with exposure to asbestos were noted in the literature between 1931 and 1960 (McDonald and McDonald, 1977). For example, in 1955 Bonser et al. (1955) reported four primary peritoneal tumours in 72 asbestos textile workers. However, there was no conclusive evidence of the relationship between occupational exposure to asbestos and mesothelioma until 1960 when Wagner et al. (1960) reported 33 pleural mesotheliomas among miners and residents of a crocidolite mmining region in South Africa during a four year period. Studies conducted since that time have further characterised the risks of developing mesothelioma in relation to factors such as fibre type.

A history of asbestos exposure has been ascertained for 22 to 100 per cent of the cases of pleural and peritoneal mesothelioma in various series (Kannerstein and Churg, 1980). It is possible that the proportion associated with asbestos exposure in some series may have been under-estimated due to recall bias; however there is evidence that some mesotheliomas are associated with exposure to agents other than asbestos (Pelnar, 1983). In addition, a small number have occurred in children where age was less than the latency period of asbestos-induced mesothelioma (Kannerstein and Churg, 1980). The latency period between first exposure and appearance of the tumour is from about 10 or 15 years to 40 years, irrespective of the duration or age at first exposure (Wagner and Elmes, 1981; Doll and Peto, 1985) and the risk increases rapidly with time from onset of exposure for at least 50 years. Indeed, it has been suggested that the incidence of mesothelioma is related to between the third and fourth power of the lapsed period since onset of exposure (Peto et al., 1982). Because of this rapid increase or risk with time, the lifetime risk associated with exposure in childhood is likely to be greater than it would be in those cases where exposure begins in adulthood.

There is some evidence from studies of workers that the risk of pleural mesothelioma increases with both intensity and duration of exposure (McDonald et al., 1980; Whitwell et al., 1981; Newhouse and Berry, 1976; Newhouse and Berry, 1979; Hobbs et al., 1980); however exposure in some cases has been as short as six weeks (Newhouse et al., 1972). On the basis of the few available data, several authors have suggested that the dose-response relationship for pleural mesothelioma may be linear (Acheson and Gardner, 1979; Peto, 1978).

There are insufficient data to draw any conclusions concerning the shape of the dose response curve for peritoneal mesotheliomas; however, the relationship is somewhat irregular, suggesting that a second causative factor may be involved (Acheson and Gardner, 1980).

There is no evidence that smoking increases the risk of developing asbestos-related mesotheliomas. However, there is some evidence that the risk varies depending upon the nature of exposure; for example, the risk for workers exposed to crocidolite in manufacturing operations are greater than those observed for crocodilite miners and millers (see Table 6.4).

Peritoneal mesotheliomas have been associated almost exclusively with exposure to crocidolite or amosite (Acheson and Gardner, 1983). The proportion of deaths due to mesotheliomas in various studies is presented in Table 6.4. Based on comparison of these proportions in populations exposed to either chrysotile or the amphiboles in similar types of occupations, it has been suggested that crocidolite and amosite are more potent in the induction of pleural mesotheliomas than is chrysotile (Acheson and Gardner, 1979; WHO, 1986; Royal Commission, 1984). For example, the proportion of deaths due to mesotheliomas was 0.3 per cent in a cohort of chrysotile miners and millers (McDonald et al., 1980) compared to 8.8 per cent in a cohort of crocidolite miners and millers (Hobbs et al., 1980). As indicated in Table 6.4 similar differences have also been observed in the manufacturing and application industries. It should be noted, however, that pleural mesotheliomas have been observed in populations exposed only to chrysotile, but not in those exposed to anthophyllite (Meurman et. al., 1974).

The results of recent studies involving analysis of the asbestos content of lung tissues have also lent evidence to the hypothesis that the amphiboles may be more hazardous than chrysotile in the induction of pleural mesotheliomas. In two studies of mesothelioma patients in the U.K. (Jones et al., 1980) and in the U.S. and Canada (McDonald et al., 1982), there were no differences in the distribution of chrysotile between cases and controls. however, amphibole fibres were present in larger quantities in cases than in controls in both series.

It is difficult, however, to draw definitive conclusions concerning the relative potency of various fibre types in the induction of pleural mesotheliomas. This is largely because the evidence is somewhat indirect, exposure to just one fibre in the occupational envirnment is rare and mesotheliomas are difficult to diagnose. It is also possible that the higher proportion of mesotheliomas associated with crocodolite exposure in the occupational environment may have been due to higher airborne concentrations of this reputedly "dustier" material or to variations in fibre size distribution.

6.2.1.5 Other Cancers

Available data concerning the relationship between exposure to asbestos and cancers of the gastrointestinal tract in cohort studies of asbestos workers are presented in Table 6.4. Excess deaths due to gastrointestinal malignancies were observed in five out of the eight statistically most powerful studies and in 13 out of 20 less powerful studies (U.S. Consumer Product Safety Commission, 1983). There is a possibility that at least some of the reported gastrointestinal tumours in these studies were actually misdiagnosed peritoneal mesotheliomas; however, the weight of evidence suggests a causal relationship between exposure to asbestos and gastrointestinal malignancies. Although there are few data available, the dose response relationship appears to be somewhat irregular, suggesting that other factors may be involved in the aetiology of these gastrointestinal tumours.

The balance of epidemiological data indicates that there is also a causal association between occupational exposure to asbestos and laryngeal cancer. An excess of laryngeal cancer in asbestos workers has been observed in five out of seven cohort studies (McDonald et al., 1980; Newhouse et al., 1982; Newhouse nd Berry, 1973; Selikoff et al., 1979); Clemmensen and Hjalgrim-Jensen, 1981; Rubino et al., 1979; Seidman et al., 1979) and four out of five case-control studies (Stell and McGill, 1973; Shettigara and Morgan, 1975; Morgan and Shettigara, 1976; Hinds et al., 1979; Burch et al., 1981). Although the excess was not observed in the best described case-control study (Newhouse et al., 1980), it was noted in the inherently more sensitive cohort studies (Clemmensen and Hjalgrim-Jensen, 1981; Newhouse and Berry, 1973; Selikoff et al., 1979; Rubino et al., 1979). The available data indicate that there may be an interaction between smoking and asbestos exposure in the aetiology of these tumours.

There was a statistically significant excess of cancers of the ovary in a high exposure group of women in a London asbestos factory (Newhouse and Berry, 1979). This association has also been observed in two recent studies of women manufacturing gas masks from crocidolite (Acheson et al., 1982; Wignall and Fox, 1982) but not among women manufacturing friction materials (Newhouse et al., 1982) or gas masks from chrysotile (Acheson et al., 1982). It is possible that the excesses may have been a result of misdiagnosed peritoneal mesotheliomas.

Goldsmith (1982) has recently reported that based on analysis of the results of 11 cohort studies, observed to expected ratios for cancer of several nonpulmonary sites ranged from 0.97 to 2.78 and wre similar to those observed for gastrointestinal cancer. An increased risk of cancer of the oral cavity and pharynx, pancreas, kidney and brain has also been observed in a large cohort of asbestos insulation workers (Selikoff et al., 1979; Seidman et al., 1982) and it has been suggested that there may be an association between non-Hodgkin's lymphoma of the alimentary tract and asbestos exposure (Ross et al., 1982; Bengtsson et al., 1982). There have been isolated reports of adenocarcinoma of the rete testis in a man with asbestosis (Gisser et al., 1977) and pericardial mesotheliomas in three asbestos workers (Beck et al., 1982). However, these associations have not been confirmed and may have been due to chance or misdiagnosis. For example, analyses using additional histological data have shown that a portion of the excess of pancreatic cancers observed in the cohort of insulation workers upon the analysis of death certificate data was actually due to misdiagnosis of peritoneal mesotheliomas (Selikoff et al., 1979).

6.2.2 Exposure of Family Contacts of Asbestos Workers

Increased risks of pleural abnormalities and mesothelioma have been observed in the families of asbestos workers, due presumably to dissemination of fibres in the home from contaminated work clothes.

6.2.2.1 Non-malignant Effects on the Pleura

In one study, the prevalence of pleural calcification in 114 blood relatives of factory workers was 3.5 per cent, compared to 0.34 per cent in over 8,000 persons from the general population (Navratil and Trippe, 1972). In a more recent study, the prevalance of pleuropulmonary abnormalities upon radiographic examination (i.e. pleural thickening, pleural plaques, pleural calcification and irregular opacities) was 36 per cent in a population of 626 household contacts of amosite asbestos workers, compared to 4.6 per cent in a control population of 326 individuals (Anderson et al., 1979). The prevalence of abnormalities increased with a longer period of active household exposure as estimated by length of the workers' asbestos employment. The authors also concluded on the basis of their study that for para-occupational exposure, "it appears that a longer elapsed time is required before disease becomes apparent, compared with direct occupational exposure".

6.2.2.2 Mesothelioma

In 1965, Newhouse and Thompson (1965) first observed nine cases of mesothelioma in household contacts of asbestos workers in a London hospital case series. By 1979, a total of 50 mesotheliomas attributable to household asbestos exposure had been observed (Anderson et al., 1979); additional cases have been reported in recent years (Vianna and Polan, 1978; McDonald, 1980). In a case control study of 52 females with mesothelioma in New York State between 1967 and 1977, the relative risk of having an asbestos worker in the household in cases compared to controls was 10 (Vianna and Polan, 1978).

6.2.3 Exposure of Populations Residing in the Vicinity of Asbestos Deposits and Industries

6.2.3.1 Non-malignant Pleural Effects

Pleural calcification has been associated with exposure to asbestos in the environment from man-made and anthropogenic sources. Increased prevalence of pleural calcification has been observed in a Finnish population residing in the vicinity of an anthophyllite mine (Kilviluoto, 1960) and similar observations have been made for populations living in the vicinity of an anthophyllite mine in Bulgaria (Zolov et al., 1967), an actinolite mine in Austria (Neuberger et al., 1978), an asbestos factory in Czechoslovakia (Navratil and Trippe, 1972), deposits of anthophyllite, tremolite and sepiolite in Bulgaria (Burilkov and Michailova, 1970) and chrysotile deposits in Greece (Bazas and McDonald, 1981). However, increased prevalence of pleural calcification has also been observed in populations with no identifiable asbestos exposure (Rous and Studeny, 1970).

6.2.3.2 Bronchial Carcinoma

Three ecological (*) epidemiological studies have been conducted to investigate the relationship between exposure to asbestos in the environment and disease (Pampalon et al., 1982; Siematycki, 1983; Fears, 1976; Graham et al., 1977). Based on the analysis of cancer incidence data from the Quebec Tumour Registry, residents of asbestos mining communities had risks from 1.5 to 8.08 times those in rural Quebec counties for ten different cancer sites among males and for seven sites among females. The higher risks in males were attributed in part to occupational exposure. There was increased risk of cancer of the pleura in both sexes, which decreased with distance of residence from the asbestos mines. The authors emphasised the limitations of their study and recommended that information concerning other exposures and lifestyle factors be considered in more powerful case-control studies.

Although such studies have not been conducted to date, an additional ecological study has recently been completed (Pampalon et al., 1982; Siemiatycki, 1983). Mortality between 1966 and 1977 in agglomerations (several municipalities) around the asbestos mining communities of Asbestos and Thetford Mines were compared to that of the Quebec population. There was a statistically significant excess of cancer among males in these agglomerations which was attributed to occupational exposure. [A telephone survey indicated that 75 per cent of the men in these communities had worked in the mines (Siemiatycki, 1983).] For women, whose exposure would have been confined to the environment or in some cases to environmental exposure and family contact, there were no statistically significant excesses of mortality due to all causes [SMR (standardized mortality ratio) (*) = 0.89], all cancers (SMR = 0.91), digestive cancers (SMR = 1.06), respiratory cancers (SMR = 1.07) or other respiratory disease (SMR = 0.58). Similarly there were no significant excesses when mortality at age less than 45 was considered or when the reference population was confined to towns of similar size (SMR=1.18). Unfortunately, very few causes of mortality were examined in this study and the classes were fairly broad. The authors concluded, however, that the results were consistent with the hypothesis of no excess risk, although a small excess risk could not be ruled out. In another ecological study conducted in the U.S. in which there was some attempt to control for the urban effect, geographic gradient and socioeconomic class, there was no correlation between general cancer mortality and the location of asbestos deposits (Fears, 1976).

Ecological studies such as those described above are considered to be insensitive because of the large number of confounding variables which are difficult to eliminate. In addition, true excess cancer risk is probably underestimated in such studies due to population mobility over a latent period of several decades (Polissar, 1980). Case-control and cohort studies are much more powerful than ecological studies because exposure and outcome is assessed

---

(*) An ecological study is one in which exposure is assessed for populations rather than individuals.

(*) Ratio of the number of deaths observed to the number of deaths expected, if the study population had the same structure as the standard population.

for individuals rather than populations. One relevant cohort study has been conducted. Mortality data for 1779 men who lived within 1/2 mile of an amosite factory in Paterson, N.J. in 1942 were compared to that of 5206 male residents of a similar Paterson neighbourhood with no asbestos plant. All men who worked in the factory were excluded. Approximately 780 (44 per cent of the "exposed" population) and 1735 (46 per cent of the "unexposed" population) died during the 15-year period 1962 to 1976. With respect to total deaths, deaths from cancer (all sites combined), and lung cancer, mortality experience was slightly worse in the "unexposed" population during this period. One death from pleural mesothelioma was observed in the "exposed" population; surprisingly, it occurred in the first 5 years of the 15-year period (Hammond et al., 1979). There was no attempt to estimate exposure to asbestos in either of the areas investigated in this study.

In summary, no evidence of excess mortality due to lung cancer in populations residing in the vicinity of industrial sources of asbestos emissions has been demonstrated. However, it should be noted that the sensitivity of the available studies is limited, due to the factors (i.e. low power, lack of exposure data) mentioned above.

6.2.3.3 Mesothelioma

There is some evidence mainly from case series and case-control studies that the risk of mesothelioma may be increased for individuals who have lived near asbestos mines or factories; however, the proportion of mesothelioma patients with neighbourhood exposure to asbestos varies markedly in different series. In Wagner et al.'s (1960) early review of 33 cases of mesothelioma in the Northeast Cape province of South Africa, approximately half were individuals with no occupational exposure who had lived in an area of crocidolite mining. Newhouse and Thompson (1965) observed 11 otherwise unexposed cases (30.6 per cent of patients in the series) that had lived within 1/2 mile of an "asbestos factory" in London. [Although the type of asbestos was not specified, it has more recently been reported that this was a "amphibole plant" (Gloague, 1981)]. Bohlig and Hain (1973) reviewed data on mesotheliomas observed in neighbourhoods of shipyards and reported 38 cases of "non-occupational" mesothelioma occurring in a ten year period in residents of a neighbourhood near a Hamburg asbestos plant. In a study conducted in Canada, however, exlcuding those individuals with occupational or household exposure to asbestos, only two out of the 254 (0.75 per cent) cases of mesothelioma recorded in Quebec between 1960 and 1978 lived within 20 miles (= 33 km) of the chrysotile mines and mills (McDonald, 1980).

There are few data available on the length of residence of the patients in the vicinity of the plants in these studies. Out of 413 notified cases of mesothelioma in the U.K. in 1966-67, 11 (2.7 per cent) individuals who were not asbestos workers and who did not have household exposure had lived within one mile of an "asbestos factory" for periods of 3-40 years. In a review of cases of mesothelioma in 52 female residents of New York State diagnosed between 1967 and 1968, three otherwise "unexposed" patients (5.8 per cent) lived within 3.6 km of asbestos factors for 18 to 27 years (Vianna and Polan,1978). In most of the studies there were few data presented concerning the type of asbestos to which neighbourhood residents were exposed.

6.2.4 The General Population

Some relevant information concerning the proportion of disease in the general population attributable to environmental exposure to asbestos has been obtained in recent time trend analyses of data on the incidence of malignant mesothelial tumours in men and women (McDonald, 1984). Data from several countries indicate that until the 1950's (i.e. 30-40 years following the introduction of widespread use of asbestos in industry), the rates of mesothelioma were similar in both sexes. Since then, as would be expected, the incidence in males has risen steeply due principally to occupational exposure. However, comparatively few females have been exposed to asbestos in the workplace, and McDonald (1984), therefore, has postulated that increased mesothelioma in women over time would more likely be a consequence of domestic and environmental exposure. However, recent data (1970-80) for the U.S. indicate that while the mesothelioma rate in males is still increasing by nearly 10 % per annum, there has been no clear convincing change in the rates among females. On the basis of this analysis, McDonald (1984) has concluded that exposure to asbestos in the general environment contributes little to the overall incidence of mesothelioma. However, there is a need to evaluate the sensitivity of this approach and additional years of observation may be required before an excess can be ruled out.

6.3 The Pathogenesis of Asbestos Associated Diseases - The Toxicological Data

For a pollutant such as asbestos where there is a great deal of information on the human health effects associated with exposure, the results of toxicological studies are important not only to verify, under controlled conditions, that associations observed in epidemiological studies are indeed causal, but also to elucidate mechanisms of toxicity. Although the mechanisms by which asbestos causes fibrosis, lung cancer and mesothelioma are not well understood, the results of toxicological studies have provided information concerning dose response relationships and risks associated with exposure to different fibre types and sizes. Probably the most important development relevant to the assessment of risk to man has been the observation in experimental studies, that both chemical and physical characteristics such as fibre dimensions are important determinants in the pathogenesis of asbestos-related disease.

6.3.1 The Role of Fibre Dimensions in the Pathogenesis of Asbestos-Related Diseases

6.3.1.1 Deposition and Retention of Fibres in the Respiratory and Gastrointestinal Tracts

Although physiological factors such as breathing patterns are also important, particle size is the most critical factor determining regional deposition of dusts (and fibres) in the respiratory system. Particles having an aerodynamic diameter (*) of 30 to 100 um are largely deposited in the nasopharyngeal region; particles with diameters of 10 to 30 um deposit mainly in the tracheobronchial region and particles with aerodynamic diameters 10 um are generally deposited in the alveoli (Ad Hoc Working Group to ISO, 1981).

(*) Diameter of a unit density sphere having the same terminal settling velocity as the particle, whatever its size, shape and density.

There are few data available concerning the specific deposition and clearance patterns for inhaled fibres in humans. However, on the basis of the available results, there is general agreement that deposition is largely determined by fibre diameter, with fibre length being only of secondary importance (Gibbs et al., 1982). Timbrell reported that the settling rates of asbestos and glass fibres of various dimensions passing through an aerosol spectrometer were dependent upon the square of the actual fibre diameter and that length was only of secondary importance (Timbrell, 1965). In a later report, Timbrell (1982) concluded that an asbestos fibre with a diameter of 3 um would have approximately the same falling speed as a 10 um unit density sphere and asbestos fibres with diameters $>$ 3 um would not, therefore penetrate and deposit in the alveolar region. The results of studies involving elctron microscopic analysis of the fibre content of lung tissue are consistent with the hypothesis that small diameter fibres ($<$ 3 um) of varying lengths (up to 50 um) deposit in the lower respiratory tract (Gibbs et al., 1982). [Since most asbestos fibres in ambient air are less than 3 um in diameter, it is probably safe to assume that most, if not all, can penetrate to the alveolar region (Gibbs et al., 1982)].

Fibre geometry probably also plays a role in deposition; it has been suggested that curved or curly fibres such as chrysotile are deposited higher in the respiratory tract than are straight ones (i.e. amphiboles) (Timbrell, 1970; Davis, 1970).

Particles that have been deposited on the surface of the respiratory tract are removed by mechanisms that vary, depending upon the site of deposition. In the nasopharyngeal and tracheobronchial regions, mucociliary clearance is predominant. In the alveolar region, phagocytosis of particles in macrophages and removal of the particle-containing macrophages either via the mucociliary escalator or lymphatic drainage are the principal routes of clearance.

Results of recent studies involving determination of the size distribution of asbestos fibres in human lung tissues have imparted some information concerning clearance of fibres from the respiratory tract. The results of these studies are consistent with the hypothesis that fibre length is the most important factor governing clearance (Walton, 1982; Timbrell, 1982). Results of such studies have also indicated that clearance is impaired in individuals with asbestosis (Timbrell, 1982).

The persistence of fibres in tissues appears to be most closely related to the chemical characteristics. Results of studies designed to investigate the relationship of asbestos-related disease to numbers and types of asbestos fibres present in lung tissue indicate that the amphiboles are more persistent than chrysotile. The results of animal inhalation studies also indicate that amosite and crocidolite are more persistent in lung tissue than is chrysotile (Wagner et al., 1974; Davis et al., 1978; Wagner et al., 1980).

Experiments with animals have demonstrated that inhaled asbestos fibres can move from the lung or trachea to other tissues. Fibres have been identified in the lymph nodes and the thyroid of guinea pigs that inhaled crocidolite and anthophyllite, respectively (Holt, 1974). Recently, widespread migration of fibres into vital organs and tissues has been reported in rats, hamsters and guinea pigs exposed to airborne potassium octatitinate fibres which have a physical configuration and size distribution similar to that of asbestos (Lee et al., 1981). Asbestos fibres have also been found in tissues distant from the site of intrapleural (Bignon et al., 1979; Holmes and Morgan, 1967; Morgan et al., 1971) and subcutaneous injection (Roe et al., 1967). However, increased pressure in the tissue following injection of relatively large amounts of asbestos may have been partially responsible for these observations. There are some human autopsy data which indicate that asbestos fibres may migrate systematically from the lung to other tissues (Godwin and Jagatic, 1970; Langer, 1974; Pontefract, 1974; Hourihane, 1965). However, the possibility of contamination of tissues with asbestos is great and there was no mention of contamination control techniques in any of these studies.

There is considerable disagreement concerning whether fibres ingested in food and drinking water can migrate from the gastrointestinal lumen into and through the walls of the gastrointestinal tract in sufficient numbers to cause adverse systemic or local effects. The available data are inconclusive due to several factors which complicate the interpretation and comparison of the results of the studies involving electron microscopic examination of the fibre content of tissue residues or biological fluids, including insensitivity of analytical techniques and contamination of samples that is not monitored in blank sample preparation and analysis.

It is not possible to conclude with certainty that ingested fibres do not cross the intact gastrointestinal tract wall. However, available evidence indicates that penetration is extremely limited (Toft et al., in press) and that the contribution of ingested asbestos to the total body burden is probably insignificant when compared to that of inhaled asbestos.

6.3.1.2 Pathogenicity

That fibre size is important in the pathogenesis of asbestos-related disease was first recognised as early as 1937, when Gardner (1937) suggested "a mechanical theory for asbestosis", based on his observation in inhalation experiments that longer fibres were more fibrogenic. This observation has been confirmed in subsequent animal inhalation studies (Vorwald et al., 1951; Lee et al., 1981) and in studies involving intrapleural (Burger and Englebrecht, 1970; Davis, 1972) and intratracheal (King et al., 1946; Smith et al., 1951; Wright and Kuschner, 1978) administration of asbestos to various animal species.

In 1962, Wagner first reported that "it is possible to produce tumours which appear to be arising from the mesothelial cells of the pleura by inoculating certain dusts into the pleural cavities of rats". Since that time, numerous similar studies have been conducted and up to 14 fibrous materials are now known to produce malignant neoplasms following implantation or injection into the pleural or peritoneal cavities of animals (Harrington, 1981); (See Table 6.5). In 1972, based on their study involving intrapleural implantation of fibrous materials in rats, Stanton and Wrench (1972) first hypothesised that "the simplest incriminating feature for both carcinogenicity and fibrogenicity seems to be a durable fibrous shape, perhaps in a narrow range of size". In later experiments, it was observed that fibres with maximum carcinogenic potency were generally longer than 8 um and less than 1.5 um in diameter (Stanton et al., 1977; Stanton and Layard, 1978; Wagner et al., 1973), and Pott (1978) has hypothesised a model in which there is a gradual transition in potency rather than a sharp demarcation between sizes. Fibres in these size ranges have also been more cytotoxic in in vitro studies in some non-phagocytic cell lines (Chamberlain et. al., 1980).

These observations concerning the importance of fibre size and shape in tumour induction have focussed a great deal of attention on this "carcinogenic subset" of fibres and have alerted us to potential hazards that might be associated with exposure to other natural and man-made mineral fibres. However, there are still several unanswered questions concerning the relative importance of fibres with dimensions in the critical size range in mesothelioma induction (Harrington, 1981). The possible role of submicroscopic fibres cannot be ignored (Harrington, 1981); fibre number may also be important (Davis, 1981; Harrington, 1981). In addition, in a recent study, acid leaching of asbestos significantly altered the carcinogenic potency after intrapleural injection (Monchaux et al., 1981); however, it is conceivable that this could be a function of fibre size change rather than chemical modification since the authors reported that maximally leached fibres are shorter and thicker than unmodified fibres. In several other studies, acid leaching (Wagner et al., 1973; Roe et al., 1967) and variation in the trace metal content (Gross and Harley, 1973) had no effect on carcinogenic potency. In addition, there is still some controversy concerning the histological nature of malignant tumours induced by intrapleural and intraperitoneal inoculation in animals (Harrington, 1981).

There are disadvantages of using a non-physiological route of administration such as intrapleural implantation to study mechanisms of asbestos-related disease in man. Specifically, neither aerodynamic factors which affect fibre deposition nor defence mechanisms which determine the retention of fibres within the lung nor factors which determine penetration of fibres from the alveolar space to the pleura are taken into consideration in this experimental model. However, the results of implantation studies can be integrated with the observations from other investigations that finer fibres are more likely to penetrate to the periphery of the lung, and that short fibres ($<$ 5 um) are more effectively cleared from the lungs by macrophages than are long fibres that cannot be phagocytosed by single cells (Harrington, 1981). Moreover, results of recently completed inhalation studies in rats indicated that long, thin fibres of amosite and chrysotile were more potent in inducing lung tumours than short thin fibres of the same varieties (Davis et al, 1986: in press). There is also some preliminary evidence in human populations that exposure to naturally occurring fibres in the critical size range may play a role in the aetiology of mesothelioma (Harrington, 1981; Wagner, 1980).

However, the need for caution in extrapolation of the results of intrapleural injection studies to predict the potency of various fibre samples with respect to induction of mesotheliomas and other types of cancer, such as lung cancer, cannot be overemphasised. In a recent study (Wagner et al., 1980), there were significant differences in tumour incidence following intrapleural injection and inhalation of the same samples of chrysotile. The authors suggested that problems of aggregation of fibres in solution for intrapleural injection might result in different size distributions.

The exposure conditions in inhalation experiments do, of course, approach most closely the circumstances of human exposure to asbestos and are most relevant for the assessment of risk to man. In an inhalation study conducted to compare the pathological effects of reference dust samples used in animal studies (UICC, International Union Against Cancer) with those collected from a factory environment, the authors concluded that while fibrogenicity and carcinogenicity both are a function of the presence of relatively long fibres in dust clouds, different lengths are involved in each process and tumour production requires the longest fibres (Davis et al., 1980).

6.3.2 The Relative Pathogenicity of the Various Forms of Asbestos

Interpretation of the results of many of the toxicological studies regarding pathogenicity of various fibre types is complicated due to the fact that often only the mass of the administered asbestos was measured; numbers of size distribution of fibres have generally not been taken into consideration. However, with few exceptions, chrysotile has been more cytotoxic to macrophages and to some non-phagocytic cell lines in in vitro studies than crocidolite or other forms of asbestos. Although haemolysis of red blood cells in vitro is not considered to be a particularly good predictive assay for in vivo pathogenesis of mineral dusts (Gormley et al., 1980), chrysotile is also more cytotoxic in this system. Furthermore, there appears to be a correlation between haemolytic potency, macrophage cytotoxicity and magnesium concentration for the various fibres (Gibbs et al., 1982; Harrington, 1976).

The results of a study by Davis et al., 1978, in which fibre size distribution was taken into consideration indicated that inhalation of chrysotile dust caused more lung fibrosis in rats than either crocidolite or amosite even when the fibre numbers (> 5 um) in the dust clouds were similar; all malignant pulmonary neoplasms occurred in chrysotile-treated animals. The authors suggested that the greater fibrogenicity and carcinogenicity of chrysotile might be related to the fact that the chrysotile clouds contained many more fibres over 20 um long.

In several studies, crocidolite was more potent in induction of malignant neoplasms than equal doses of chrysotile following implantation or injection into the pleural or peritoneal cavities of animal species (Wagner et al., 1973; Englebrecht and Burger, 1975; Monchaux et al., 1981; Gross and Harley, 1973). However, in contrast to the observation in human populations that mesotheliomas are most often associated with the inhalation of crocidolite, small numbers of mesotheliomas have been found in animals inhaling all types of asbestos (Wagner et al., 1974). Several reasons have been suggested for this seeming discrepancy between the results of the toxicological and epidemiological studies (Davis, 1981). The differences in the risk of development of mesothelioma in humans may be related to differences in past airborne concentrations and fibre size distributions in occupational environments (crocidolite is reputedly a more "dusty" material than chrysotile) (Walton, 1982). The possibly greater potency of crocidolite in mesothelioma induction in humans may also be due to the observed persistence of crocidolite fibres in biological tissues; chrysotile fibres may persist in the body for a sufficiently long period to induce tumours in rats but not in man.

Therefore, in general, chrysotile has been more pathogenic in the induction of both lung fibrosis and lung cancer in animal studies, even when fibre numbers in the dust clouds were similar. In addition, results of inhalation studies do not confirm the possible variations in risk of mesothelioma associated with exposure to different fibre types observed in epidemiological studies. These observations may be attributable to variations in persistence of different fibre types in relation to proportion of the lifespan for animals than for man.

6.3.3 Dose-Response Data

Available data from toxicological studies confirm the observation made in human populations that the incidence of asbestosis, bronchial carcinoma and mesothelioma increases with cumulative dose. Data from inhalation studies with animals indicate that the dose-response relationship for the incidence of fibrosis and lung cancer following exposure to various forms of asbestos is reasonably consistent with a linear model. The numbers of mesotheliomas observed in inhalation studies with animals have been small. The incidence of these tumours appears to increase with increasing length of exposure and cumulative dose; however, incidence following short periods of exposure would be greater than would be expected on the basis of a linear hypothesis for the dose-response relationship (Meek, 1984). There has been evidence of a dose response relationship for malignant tumour incidence following intrapleural injection of both chrysotile and crocidolite (Wagner et al., 1973); however, occasional tumours were observed even at the lowest dose levels (0.5 - 1 mg).

6.4 Risk Assessment

Based on the results of available studies, the estimated risk of prevalence of asbestosis at current levels of occupational exposure appears to be very low (Acheson and Gardner, 1983; Chronic Hazard Advisory Panel on Asbestos, 1983) and risks for the general population exposed to asbestos in ambient air are probably negligible. (Acheson and Gardner, 1983; Chronic Hazard Advisory Panel on Asbestos, 1983; Expert Advisory Committee to the Department of National Health and Welfare, 1984).

Information concerning the quantitative relationship between asbestos exposure and mortality due to lung cancer is available from several historical prospective mortality studies of populations exposed occupationally to past high airborne concentrations of mainly chrysotile. The results of these studies, which include estimates of individual levels of exposure, are presented in Table 6.1. In some studies, exposures of groups of workers have been estimated either by integrating average dust levels and duration of exposure or by assigning a numerical dust level to qualitative assessments of the degree of exposure. The results of these studies are presented separately in Table 6.2.

For lung cancer, there is general agreement that a linear non-threshold model should be assumed for calculating the slope of the exposure-response relationship. The data presented in these tables indicate that estimates of lung cancer risk per unit exposure derived through linear approximation of the results of these studies vary over an approximately 100-fold range. These variations are due partially to problems inherent in using epidemiological studies for risk assessment and partially to the complexity of asbestos itself. Often exposure data are inadequate, and measurements of airborne fibre concentrations in the occupational environment have been made only in recent years. In addition, accepted methods for sampling and analysis have changed over the years and as a result, it is difficult to compare exposure data. Available exposure-response data from occupational cohort studies are based on total respirable dust measurements made by impinger methods and expressed in millions of particles per cubic foot. Conversion of these measurements to fibres/ml ($>$ 5um) determined by optical microscopy is fraught with uncertainty. The potential to cause disease may also be underestimated or occasionally overestimated due to methodological limitations of mortality studies such as misdiagnosis, or inadequate comparison groups or observation periods. The risk appears to vary, depending on the nature of occupational exposure, with risks increasing from mining to production to application industries. However, very little is known about the differences in size distribution and properties of asbestos fibres in different industries which may be responsible for the variations in risk. The specific factors which complicate interpretation of the risk estimates derived from studies of occupationally exposed populations are presented in Table 6.3.

For mesothelioma, due to more limited data on exposure response relationships and questions concerning the relative potency of different fibre types, there is greater uncertainty concerning the choice of the appropriate model for extrapolation in risk estimation. However, models which assume linearity of the exposure-response relationship and which incorporate a relationship between risk and time since first exposure have been proposed (U.S. Consumer Product Safety Commission, 1984). However, since such models have been derived on the basis largely of observations in populations exposed to amosite alone or to mixtures of fibres, it has been suggested that they may not be appropriate for estimating risks associated with exposure to chrysotile (Expert Advisory Committee to the Department of National Health and Welfare, 1984).

Recently, there have been attempts to quantitatively estimate the risks associated with exposure of the general population to asbestos in ambient air, through extrapolation by such models of data from epidemiological studies of populations exposed to much higher levels in the occupational environment. For example, the Committee on Non-Occupational Health Risks of Asbestiform Fibres have estimated the lifetime (73 yrs) risks of mesothelioma and lung cancer associated with exposure to 0.0004 f/mL asbestos in ambient air. The Committee believed that based on avaialbe data, 0.0004 f/mL was the median population exposure level. The estimated risks were as follows: (National Academy of Sciences, 1984; Breslow et al., 1986).

	lung cancer (per million population)	mesothelioma (per million population)
male non-smokers	27	156
female non-smokers	14	156
male smoker	292	156
female smoker	105	156

The Committee also calculated the lifetime cancer risks at 0.002 f/mL, the value estimated to be the 90th percentile of asbestos levels in ambiant air. Since the models are linear, the estimated risks were five times greater than those presented on the previous page.

Approaches adopted by others (e.g. Chronic Hazard Advisory Panel on Asbestos, 1983) and the resulting estimated risks have been similar (McDonald, 1984). However, there are numerous uncertainties involved in estimation of risks for the general population and they should be considered to be rough approximations. One author has suggested that the range of error of such values is greater than five orders of magnitude (McDonald, 1984). The models used for extrapolation are based on conservative assumptions and probably tend to overestimate rather than underestimate the risks. For example, in addition to the difficulties described previously (inaccurate exposure data in occupational studies and variations in risk in different cohorts), additional uncertainty is introduced by the conversion of mass concentrations in ambient air determined by electron microscopy to fibres/c.c., observed by optical methods. The accuracy of estimates of risk to the general population is also limited by the paucity of available data upon which to base estimates of population exposure to asbestos in ambient air, and the variation in characteristics of asbestos fibres (e.g. size) between the occupational and general environments.

6.5 Summary

On the basis of available toxicological and epidemiological data, it can be concluded with some certainty that there is a dose-response relationship for all of the main types of asbestos-related disease. It can also be concluded that the risk of asbetosis associated with exposure to the low levels of asbestos present in ambient air is probably negligible and that strategies to limit exposure of the general population should be based on consideration of the more significant risks of lung cancer and mesothelioma associated with inhalation of respirable airborne asbestos.

There is evidence that the risk of mesothelioma is increased for family contacts of asbestos workers and for individuals who live near asbestos mines or factories. There was no evidence of increased mortality due to lung cancer in an ecological study of females residing in the vicinity of chrysotile mining communities in Quebec (Siemiatycki, 1983) or in an inherently more sensitive cohort study of male residents in the vicinity of a amosite factory (Hammond et al, 1979). However, the power of these studies was limited. Although few data concerning the exposure of the populations in these studies were presented, it has been reported that the concentrations of airborne asbestos in the homes of workers were considerably greater than those in the general environment (Gibbs et al., 1982). It is also likely that in the past, airborne fibre levels near asbestos facilities were probably significantly higher than they are today.

On the basis of time trend analysis of data concerning mesothelioma rates in males and females, it has recently been concluded that exposure to asbestos in the general environment contributes little to the overall incidence of mesothelioma (McDonald, 1984). However, there is a need to evaluate the sensitivity of this approach.

Available epidemiological data are insufficient to permit a precise determination of the cancer risks associated with exposure of the general population to asbestos in ambient air, and there are numerous uncertainties associated with estimation of these risks through extrapolation of epidemiological data on exposure to the much higher levels of asbestos present in the occupational environment. Such estimates can serve only as a rough guide. The Committee on Non-Occupational Health Risks of Asbestiform Fibres (1984) has estimated that lifetime risks of lung cancer associated with median exposure to asbestos in ambient air in the U.S. (0.0004 f/mL) vary from 14 per million for female non-smokers to 292 per million for male smokers. They estimated that the lifetime risk of mesothelioma attributable to environmental exposure to asbestos was 156 per million.

Table 6.1 Estimated Slopes of the Assumed Linear Relationships* Between Mortality Due to Lung Cancer and Cumulative Exposure to Asbestos - Individual Exposure Estimates Studies[a]

Occupational Group	Estimate of slope by: Nicholson (1981) (Selikoff, 1981) (SMR)	Liddell (1982)	Original Authors	Reference
Chrysotile miners and millers	0.06	0.038 (RR)	0.038 (RR)	McDonald *et al.*, (1980b)
Workers manufacturing textiles from chrysotile	5.3	2.3 (RR)	4.0 (SMR)	Dement *et al.*, (1982)
Workers manufacturing textiles from chrysotile	-	1.6 (RR)	1.7 (RR)	McDonald *et al.*, (unpublished a)
Workers manufacturing friction materials containing chrysotile and some crocidolite	-	0.058 (RR)	0.058 (RR)	Berry & Newhouse, (1983)
Manufacturers of textiles from chrysotile and some crocidolite	0.07 0.8	-	0.5 (SMR)	Peto, (1980a)
Manufacturers of products from chrysotile	0.3	0.12 (RR)	0.219 (SMR)	Henderson & Enterline, (1979)
Maintenance workers exposed to chrysotile, amosite and crocidolite	0.3	0.12 (RR)	0.219 (SMR)	Henderson & Enterline, (1979)
Manufacturers of asbestos cement products containing chrysotile and some crocidolite	-	0.22 (RR)	-	Weill *et al.*, (1979)
Manufacturers of textiles using chrysotile, amosite and crocidolite	-	-	1.7 (RR)	McDonald *et al.*, (unpublished b)

[a] Modified from Acheson and Gardner (1983)

* SMR (Standardized Mortality Ratio) = 100 + slope x cumulative dose in fibre-years/ml.

or

RR (Relative Risk) = $1 + \frac{slope}{100}$ x cumulative dose in fibre-years/ml.

Table 6.2 Estimated Slopes of the Assumed Linear Relationships Between Mortality Due to Lung Cancer and Cumulative Exposure to Asbestos - Group Exposure Estimate Studies[a]

	Estimate of slope by:		
Occupational Group	Nicholson (1981) (Selikoff, 1981) (SMR)	Liddell (1982)	Reference
Workers manufacturing products containing chrysotile, crocidolite and amosite.	M 1.3 F 8.4	0.4-1.1 (RR) 2.7 (RR)	Newhouse & Berry (1979)
Manufacturers of insulation products containing amosite.	9.1	1.1 (RR)	Seidman et al., (1979)
Insulation workers exposed to amosite and chrysotile	1.7	1.5 (SMR)	Selikoff et al., (1979)

[a] Modified from Acheson and Gardner (1983)

SMR - Standardized Mortality Ratio

RR - Relative Risk.

Table 6.3 Reasons for the Variation in Slope of the Relationship Between Mortality from Lung Cancer and Cumulative Asbestos Exposure in Various Studies of Asbestos Workers*

a) exposures to different fibre types or mixtures;

b) different work conditions;

c) varying accuracies of dust measurements, arising from different methods and positions of dust sampling, techniques of counting, use of measurements from other locations or factories, and 'guesstimates' made where no measurement data are available;

d) varying fibre:dust ratios;

e) differences in size distribution of the fibres;

f) different relationships between airborne fibre concentrations and the amount of fibre deposited in the lungs;

g) differing follow-up periods;

h) appropriateness or otherwise of external standard population;

i) differences in background level of lung cancer in standard populations;

j) smoking habits of industrial population relative to standard population;

k) differences in smoking habits between men at varying levels of cumulative dose;

l) use of retired population compared with a full cohort.

---

* Acheson and Gardner (1983).

Table 6.4 Proportion of Deaths Due to Mesothelioma and Ratio of Observed to Expected Deaths Due to Digestive Cancer in Cohort Studies of Asbestos-exposed Workers*

Occupation	Size of Cohort Traced	Proportion of Deaths Due to Mesothelioma	Ratio of Observed to Expected Deaths from Digestive Cancer	Reference
		Males		
Mining and Milling				
Chrysotile	9,850	0.30	1.01	McDonald et al. (1980)
	544	0.56	1.05	Nicholson et al. (1979)
	933	0	0.98	Rubino et al. (1979)
Anthophyllite	1,041	0	0.88	Meurman et al. (1974)
Talc	220	2.20	4.00	Kleinfeld et al. (1967b)
	382	1.35	1.00	Brown et al. (1979)
Crocidolite	4,960	8.84	-	Hobbs et al. (1980)
Manufacture				
Chrysotile	1,024	2.17	-	Elwood & Cochrane (1964)
	264	0	1.00	Weiss (1977)
	746	0.52	1.27	Dement et al. (1981)
Crocidolite	93	18.60	0.50	McDonald & McDonald (1978)
Amosite	820	2.65	-	Seidman et al. (1979)
Mixed	2,887	8.44	1.18	Newhouse & Berry (1979)
	8,804	0.49	0.96	Newhouse et al. (1981)
	796	3.07	-	Peto et al. (1977)
	1,075	0.51	1.38	Henderson & Enterline (1979)
	2,666	1.43	1.21	Robinson et al. (1979)
	5,645	0	0.50	Hughes & Weill (1980)
	1,266	2.29	1.71	Mancuso & Coulter (1963)
Insulation				
Mixed	152	8.70	2.59	Kleinfeld et al. (1967a)
	632	7.95	-	Selikoff et al. (1979)
	17,800	7.71	1.45	Selikoff et al. (1979)
	162	10.66	-	Elmes & Simpson (1977)
	1,368	12.05	0.70	Newhouse & Berry (1978)
Shipyards				
Mixed	6,076	2.69	0.88	Rossiter et al. (1980)
	4,779	0.78	-	Kolonel et al. (1980)
		Females		
Manufacture				
Crocidolite	578	10.24	0.49	Jones et al. (1980)
	83	15.38	-	McDonald & McDonald (1978)
Mixed	284	4.17	-	Peto et al. (1977)
	783	10.50	0.70	Newhouse & Berry (1979)
	4,219	0.58	1.06	Newhouse et al. (1981)
	544	3.12	1.33	Robinson et al. (1979)
	229	5.00	2.00	Mancuso & Coulter (1963)

* Modified from McDonald and McDonald (1981)

Table 6.5 Fibrous Materials Producing Malignant Neoplasms Following Implantation in the Pleural or Peritoneal Cavities of Animals*

amosite	fibrous glass
anthophyllite	mineral wool
chrysotile	aluminum oxide
crocidolite	potassium titanate
tremolite	silicone carbide
borosilicate glass	sodium aluminum carbonate
aluminum silicate glass	wollastonite
dawsonite	attapulgite

*Leineweber, J.P. (1980); cited in Harrington (1981).

6.6 References

Acheson, E.D., and Gardner, M.J. (1979), The ill effects of asbestos on health, in: Asbestos - Final Report of the Advisory Committee, Volume 2, U.K. Health and Safety Commission, London.

Acheson, E.D., and Gardner, M.J. (1980), Asbestos: scientific basis for environmental control of fibres, in: Biological Effects of Mineral Fibres, Wagner, J.C., Ed., IARC Scientific Publication 30, Lyon.

Acheson, E.D., and Gardner, M.J. (1983), Asbestos: the control limit for asbestos, U.K. Health and Safety Commission, London.

Acheson, E.D., Gardner, M.J., Pippard, E.C., and Grime, L.P. (1982), The mortality of two groups of women who manufactured gas masks from chrysotile and crocidolite asbestos: a 40-year follow-up, Br. J. Ind. Med., 39, 344-348; cited in Acheson and Gardner (1983).

Anderson, H., Lilis, R., Daum, S., Fischbein, A., and Selikoff, I.J. (1979), Household exposure to asbestos and risk of subsequent disease in: Dusts and Disease, Lemen, R., and Dement, J.M., Ed., Pathotox Publishers Inc., Park Forest South.

Bazas, T.B. and McDonald, J.C. (1981), Pleural calcification in north-west Greece, Lancet 2, 254.

Beck, B., Konetzke, G., Ludwig, V., Rothig, W., and Sturm, W. (1982), Malignant pericardial mesotheliomas and asbestos exposure: a case report, Amer. J. Ind. Med., 3, 149.

Becklake, M.R. (1982), Asbestos-related diseases of the lungs and pleura: Current clinical issues, Am. Rev. Respir. Dis., 126(2), 187-194.

Bengtsson, N.O., Hardell, L. and Eriksson, M. (1982), Asbestos exposure and malignant lymphoma, Lancet 2, 1463; cited in Acheson and Gardner (1983).

Berry, G., Gilson, J.C., Holmes, S., Lewinsohn, H.C. and Roach, S.A. (1979), Asbestos: a study of dose-response relationships in an asbestos textile factory, Br. J. Ind. Med., 36, 98-112; cited in Acheson and Gardner (1983).

Bignon, J., Monchaux, G., Sebastien, P., Hirsch, A. and Lafuma, J. (1979), Human and experimental data on translocation of asbestos fibers through the respiratory system, Ann. N.Y. Acad. Sci. 330, 745-750.

Bohlig, H. and Hain, E. (1973), Cancer in relation to environmental exposure, in: Biological Effects of Asbestos, Bogovski, P., Gilson, J.C., Timbrell, V., and Wagner, J.C., Ed., IARC Scientific Publication 8, Lyon.

Bolton, R.E., Davis, J.M.G. and Lamb, D. (1982), The pathological effects of prolonged asbestos ingestion in rats, Environ. Res. 29: 134-150.

Bonser, G.M., Faulds, J.S., and Stewart, M.J., (1955), Occupational cancer of the urinary bladder in dyestuffs operatives and of the lung in asbestos textile workers and iron-ore miners, Amer. J. Clin. Pathol., 25, 126.

Breslow, L., Brown, S., and Van Ryzin, J., (1986), Risk from Exposure to Asbestos, Science, November 21, 923.

British Occupational Hygiene Society: Committee on Asbestos (1983), A study of the health experience in two UK asbestos factories, Ann. Occup. Hyg., 27, 1-55; cited in Acheson and Gardner (1983).

Burch, J.D., Howe, G.R., Miller, A.B. and Semenciw, R. (1981), Tobacco, alcohol, asbestos and nickel in the aetiology of cancer of the larynx: a case-control study, J.N.C.I., 67, 1219-1224; cited in Acheson and Gardner (1983).

Burger, B.F., and Englebrecht, F.M. (1970), The biological effects of long and short fibres of crocidolite and chrysotile A after intrapleural injection into rats, S. Afr. Med. J., 44, 1268.

Burilkov, T. and Michailova, L. (1970), Asbestos content of the soil and endemic pleural asbestosis, Environ. Res. 3, 443-451.

Casey, K.R., Rom, W.N. and Moatamed, F. (1981), Asbestos-related diseases, Clinics in Chest Medicine, 2(2), 179-202.

Chamberlain, M., Brown, R.C., and Griffiths, D.M. (1980), The correlation between the carcinogenic activities *in vivo* and the cytopathic effects *in vitro* of mineral dusts, in: In Vitro Effects of Mineral Dusts, Academic Press Inc.

Clemmensen, J. and Hjalgrim-Jensen, S. (1981), Cancer incidence among 5686 asbestos-cement workers followed from 1943 through 1976, J. Ecotox. Environ. Safety, 5, 15-23; cited in Acheson and Gardner (1983).

Davis, J.M.G. (1970), The long-term fibrogenic effects of chrysotile and crocidolite asbestos dust injected into the pleural cavity of experimental animals, Br. J. Exp. Pathol., 51, 617.

Davis, J.M.G. (1972), The fibrogenic effects of mineral dusts injected into the pleural cavity of mice, Br. J. Exp. Pathol., 53, 190.

Davis, J.M.G. (1979), Current concepts in asbestos fiber pathogenicity, in: Dusts and Disease, Lemen, R., and Dement, J.M., Ed., Pathotox Publishers Inc., Park Forest South.

Davis, J.M.G., (1981), The biological effects of mineral fibres, Ann. Occ. Hyg., 24, 227.

Davis, J.M.G., Addison, J., Bolton, R.E., Donaldson, K., Jones, A.D., and Smith, T. (1986), The pathogenicity of long versus short fibre samples of amosite asbestos administered to rats by inhalation and intraperitoneal injection, Br. J. Exp. Pathol., 67, 415.

Davis, J.M.G. et al (in press), Comparisons of the pathogenicity of long and short fibers of chrysotile asbestos in rats.

Davis, J.M.G., Beckett, S.T., Bolton, R.E., Collings, P., and Middleton, A.P. (1978), Mass and number of fibres in the pathogenesis of asbestos-related lung disease in rats, Br. J. Cancer, 37, 673.

Davis, J.M.G., Beckett, S.T., Bolton, R.E., and Donaldson, K. (1980), A comparison of the pathological effects in rats of the UICC reference samples of amosite and chrysotile collected from the factory environment, in: Biological Effects of Mineral Fibres, Wagner, J.C., Ed., IARC Scientific Publication 30, 285.

Doll, R. (1955), Mortality from lung cancer in asbestos workers, Br. J. Ind. Med., 12, 81.

Doll, R. and Peto, J. (1985), Effects on Health of Exposure to Asbestos, U.K. Health and Safety Commission, H.M.S.O, London.

Edge, J.R. (1979), Incidence of bronchial cancer in shipyard workers with pleural plaques, Ann. NY Acad. Sci., 330, 289-294; cited in Becklake (1982).

Englebrecht, F.M., and Burger, B.F. (1975), Mesothelial reaction to asbestos and other irritants after intraperitoneal injection, S. Afr. Med. J., 49, 87.

Expert Committee Advising the Department Concerning the Scientific Basis for Occupational Standards for Asbestos (1984). Report to the Department of National Health and Welfare, Ottawa.

Fears, T.R. (1976), Cancer mortality and asbestos deposits, Am. J. Epidemiol., 104, 853.

Finkelstein, M.M. (1982), Asbestosis in long-term employees of an Ontario asbestos-cement factory, Am. Rev. Respir. Dis., 125, 496-501; cited in Chronic Hazard Advisory Panel on Asbestos (1983).

Fletcher, D.E. (1972), A mortality study of shipyard workers with pleural plaques, Brit. J. Ind. Med., 29, 142; cited in Casey _et al_., (1981).

Fridriksson, H.V., Hedenstrom, H., Hillerdal, G. and Malberg, P. (1981), Increased lung stiffness in persons with pleural plaques, Eur. J. Respir. Dis., 62, 412-424; cited in Chronic Hazard Advisory Panel on Asbestos (1983).

Gardner, L.U. (1937), First Progress Report on Asbestosis Experiments at the Saranac Lab., cited in King _et al_. (1946).

Gibbs, G.W., Arhirrii, M.I., and Doganoglu, Y. (1982), Effects of Inhaled Particles on Human Health, Report prepared for the Associate Committee on Scientific Criteria for Environmental Quality, National Research Council of Canada, Ottawa.

Gisser, S.D., Nayak, S., Kaneko, M., and Tchertkoff, V. (1977), Adenocarcinoma of the rete testis: a review of the literature and presentation of a case with associated asbestosis, Human Pathol., 8, 219.

Gloague, D. (1981), Asbestos - can it be used safely? Brit. Med. J., 282, 551.

Gloyne, S.R. (1935), Two cases of squamous carcinoma of the lung occurring in asbestosis, Tubercule, 17, 5.

Godwin, M.C. and Jagatic, J. (1970), Asbestos and mesotheliomas, Environ. Res. 3, 391-416.

Goldsmith, J.R., (1982), Asbestos as a systemic carcinogen: the evidence from eleven cohorts, Amer. J. Ind. Med., 3, 341.

Gormley, I.P., Brown, R.C., Chamberlain, M., and Davies, R. (1980), Report on an international workshop on the in vitro effects of mineral dusts, Ann. Occup. Hyg., 23, 225.

Graham, S., Blanchet, M., and Rohrer, T. (1977), Cancer in asbestos-mining and other areas of Quebec. J. Natl. Cancer Inst., 59, 1139.

Gross, P., and Harley, R.A. (1973), Asbestos-induced intrathoracic tissue reactions, Arch. Pathol., 96, 245.

Hammond, E.C., Garfinkel, L., Selikoff, I.J., and Nicholson, W.J. (1979), Mortality experience of residents in the neighbourhood of an asbestos factory, Ann. N.Y. Acad. Sci., 330, 417.

Harrington, J.S. (1976), The biological effects of mineral fibres, especially asbestos, as seen from in vitro and in vivo studies, Annals d'Anatomie Pathologique, 21, 155.

Harrington, J.S. (1981), Fiber carcinogenesis: Epidemiological observation and the Stanton hypothesis, J. Natl. Cancer Inst., 67, 977.

Hedenstierna, G., Alexandersson, R., Kolmodin-Hedman, B., Szamosi, A. and Tollquist, J. (1981), Pleural plaques and lung function in construction workers exposed to asbestos, Eur. J. Respir. Dis. 62, 111-122; cited in Chronic Hazard Advisory Panel on Asbestos (1983).

Hillerdal, G. (1978), Pleural plaques in a health survey material: Frequency, development and exposure to asbestos, Scand. J. Resp. Dis., 59, 257; cited in Casey et al., (1981).

Hinds, M.W., Thomas, D.B., O'Reilly, H.P. (1979), Asbestos, dental x-rays, tobacco and alcohol in the epidemiology of laryngeal cancer, Cancer, 44, 1114.

Hobbs, M.S.T., Woodward, S.D., Murphy, B., Musk, A.W. and Elder, J.E. (1980), The incidence of pneumoconiosis, mesothelioma and other respiratory cancer in men engaged in mining and milling crocidolite in Western Australia, Biological Effects of Mineral Fibres 2, 615-625, IARC Scientific Publications No. 30; cited in Acheson and Gardner (1983).

Holmes, A. and Morgan, A. (1967), Leaching of constituents of chrysotile asbestos in vivo, Nature 215, 441-442.

Holt, P.F. (1974), Small animals in the study of pathological effects of asbestos, Environ. Health Perspect. 9, 205-211.

Hourihane, D.O'B. (1965), A biopsy series of mesotheliomata, and attempts to identify asbestos within some of the tumours, Ann. N.Y. Acad. Sci. 132, 647-673.

Hughes, J., and Weill, H. (1980), Lung cancer risk associated with manufacture of asbestos cement products, in: Biological Effects of Mineral Fibres, Wagner, J.C., Ed., IARC Scientific Publication 30, Lyon.

Jacobs, R., Humphrys, J., Dodgson, K.S. and Richards, R.J. (1978), Light and electron microscope studies of the rat digestive tract following prolonged and short-term ingestion of chrysotile asbestos, Br. J. Exp. Pathol. 59: 443-543.

Jones, J.S.P., Pooley, F.D., Clark, N.J., Owen, W.G., Roberts, G.H., Smith, D.G., Wagner, J.C., Berry, G., and Pollock, D.J. (1980), The pathology and mineral content of lungs in cases of mesothelioma in the United Kingdom in 1976, in: Biological Effects of Mineral Fibres, Wagner, J.C., Ed., IARC Scientific Publications 30, Lyon.

Kannerstein, M., and Churg, J. (1980), Mesothelioma in man and experimental animals, Environ. Health Perspect., 34, 31.

Kilviluoto, R. (1960), Pleural calcification as a roentgenologic sign of non-occupational endemic anthophyllite-asbestosis, Acta. Radiol. Suppl., 194, 1.

King, E.J., Clegg, J.W., and Rae, V.M. (1946), The effect of asbestos, and of asbestos and aluminum, on the lungs of rabbits, Thorax, 1, 188.

Langer, A.M. (1974), Inorganic particles in human tissues and their association with neoplastic disease, Environ. Health Perspect. 9, 229-233.

Lee, K.P., Barras, C.E., Griffith, F.D., Waritz, R.S., and Lapin, C.A. (1981), Comparative pulmonary response to inhaled inorganic fibers with asbestos and fiberglass, Environ. Res. 24, 167.

Lynch, K.M., and Smith, W.A. (1935). Pulmonary asbestosis. III. Carcinoma of lung in asbestos-silicosis, Amer. J. Cancer, 24, 56.

McDonald, J.C. (1984), Health implications of environmental exposure to asbestos, presented at the Fifth Annual Symposium on Environmntal Epidemiology, April 24-26, Pittsburgh.

McDonald, A.D. (1980), Malignant mesothelioma in Quebec, in: Biological Effects of Mineral Fibres, Wagner, J.C., Ed., IARC Scientific Publication 30, Lyon.

McDonald, A.D., McDonald, J.C., and Pooley, F.D. (1982), Mineral fibre content of lung in mesothelial tumours in North America, in: Inhaled Particles V, Walton, W.H., Ed., Pergamon Press, Oxford.

McDonald, J.C. (1980), Asbestos-related disease: an epidemiological review, in: Biological Effects of Mineral Fibres, Wagner, J.C., Ed., IARC Scientific Publication 30, Lyon.

McDonald, J.C., Liddell, F.D.K., Gibbs, G.W., Eyssen, G.E., and McDonald, A.D. (1980), Dust exposure and mortality in chrysotile mining, 1910-1975, Br. J. Ind. Med., 37, 11.

McDonald, J.C., and McDonald, A.D. (1977), Epidemiology of mesothelioma from estimated incidence, Preventive Medicine, 6, 426.

McDonald, J.C., and McDonald, A.D. (1981). Mesothelioma as an index of asbestos impact, in Quantification of Occupational Cancer, Banbury Report No. 9, Cold Spring Harbor, N.Y., 1981.

Meek, M.E. (1984), The scientific basis for standards for occupational exposure to asbestos - the toxicological data. Report prepared as background documentation for the Expert Committee on Asbestos, Department of National Health and Welfare, Ottawa.

Meek, M.E., Shannon, H.S. and Toft, P. (1985) Case Study - Asbestos, in: Toxicological Risk Assessment, Volume II, CRC Press, Baton Rouge.

Monchaux, G., Bignon, J., Jaurand, M.C., Lafuma, J., Sebastien, P., Masse, R., Hirsch, A., and Goni, J. (1981), Mesotheliomas in rats following inoculation with acid-leaded chrysotile asbestos and other mineral fibres, Carcinogenesis, 2, 229.

Morgan, A., Holmes, A. and Gold, C. (1971), Studies of the solubility of constituents of chrysotile asbestos in vivo using radioactive tracer technqiues, Environ. Res. 4, 558-570.

Morgan, R.W., and Shettigara, P.T. (1976), Occupational asbestos exposure, smoking and laryngeal carcinoma. Ann. N.Y. Acad. Sci., 271, 308.

Navratil, M., and Trippe, F. (1972), Prevalence of pleural calcification in persons exposed to asbestos dust, and in the general population in the same district, Environ. Res., 5, 210.

Neuberger, M., Grundorfer, W., Haider, M., Konigshofer, R., Muller, H.W., Raber, A., Riedmuller, G. and Schwaighofer, G. (1978), Endemic pleural plaques and environmental factors, Zbl. Bakt. Hyg., I. Abt. Orig. 167, 391-404.

Newhouse, M.L. and Berry, G. (1973), Asbestos and laryngeal carcinoma, Lancet, ii, 615.

Newhouse, M.L., and Berry, G. (1976), Predictions of mortality from mesothelial tumours in asbestos factory workers, Br. J. Ind. Med., 33, 147.

Newhouse, M.L., and Berry, G. (1979), Patterns of mortality in asbestos workers in London, Ann. N.Y. Acad. Sci., 330, 53.

Newhouse, M.L., Berry, G., and Skidmore, J.W. (1982), A mortality study of workers manufacturing friction materials with chrysotile asbestos, Ann. Occup. Hyg., 26, 899-909; cited in Acheson and Gardner (1983).

Newhouse, M.L., Berry, G., Wagner, J.C., and Turok, M.E. (1972), A study of the mortality of female asbestos workers, Brit. J. Ind. Med. 29, 134.

Newhouse, M.L., Gregory, M.M., and Shannon, H. (1980), Etiology of cancer of the larnyx, in: Biological Effects of Mineral Fibres, Volume 2, Wagner, J.C., Ed., IARC Scientific Publication 30, Lyon.

Newhouse, M.L., and Thompson, H. (1965), Mesothelioma of pleura and peritoneum following exposure to asbestos in the London area, Br. J. Ind. Med., 22, 261.
Pampalon, R., Siemiatycki, J., and Blanchet, M. (1982), Pollution environnementale par l'amiante et santé publique ou Québec. Une analyse comparative de la mortalité dans les agglomérations du Québec, 1966-1977, Union Med. Can., 111, 475.

Patel-Mandlik, K.J. and Millette, J.R. (1980), Evidence of migration of ingested asbestos into various baboon organs, Scanning Electron Microscopy 1: 342-354.

Pelnar, P.V. (1983), Non-asbestos related malignant mesothelioma: A review of the scientific and medical literature, Canadian Asbestos Information Centre, Montreal, Canada.

Peto, J. (1978), The hygiene standard for chrysotile asbestos, Lancet, i, 484.

Peto, J., Seidman, H. and Selikoff, I.J. (1982), Mesothelioma mortality in asbestos workers: implications for models of carcinogenesis and risk assessment, Br. J. Cancer, 45, 124-135; cited in Acheson and Gardner (1983).

Polissar, L. (1980), The effect of migration on comparison of disease rates in geographic studies in the United States, Amer. J. Epidemiol., 111, 1975.

Pontefract, R.D. (1974), Penetration of asbestos through the digestive wall in rats, Environ. Health Perspect. 9, 213-214.

Pott, F. (1978), Some aspects on the dosimetry of the carcinogenic potency of asbestos and other fibrous dusts, Staub.-Reinhalt Luft, 38, 486.

Roe, F.J.C., Carter, R.L., Walters, M.A., and Harington, J.S. (1967), The pathological effects of subcutaneous injections of asbestos fibres in mice: migration of fibres to submesothelial tissues and induction of mesotheliomata, Int. J. Cancer, 2, 628.

Ross, R., Dworsky, R., Nichols, P., Paganini-Hill, A., Wright, W., Koss, M., Lukes, R. and Henderson, B. (1982), Asbestos exposure and lymphomas of the gastro-intestinal tract and oral cavity, Lancet ii, 1118-1119; cited in Acheson and Gardner (1983).

Royal Commission on Matters of Health and Safety Arising from the Use of Asbestos in Ontario (1984) Report. Ontario Ministry of the Attorney General, Toronto.

Rubino, G.F., Piolatto, G., Newhouse, M.L., Scansetti, G., Aresini, G.A., and Murray, R. (1979), Mortality of chrysotile asbestos workers at the Balangero Mine, Northern Italy, Br. J. Ind. Med., 36, 187.

Saracci, R. (1981), Personal-environmental interactions in occupational epidemiology, Recent Advances in Occupational Health, (ed. J.C. McDonald), 119-128, London: Churchill Livingstone; cited in Acheson and Gardner (1983).

Schneiderman, M.S., Nisbet, I.C.T., and Brett, S.M. (1981), Assessment of risks posed by exposure to low levels of asbestos in the general environment, Bundesgesundheitsamt-Berichte, 4, 3/1.

Seidman, H., Selikoff, I.J., and Hammond, E.C. (1982), Mortality of brain tumors among asbestos insulation workers in the United States and Canada, Ann. N.Y. Acad. Sci., 381, 160.

Seidman, H., Selikoff, I.J., and Hammond, E.C. (1979), Short-term asbestos work exposure and long-term observation, Ann. N.Y. Acad. Sci., 330, 61.

Selikoff, I.J., Hammond, E.C., and Seidman, H. (1979), Mortality experience of insulation workers in the United States and Canada, 1943-1976, Ann. N.Y. Acad. Sci., 330, 91.

Sheers, G. (1979), Asbestos associated disease in employees of Devonport dockyard, Ann. N.Y. Acad. Sci, 300, 281-288; cited in Becklake (1982).

Shettigara, P.T., and Morgan, R.W. (1975), Asbestos, smoking and laryngeal carcinoma, Arch. Environ. Health, 30, 517.

Siemiatycki, J. (1983), Health effects on the general population (Mortality in the general population in asbestos mining areas); in: Proceedings of the World Symposium on Asbestos, May 25-27, 1982, Montreal, Canada.

Smith, J.M., Wootton, I.D.P., and King, E.J. (1951), Experimental asbestosis in rats. The effect of particle size and of added alumina, Thorax, 6, 127.

Stanton, M.F., and Layard, M. (1978), The carcinogenicity of fibrous materials, in: Proceedings of Workshop on Asbestos: Definitions and Measurement Methods, U.S. National Bureau of Standards, Gaithersburg, Md.

Stanton, M.F., Layard, M., Tegeris, A., Miller, E., May, M., and Kent, E. (1977), Carcinogenicity of fibrous glass: pleural response in the rat in relation to fiber dimension, J. Natl. Cancer Inst., 58, 587.

Stanton, M.F., and Wrench, C. (1972), Mechanisms of mesothelioma induction with asbestos and fibrous glass, J. Natl. Cancer Inst., 48, 797.

Stell, P.M., and McGill, T. (1973), Asbestos and laryngeal carcinoma, Lancet ii, 416.

Timbrell, V. (1965), The inhalation of fibrous dusts, Ann. N.Y. Acad. Sci. 132, 255-273; cited in Timbrell (1982).

Timbrell, V. (1970), The inhalation of fibres, in: Proceedings of the Pneumoconiosis Conference, Johannesburg, South Africa, 1969; cited in Gibbs <u>et al</u>., (1982).

Timbrell, V. (1982), Deposition and retention of fibres in the human lung, Ann. Occup. Hyg. 26(1-4), 347-369.

Toft, P., Meek, M.E., Wigle, D.T. and Méranger, J.C. (1984) Asbestos in drinking water, CRC Critical Reviews in Environmental Control. 14, 151-197

U.K. Health and Safety Commission (1979), Asbestos, Final Report of the Advisory Committee on Asbestos, London.

U.S. Consumer Product Safety Commission (1984), Chronic Hazard Advisory Panel on Asbestos (1983), Report. Washington, D.C.

U.S. National Academy of Sciences (1984), Report of the Committee on Non-occupational Health Risks of Asbestiform Fibres, Washington, D.C.

Vianna, N.J., and Polan, A.K. (1978), Non-occupational exposure to asbestos and malignant mesothelioma in females, Lancet, i. 1061.

Vorwald, A.J., Durkan, T., and Pratt, P.C. (1951), Experimental studies of asbestosis, Arch. Ind. Hyg. Occup. Med., 3, 1.

Wagner, J.C. (1962), Experimental production of mesothelial tumours by implantation of dust in laboratory animals, Nature, 196, 180.

Wagner, J.C. (1980), Opening discussion in: Biological Effects of Mineral Fibres, Wagner, J.C., Ed., IARC Scientific Publication 30, Lyon.

Wagner, J.C., Berry, G., Skidmore, J.W., and Pooley, F.D. (1980), The comparative effects of three chrysotiles by injection and inhalation in rats, in: Biological Effects of Mineral Fibres, Wagner, J.D., Ed., IARC Scientific Publication 30, Lyon.

Wagner, J.C., Berry, G., Skidmore, J.W., and Timbrell, V. (1974), The effects of the inhalation of asbestos in rats, Brit. J. Cancer, 29, 252.

Wagner, J.C., Berry, G., and Timbrell, V. (1973), Mesothelioma in rats after inoculation with asbestos and other minerals, Brit. J. Cancer, 28, 173.

Wagner, J.C., and Elmes, P.C. (1981), The mineral fibre problem, in: Recent Advances in Occupational Health, McDonald, J.C., Ed., Churchill Livingstone, Edinburgh.

Wagner, J.C., Hill, R.J., Berry, G., and Wagner, M.M.F. (1980), Treatments affecting the rate of asbestos-induced mesotheliomas, Br. J. Cancer, 41, 918.

Wagner, J.C., Sleggs, C.A., and Marchand, P. (1960), Diffuse pleural mesothelioma and asbestos exposured in the North Western Cape Province, Br. J. Ind. Med., 17, 260.

Walton, W.H. (1982), The nature, hazards and assessment of occupational exposure to airborne asbestos dust: a review, Ann. Occup. Hyg., 25, 117.
Wehner, A.P., Stuart, B.O., and Sanders, C.L. (1979), Inhalation studies with Syrian golden hamsters, Prog. Exp. Tumor Res., 24, 177.

Whitwell, F., Scott, J., and Grimshaw, M. (1981), Relationship between occupation and asbestos-fibre content of the lungs in patients with pleural mesothelioma, lung cancer and other diseases. Clinics in Chest Medicine, 2, 179.

Wignall, B.K. and Fox, A.J. (1982), Mortality of female gas-mask assemblers, Br. J. Ind. Med., 39, 34-35; cited in Acheson and Gardner (1983).

World Health Organization (1986). Asbestos and other Natural Mineral Fibres, IPCS Environmental Health Criteria 53, Geneva.

Wright, G.W., and Kuschner, M. (1978), The influence of varying lengths of glass and asbestos fibres on tissue response in guinea pigs, in: Inhaled Particles IV, Walton,WH, Ed., Pergamon Press, Oxford.

Zolov, C., Bourilkov, T., and Babadjov, L. (1967); Pleural asbestosis in agricultural workers, Environ. Res., 1, 287.

7. NATIONAL STANDARDS

Several OECD Member countries have taken or are considering regulatory action to reduce emissions of asbestos into the atmosphere.

A number of different approaches can be distinguished by which this aim may be achieved.

(1) Regulations limiting direct emissions into the atmosphere from asbestos fibre production and transformation industries (from aircleaning devices in particular).

(2) Regulations limiting occupational exposure to asbestos in industry which, indirectly, can result in reduced emissions into the atmosphere.

(3) Regulations restricting or prohibiting the use of asbestos in some products or applications, which are likely to constitute sources of pollution, or prohibiting the use of some work processes or tools.

(4) Regulations covering removal of asbestos from existing applications, and on demolition of buildings containing asbestos.

(5) Regulations on asbestos waste disposal, in view of reducing emissions into the atmosphere from waste disposal sites.

(6) Ambient Air Quality Standards.

These different approaches are discussed individually hereafter because the regulations they refer to address very specific and well defined areas. It is clear however that various approaches may be followed at the same time, since they can complement each other.

In countries where no asbestos regulations exist as yet, introduction of Worker protection regulations should be given priority over specific environment protection legislation. The rationale for this is not only the fact that the risk-levels are quite distinct between occupational and environmental exposure, but also the fact that the environment can benefit a great deal as well from properly designed worker protection regulations, and in particular from the controlled use of asbestos to which they should lead.

7.1 Emission Standards

National emission standards are presented in Table 7.1. It should be noted that in several other countries, asbestos emissions are regulated by local authorities, and some countries, such as Belgium, Denmark, Luxembourg and U.K. employ best practical means.

TABLE 7.1

National Asbestos Emission Standards

Country	Concentration [mg/m^3]	Year	Remarks	Reference
Canada	2 fibers/cm^3	1978	At mine or mill: from crushing, drying, milling, and dry rock storage; measured undiluted In case of malfunction: standard may be exceeded for not more than 1 hr/month for crushing, milling and dry rock storage; 2 hrs/month for drying	Gazette du Canada, 1977
France	0.1	1980	For pure asbestos dust	Association Française de l'Amiante, 1980
	0.5	1980	For asbestos containing dust if asbestos content < 50 %; voluntary agreement between the French government and asbestos industry	
Germany (Federal Republic of)	0.1	1983	For pure asbestos dust and for stationary sources with a mass flow of 100 mg/hr	TA-Luft, Bundes-immissionschutz-gesetz, Germany 1983

TABLE 7.1 (Contd)

Country	Concentration [mg/m^3]	Year	Remarks	Reference
U.K.	-	1983	Asbestos Works are scheduled works under the Health and Safety (Emissions to atmosphere Act) H.M. Industrial Air Pollution Inspectorate are responsible for monitoring emissions which must be controlled by the best practicable means.	-
U.S.A.	No visible emission	1978	For new and existing facilities	Jarrault, 1980
	No visible emission or baghouse	1973-1978	NESHAP for asbestos mills, manufacturing, demolition and renovation, spraying, fabricating, insulating, and waste disposal	USEPA, 1980
USSR	0.15	1974	24-hour average	EEC, Directorate Social Affairs, 1976
	0.5	1974	maximum concentration in the sample not to be exceeded	EEC, Directorate Social Affairs, 1976
WHO	0.15	1974	24-hour average	EEC, Directorate Social Affairs, 1976
	0.5	1974	maximum concentration in the sample not to be exceeded	EEC, Directorate Social Affairs, 1976

The view in some countries is that, on the one hand, permanent control of compliance with emission standards is not achievable, and that on the other hand, periodic control of compliance is not representative. Preference is given therefore to obliging industry to use the best practical means for emission control. Periodic inspections are carried out to check whether the equipment is properly operated and kept in good working order.

Table 7.1 shows that, where emission standards are in use (or are recommended) the limits are expressed gravimetrically (mg/m^3) except in Canada (fibres/ml).

Gravimetric monitoring of emission seems to be the current trend in Europe (France 1980; Germany 1983; EEC asbestos emission regulations, 1984, currently under discussion).

There is no uniformity in the way emission measurements are interpreted for controlling compliance with the standard. In some countries the limit values not to be exceeded are short term average (2 hours), in other cases the limits refer to a 24 hour average.

In some countries the maximum allowed emission (mg/hr) varies according to the actual asbestos content in the emitted dust.

The choice between gravimetric measurements and fibre counting has been the subject of much discussion in the past.

On the basis of present scientific knowledge it is not possible to propose any limit value for stack emission which could be correlated directly to health protection of the population at large. Therefore, the prime object of establishing emission limit values and of monitoring emissions is to reduce as much as possible the total amount of asbestos emitted into the general environment. Gravimetric measurements are quite adequate for this purpose, and by measuring total dust rather than respirable dust only, there is no risk of underestimating the emissions. In addition, emission measurements expressed on a weight basis provide a direct link to the tonnage of asbestos produced or consumed, thus allowing calculation of emission proportions.

Mass measurements being quicker and easier, would seem more suitable for routine control than fibre counting, which is difficult to perform when isokinetic sampling is required. However, it is difficult to compare mass measurements across industries since the percentage of asbestos will vary from one to another.

Signals to operate warning systems (e.g. to indicate faulty operation of an airfiltering plant) are also more easily derived from automatic mass determination devices than from fibre counting.

In some particular and rare cases such as diffuse emissions, fibre counting may be the only possible approach. This situation occurs for instance in the case of discharge of filtered air from a filter baghouse through louvres in the walls, rather than through a stack. Such baghouses being accessible to the workforce however, measurements made inside the baghouse are to be looked at as workplace measurements, where fibre counting is at any rate the method to be used, the workplace limits being expressed in fibres/ml (except in USSR).

Trink (Ministère de l'Environnement et du Cadre de Vie, Direction de la Prévention des pollutions, Paris 1981) indicates that, when advanced air cleaning devices are used, emissions as low as 0,1 mg asbestos per m^3 air can be achieved. This level, adopted in Franece as an emission standard for pure asbestos dust in 1980, has also been introduced, more recently, in Germany (1983) and is, at present, being considered by the EC Authorities (Directorate General XI, Environment and Consumer Protection Department of the Commission of the European Communities) as a possible emission limit for all EC Member States.

Currently, many countries enforce particulate matter emission standards from stationary, and partly from fugitive, emission sources; these emission limits indirectly also control asbestos dust emissions into the atmosphere.

7.2 Occupational Exposure Limits

Although occupational exposure and corresponding regulations are beyond the scope of this report, it is useful to point out that the controlled use of asbestos and the better housekeeping which results from worker protection regulations, will also eliminate many potential sources of pollution of the environment.

A comprehensive survey of current worker protection regulations is contained in the Report of the Meeting of Experts on Safety in the Use of Asbestos (International Labour Office, Geneva, 11 - 20 October 1983). This report, to which a Code of Practice is appended, and which was unanimously adopted by the ILO Governing Body on 16 November 1983, contains data on National Regulations for the protection of asbestos industry workers in 25 countries. The vast majority of countries listed has a 2 fibres/ml standard. There has been a trend towards lower levels in recent years, whereas, on the other hand, in some countries levels higher than 2 f/ml are still in use today. In various countries, one single limit value applies to all asbestos varieties. Other countries have introduced more stringent exposure limits for some or all of the amphibole varieties.

The Asbestos International Association, in its Industry Code on Asbestos (first published December 1979, updated December 1983) now recommends to its Member Associations in countries where no specific worker protection regulations for asbestos industry workers exist, that measures should be taken on a voluntary basis, to keep exposure levels below 1 fibre/ml.

As already pointed out for emission standards, there is no uniformity of interpretation for occupational exposure limits either. In some countries the figures constitute absolute ceilings which on no account may be exceeded. In other countries, it is the long term average exposure level which may not exceed the limit values laid down in the regulations.

The EEC asbestos regulations are among the most recently adopted. The Council Directive 83/477/EEC on the protection of workers from the risks related to exposure to asbestos at work was adopted on 19 September 1983 and EC Member States must comply with this Directive before 1 January 1987 for the transformation industry and before 1 January 1990 for the asbestos mining industry. The Directive fixes the (8 hr TWA) exposure limit at 0.5 fibres/ml for crocidolite and at 1.0 fibres/ml for other asbestos varieties.

As a rule, occupational exposure limits for asbestos are expressed in terms of fibres/ml, a countable fibre being (generally) defined as a particle with a length to diameter ratio exceeding 3 : 1, with a length greater than 5 um, and a diameter less than 3 um.

In some countries dual criteria are in use (fibre number and/or mass) and in a single case, the USSR, the occupational exposure limit is expressed as a gravimetric limit only.

7.3 Regulations restricting or prohibiting the use of asbestos for some applications, or prohibiting the use of some work methods or tools

Application of asbestos by the technique commonly referred to as spraying has been prohibited in most European and many other countries. This technique has been widely used in the past, mainly on account of the valuable and extremely efficient fire proofing of buildings and ships it provides. Occupational exposure levels during application of the process however are such that the workplace standards cannot be met. As the process does not lend itself well to dust prevention measures, prohibition appears to be the only possible approach. In addition, existing asbestos spraying can become in some cases, after some time, a source of indoor air pollution as well as an occupational exposure risk in case of repair works to, or demolition of the structures on which it has been applied.

Similar prohibitions exist in some countries on the use of loose asbestos fibres for thermal or acoustical insulation or for fire protection.

Various countries have prohibited the use of asbestos for applications where its use is not justified for technological reasons or for uses where perfectly safe alternative fibres of equivalent performance exist (e.g. decoration, airfiltering).

Restrictions on use of amphibole asbestos varieties are, in some countries, more stringent than for chrysotile asbestos. In the recently adopted EEC regulations limiting marketing and use of asbestos and asbestos-containing products (Council Directive 83/478/EEC of 19 September 1983) further use of crocidolite is prohibited (from 21 March 1986 onwards) except for 3 specific uses. Similar prohibitions on amphiboles are already in force, either de facto or by law, in various countries.

In the Netherlands, marketing and use of non-crocidolite containing asbestos products is only permitted if the asbestos fibres are firmly bound in a matrix. A fibre fixity test has been developed to test these asbestos-containing products.

Some countries like Denmark have fixed the maximum allowable asbestos content in some products. Also in Denmark, deadlines have been set after which the use of asbestos will no longer be allowed for some specific applications. For products where the performance of the asbestos-free alternative is still questionable, such as friction materials, no limit dates have been set.

For the asbestos cement industry, the deadline had originally been fixed at 1 January 1985, as it was believed that the technological problems linked with asbestos substitution would have been overcome by then, but the permission to use asbestos (except crocidolite) in asbestos-cement has recently had to be extended by the Danish Autorities till 1 January 1990.

In Germany, an innovation programme has been agreed on between the Authorities and Industry for the stepwise reduction of the asbestos consumption in industry over the next few years.

Various countries have prohibited, or are considering prohibition of some working methods or tools which, under some circumstances, can lead to workplace and/or environment pollution.

Typical examples are:

- prohibition on use of compressed air for brake drum cleaning in garages and vehicle maintenance work shops.

- prohibition on use of the high rotary speed angle grinders for cutting asbestos cement products on the building site (Germany, Holland, France, U.K.).

7.4 Regulations covering removal of asbestos from existing applications and demolition of buildings containing asbestos

Removal of asbestos from existing applications (mainly spraying and lagging) can constitute a non-negligible pollution source for both the workplace and the environment, and is therefore, in some countries, subject to worker protection legislation or has to be carried out according to a Code of Practice (France, Holland, U.K.). The Environment and Consumer Protection department of the Commission of the E.E.C. is presently drafting such a Code which would apply to all 10 E.E.C. Member States.

Similarly, demolition of buildings and other structures or equipment containing spray-asbestos, asbestos lagging, or any other form of loose or poorly bonded asbestos fibre is either subject to regulations or to a Code of Practice in various countries.

It should be pointed out here that removal is not always required to eliminate indoor or environmental pollution caused by fibre release from applications such as spraying. Encapsulation or other methods of sealing the surface can give good results when the sprayed asbestos layer is in adequate condition for treatment. These solutions are in general less expensive and less hazardous to carry out, without affecting the fire safety of the buildings or structures in question.

7.5 Waste disposal Regulations

Waste disposal regulations for asbestos-containing waste materials have been introduced in various countries or are under preparation.

What is understood by asbestos waste differs widely from country to country. In the E.E.C., Council Directive 78/319/EEC of 20 March 1978, on toxic and dangerous waste applies to asbestos containing waste when present as dust or fibres. (Annex to the Directive, entry N° 21).

In addition to, or in absence of specific asbestos waste disposal regulations, some countries have issued recommendations, guidelines, or codes according to which asbestos-containing waste should be disposed off. They usually contain requirements for avoiding fibre release during storage or transport of the waste material, as well as measures to be taken after disposal at the site, such as covering with a specified minimum thickness of earth at a given minimum frequency. Record keeping is generally required, and precautionary measures must be taken to prevent access for unauthorized persons.

7.6 Ambient Air Quality Standards and Guidelines

Currently, no country has an ambient air quality standard for asbestos. However, a number of proposals have been made in North American and European countries. Some of these are listed in Table 2.

Also, the Council of the European Communities has made a proposal in order to protect the general public which, however, does not specify a certain concentration limit, but regulates the use of asbestos. (Council Directive 83/478/EEC of 19 September 1983).

Specification of a universally acceptable concentration limit does not seem possible as yet, because there is no unanimity of view on the question of what level of asbestos fibre in the general atmosphere can be considered normal, bearing in mind that asbestos is a naturally-occurring substance. Another difficulty, as pointed out by Robock (1983) is the fact that, as yet, there is no agreed measuring system for asbestos fibres in ambient air. It is impractical to establish a standard until it can be measured.

TABLE 7.2

Ambient Air Guidelines

(After Chatfield, 1983)

State of Connecticut (proposed) - 30 day Average (electron microscopy)	30 ng/m^3 or 30,000 total asbestos fibres/m^3
Province of Ontario - 24 hour Average (electron microscopy)	40 fibres/litre (>5 um)
- 30 minute Average (weight)	5 ug/m^3
Province of British Columbia (optical)	0.04 fibre/ml
West Germany (proposed) (electron microscopy)	1 fibre/litre (>5 um)
Montreal Urban Community (optical)	0.05 fibre/ml
New York City (recommended by Nicholson) (electron microscopy)	100 ng/m^3
France (recommended by Conseil Supérieur d'Hygiène publique de France) (electron microscopy)	50 ng/m^3

7.7 REFERENCES TO CHAPTER 7

Association Française de l'Amiante, Ministère de l'Environnement et du Cadre de Vie; The Asbestos Cement Industry Programme, Paris, 1980.

Aurand, K. and Kierski, W.S. (1981); Gesundheitliche Risiken von Asbest, BGA-Berichte 4, 1-17, Berlin.

Bruckman, L. and Rubino, R.A.; Asbestos: Rationale Behind a Proposed Air Quality Standard, Journal of Air Poll. Control Assoc., Vol. 25, No. 12: 1207-1212, December 1975.

Canada Gazette, Clean Air Act; Regulations Prescribing National Emission Standards in Respect of Asbestos Mines and Mills, Part II, Vol. III, No. 13, Registration SOR/77-514, 1977.

Deutsche Forschungsgemeinschaft (DFG); Maximum Concentrations at the Workplace, 1981, Report No. XVII, Bonn, 1981.

EEC, Directorate Social Affairs; Air Quality Criteria for Asbestos - Preparatory Study Basic to the Setting-up of Guidelines for Asbestos Exposure, 1976. ILO Meeting of Experts RESA (2) 1983/VI, Geneva, Nov. 1983.

P. Jarrault; Limitation des Emissions de Polluants et Qualité de l'Air, Vol. II: Normes de rejets de Polluants, Institut Français de l'Energie, Paris, 1980.

Kogan, F.M.; Asbestos Containing Dust and Their Influence to the Health Problems of Industrial Workers, Publishing House "Sverdlovsk", USSR (1975).

Lanting, R.W. and den Boeft, J.; Atmospheric Pollution by Asbestos Fibers, EC Report EUR 6768 EN, Report G908, IMG-TNO, November 1979.

Rajhans, G.S. and Sullivan, J.L.; Asbestos Sampling and Analysis, Ann Arbor Science Publ., Ann Arbor, Michigan (1981).

Robock, K., "Analytical methods for Airborne Asbestos" 6th Convention on Industrial Hygiene, Rome. Dec. 1983.

Technische Anleitung (TA)-Luft (1981); Erste Allgemeine Verwaltungsvorschrift zum Bundes-Immissionsschutzgesetz, Gemeinsames Ministerialblatt, Ausg.

Trink, C., (1981). L'Industrie au Regard de l'Environnement; Industries de l'Amiante (Ministère de l'Environnement et du Cadre de Vie. Direction de la Prévention des Pollutions).

Umweltbundesamt (UBA); Luftqualitätskriterien - Umweltbelastung durch Asbest und andere faserige Feinstäube, Kapitel 9 - Nationale und internationale Massnahmen zur Prävention gesundheitlicher Risiken durch Asbest, Berichte 7/80, Berlin, 1980.

USEPA; National Emission Standards for Hazardous Air Pollutants, a Compilation, Report EPA-340/1-78-008, Office of Enforcement, Washington D.C., 1978.

USEPA; Workplan - Phase I: Review of Asbestos Standard, EPA Project 444-1736-13, November 1980.

Zielhuis, R.L.; Public Health Risk of Exposure to Asbestos, ECE, Directorate Social Affairs, Rep. 18-6 (1976).

8. CONTROL TECHNOLOGIES AND COST CONSIDERATIONS

As mentioned previously in the report, the manufacture of asbestos-containing products covers a wide range of processes and applications which have rather little in common apart from the fibre itself.

Furthermore, the asbestos fibre type, its grade and origin may be important factors in determining the appropriate control technologies for the workplace, as well as the environment.

Once the asbestos fibre has left the mine as a raw material, it usually undergoes a number of processing stages leading up to the final product. Initially, it is often processed in order to "open" the fibre (fiberizing) to the degree required for the process or final product. Then, it is usually incorporated into a matrix which bonds the fibres in the final product. These products then may require cutting, grinding, etc., during the finishing operations and/or installation.

In the course of these different stages, the control technologies need to be properly adapted to the nature of potential emissions which may result from the process itself, taking into account the quantities of dust involved and also the possibility of dust release into the environment when residues are later transported and deposited in a waste disposal site.

This chapter describes the principles and methods which, from the experience accumulated over many years, have proven to be most effective in reducing the environmental emission of asbestos dust. Except for the mining activity, which as such is quite distinct, the chapter does not systematically review every asbestos industry sector. Rather, examples are used to illustrate the principles which are described, though it should be understood that a complete dissussion of such a complex technical subject would in itself require a lengthy dissertation.

Control costs are discussed using estimates that have been reported in the literature, or more recent data when available for specific applications.

Unfortunately, the inter-relationship between occupational and environmental dust control measures does not always permit a clear distinction to be made between their respective costs. Moreover, some process changes which may have a significant impact on environmental protection can also influence these cost estimates by either increasing or decreasing the overall costs of the operation.

8.1 Mining and milling of asbestos ores

8.1.1 Mining

Without dust control measures, the very nature of the asbestos mining and milling process, which includes blasting, rock extraction, crushing, grinding and transportation of ore, is prone to high fibre emissions.

For open-pit mining, by far the most common asbestos mining method, potential emissions of dust primarily originate during drilling, blasting, transportation and handling operations; these emissions can be minimized by using wetting methods whenever possible (M. Sittig, 1975).

In practice, wet drilling methods are not always possible in very cold climates due to freezing problems, though portable systems mounted with a dust extractor and air cleaning system can be used effectively.

Fibre emissions during blasting operations are largely dependent on the blasting pattern employed. Minimizing fine fracturing of the rock is usually the best means to control atmospheric emissions.

Minimizing reentrainment of the road dust during ore transportation is a continual problem in the mines that can be effectively controlled through water wetting and the use of more efficient chemical wetting agents.

Dust generated during primary crushing and screening operations can be controlled by high efficiency cyclones or, more effectively, by baghouses. Exhaust gases from ore drying installations can be passed through cyclone separators, preferably followed by a wet scrubber, electrostatic precipitator or baghouse to reduce emissions.

Efficiencies of these different control devices are generally classified in the following order of increasing effectiveness: cyclones, electrostatic precipitators, wet scrubbers and baghouses, with the latter having by far the highest collection efficiency, up to 99.99% or more, under the best operating conditions (see section 8.2.4).

8.1.2 Milling

The separation, cleaning, and grading of asbestos fibres requires large volumes of air which are ventilated through fabric filters before being exhausted to the atmosphere or recirculated to the mill building (M. Sittig, 1975). It should be pointed out that air processing (aspiration) is the basic principle for separating and recovering the asbestos fibres from the ore. In general, the metallurgical balance for this process is (G.S. Rajhans and G.M. Braggs, 1978):

40%	rejected as coarse rock and sand sized fragments
53%	rejected as fine rock fragments and powders
5%	recovered as fibre
2%	recovered as float grades
100%	

Consequently, dust emissions inside the mill building are mainly of occupational concern, whereas environmental emissions occur only when the air filtration systems are not recycling the cleaned air back to the mill. In colder climates, complete recycling of mill air is conducted for at least six months of the year (J. Lebel, 1984). Moreover, emission control is optimal when the volume of air exhausted is sufficient to maintain the entire mill building under negative pressure (M. Sittig, 1975).

Based on actual source dust sampling, the total asbestos emissions from specific mining operations and during milling, under controlled conditions using high efficiency fabric-filters, are reported in Table 8.1 (J. Lebel, 1984).

TABLE 8.1

Source	Emission kg/t asbestos produced
Mining	
drilling	0,0003
underground	0,005
Milling	
high efficiency filter	0,0055

These data, when compared to earlier engineering estimates (M. Sittig, 1975) indicate that current emission levels are some 1,000 times less than the estimates, particularly for the milling operation.

8.1.3 Tailings

Surface tailing piles can generate wind diffused emissions which are best prevented by immediately applying a covering over the tailings. Active tailings piles can be watered to minimize dust emissions.

Revegetation is also being tested at present, but the high alkalinity (pH = 9) of the tailing has limited the establishment of sound vegetative cover.

8.1.4 Control costs

In mining and milling, the most appropriate gas cleaning devices appear to be baghouses and dry centrifugal collectors, both as fixed installations on mill buildings, and as portable devices on drilling equipment, etc. Costs are thus the same as described in section 8.2.4.5.

Additional emission control can be achieved by partial or complete enclosure of external conveyor systems. Housings (i.e. partial enclosure) in the form of curved sections of corrugated sheet metal cost approximately $US 100* (1982) more per lineal metre than completely exposed conveyor systems. Complete enclosure, such as enclosed galleries, cost $US 880* (1982) per lineal metre of conveyor in excess of what a corresponding fully exposed system costs (USEPA, 1973). Standard belt conveyors, with walkway along one side, have been priced by USEPA at $US 1,400* (1982) per lineal metre (USEPA, 1973).

Chemical coating agents, used to reduce asbestos emissions from surfaces, cost between $US 270* (1982) per hectare, lasting for one month, and $US 6,070* (1982) per hectare, lasting for at least one year (USEPA, 1973). In addition to the material costs, application is estimated to cost $US 370 per hectare resulting in total annual costs ranging between $US 6,500* and $US 7,700* (1982) per hectare.

When calculating control equipment costs for mechanical cyclones and baghouses in milling operations, it should be noted that a substantial amount of product is collected and recycled; these savings should be substracted from total environmental control expenditures. However, data is not available to determine the micro- or macro-economic impact of asbestos emission control from ore mining and milling.

8.2 Manufacture of asbestos products

8.2.1 Asbestos fibre packaging, handling, transportation and opening

In the past and particularly prior to 1976, asbestos containing bags originating from various countries were shipped to customers in different forms and various packages, such as uncompressed gunny bags, various kinds of plastic bags, paper bags, compressed or uncompressed, etc. In many instances pallets were not available necessitating unit bag handling procedures resulting in all possible forms of damage during transit.

This situation was known to have produced some high worker exposures in the past and also had a negative impact on the environment due to spillages caused by damaged asbestos bags.

Since 1976, the question of initial packing of fibre and packaging for consignment has received particular attention from the asbestos producers and consumers. A publication of the Asbestos International Association (AIA) (1983) provides details on the current packaging methods in use in most producing countries. At present, asbestos fibre is packed in plastic bags, these bags are then pelletized in an interlocking fashion and finally the entire pallet and bags are protected by a plastic cover (shrink or stretch wrapped). This procedure prevents emission into the environment during transportation and handling.

---

* Costs are based on USEPA 1972 estimates adjusted to 1982 US dollars, using gross domestic product in purchasers' values-price indices as published in OECD's National Accounts (1982) and Main Economic Indicators (1982).

A health warning label incorporating the symbol "a" is also printed on the asbestos bags. Workers who handle the units are instructed to reseal any damaged bags with appropriate adhesive tape.

Bag opening in the plant is generally performed by either automatic or manual machines. Although the choice of method would appear to have little influence on the environment, automatic machines usually require complete enclosure including conveying systems to the next stage of the process. The automatic installation consequently requires rather large quantities of air and subsequent filtration devices. Conversely, individual bag opening stations, located close to the processing stage, minimize the necessary air flow for the worker protection resulting in a lower up-stream loading of filter devices and generally requiring less air filtration capacity.

Actual data are not available; it should be noted that the following general principle usually applies: the less fine dust that is produced at any stage in the process the easier is the emission control at the following stage.

Empty asbestos bags, since they contain some residue of loose fibre, may also generate dust emissions if they are not correctly disposed of. The different methods presently in use to prevent environmental emissions from this source are described by AIA (1983). Four alternatives are proposed:

- grinding of the bags for inclusion in the product
- melting for safe disposal in normal waste dumps
- recycling into secondary plastic products
- bagging into new plastic containers.

With regards to the costs for proper packaging of asbestos fibre for shipment described above, this is included in the raw fibre price and is estimated to be in the range of $US 8 to 12 (1984) per tonne of fibre.

Cost considerations for empty bag disposal can vary from negligible, as in the case of grinding, to very high if new moulding equipment is required, as in secondary plastic applications. Consequently, reliable cost estimates for empty bag disposal are not available.

8.2.2 Process changes

It is a fact that the environmental emission of fine asbestos dust is the consequence of a particle, which at one stage or another, escapes the established control procedures. The prime and simplest means of limiting this escape is to avoid, to the extent possible, the generation of dust at every stage in the process.

A number of techniques have been developed along these lines and can be classified into the following four categories:

- complete asbestos bag incorporation into the mix
- wetting and wet processing techniques

- production rationalization

- coarse dust producing tools.

8.2.2.1 Complete bag incorporation in the mix

Complete asbestos bag incorporation is particularly useful in the paper industry where multiwall water soluble bags can be completely incorporated in the first mixing stage. In the asbestos-cement product industries, the paper bag and its contents can also be introduced in the mixture without causing any problems. In these cases, dust extraction systems are not required and disposal of the empty bags is also avoided. Another example is asbestos bituminous compounds where plastic asbestos containing bags can be totally incorporated in the mix.

8.2.2.2 Wetting and wet-processing techniques

Wet-processing techniques have attracted particular interest in recent years. Three applications are described below.

In the milling of raw asbestos fibre and in the asbestos-cement products industry, the wetting procedure provides two distinct advantages (R.W. Lanting and J. den Boeft, 1980):

- reduction in workplace air contamination, which reduces dust loading on air filtering devices and also provides a direct means of recycling collected dust (i.e. pumping) when the pumping equipment is fitted directly on the kollergang;

- wet-milled fibres are more cost effective for the operation as the slurry can be pumped.

Reduction in air pollution using this wet process is significant though data are not available to quantify the benefits (R.W. Lanting and J. den Boeft, 1980).

Investments for implementation of this technique have been estimated at some $US 0.8 million for a 60,000 tonne asbestos-cement production facility (R.W. Lanting and J. den Boeft, 1980).

Another area where wetting techniques are employed is in asbestos textile manufacture. The process was initially developed to reduce occupational exposures though it also has major environmental benefits by reducing overall dust emissions during processing and, by implication, dust loading on control devices. This technique also necessitated the development of some special equipment to maintain wet conditions during the entire processing operation, from carding to weaving.

Asbestos millboard manufacture is a third example where the boards often require cutting by means of a press for sealing and jointing. An effective procedure to avoid dust emission during this operation is to spray water directly on the sheets before the cutting press.

For the latter two examples, reduction in source dust emissions contributes to improved environmental control. However, quantitative data and distinct costs, in relation to the benefits for environmental protection, cannot be estimated in view of the primarily occupational interest of these technologies.

Wet mixing technology is also partially employed in the friction materials industry, though its use is primarily dictated by the field of application of the product. Consequently, wet processing cannot be regarded as universally applicable in this sector and the impact of solvent vapour emissions on the environment must also be carefully considered (R.W. Lanting and J. den Boeft, 1980).

8.2.2.3 Production rationalization

Production rationalization is applicable to all asbestos industries and usually allows for better means of control by limiting the number of dust sources and, consequently, the number of dust extraction systems required.

A typical example of its application is in the friction materials industry where a large number of small unit pieces have to be handled, ground, drilled, etc., a number of times during the process.

8.2.2.4 Coarse dust producing tools

High speed cutting and abrading tools produce large quantities of fine dust which necessitates well designed extraction systems coupled to efficient filtering devices.

This is a particularly acute problem when working on-site in the construction industry as exhaust ventilation systems are not readily available nor often accessible. Even when supplied, they may not be properly adjusted nor maintained for efficient emission control.

An effective solution appears to have been found in the Federal Republic of Germany (U. Teichert, 1982) where low-speed cutting tools and specialized hand tools have been developed that minimize the production of fine dust.

France is proposing regulations (Ministère de l'Environnement) whose objective is to ensure the use of low speed tools in activities related to working on asbestos-cement.

These tools are also recommended for use by the Asbestos International Association when working on-site with asbestos-cement products. They have been tested following a special procedure (Asbestos International Association, 1983) which facilitates the selection of only those tools that primarily produce coarse dust. On the other hand, the commonly used "grinder" should be systematically withdrawn from use due to the high personal exposures and environmental emissions generated during its operation.

Unit costs of most low-speed tools currently available are in the range of $US 250-400 (Preisliste BG 6, 1982).

Asbestos-cement products can also be designed to avoid the use of tools in on-site working for installation. For example, the cutting of corners of asbestos-cement corrugated sheets on-site is no longer required if the sheets are provided with notches, allowing the corners to be broken off rather than being sawn off.

Finally, it should also be noted that complete prefabrication by the primary manufacturing industries, e.g. asbestos-cement sheet, is growing to minimize on-site cutting and drilling operations (R.W. Lanting and J. den Boeft, 1980). In the Federal Republic of Germany more than 50% of the roofing and cladding sheets installed in 1980 were reported to have been prefabricated (P. Borneman, 1980).

8.2.3 Recycling

8.2.3.1 Recycling of air

Air filtering devices are likely among the major potential sources of environmental emissions of asbestos dust, as the industries employing these devices usually require large volumes of air to protect employees in the occupational setting.

Certain country regulations specifically address the problem of air recycling back to the workplace after filtration. The Federal Republic of Germany has promulgated guidelines that authorize partial recycling (up to 10%) and in France, the regulation (Ministère de l'Environnement et du Cadre de Vie, 1981) permits total recycling provided that workplace exposure levels remain below the threshold limit value (TVL). For the United Kingdom, the recommendations stipulate that asbestos levels in recycled air should be less than one-tenth of the workplace control limit value.

Ideally, most dust emissions from factories could be eliminated if all filtering devices were operating in a total recycling mode. However, this condition is not suitable for all types of asbestos industries and the present situation in most OECD countries is quite heterogeneous. Moreover, total recycling may have significant implications to the workplace environment and additional protection against unforeseable incidents must be provided for. On the other hand, it should be noted that one of the main aims in recycling filtered air is to minimize heat loss during cold weather. Consequently, the energy savings in recycling are an important cost consideration with substantial economic benefits for industries located in regions with cold climates.

Efficiencies of filtering devices are discussed under section 8.2.4, but it is readily apparent from the preceding remarks that the total volume of exhausted air, and not only the performance of individual control devices, will determine the contribution of the asbestos industry to ambient air asbestos levels.

8.2.3.2 Recycling of water

Though water treatment and recycling are not the subject of this report, this topic is partially addressed as it relates to the waste disposal problem which may have a direct impact on air emissions.

Waste-water treatment is of prime importance for the asbestos-cement and the asbestos millboard industries, which are large volume users of water as a process medium in manufacturing.

Total recycling of waste-water is the ultimate goal of France's "contrat de branche" (Ministère de l'Environnement et du Cadre de Vie, 1981) between the Ministry of Environment and the asbestos-cement industry. This programme, to be achieved over a five-year period, is reported to be well underway (Secrétariat d'Etat à l'Environnement with water effluent levels at some 0.4 m^3/tonne of production recorded in 1983. This figure represents one-twentieth (1/20) of the effluent volume discarded in 1977.

A second benefit of enforced recycling of process water, particularly at the machine stage, is a large reduction in sludge production (R.W. Lanting and J. den Boeft, 1980). This minimizes the problem of sludge waste disposal, usually discarded in waste dumps.

8.2.3.3 Recycling of solid waste

Maximizing the recycling of solid waste usually enhances the control of asbestos fine dust emissions by avoiding handling and eventual dispersion problems when it is taken out of the factory for disposal.

Solids recycling is a basic requirement of France's regulations for all types of asbestos activities (Ministère de l'Environnement et du Cadre de Vie, 1981). In some instances, material savings and economic benefits can accrue to manufacturers following this practice.

Fine dust collected from air filtering devices can be partially or totally recycled in many applications, such as asbestos-cement, millboard and friction materials. Limitations to this practice generally relate to:

- the quantities of waste to be recycled, i.e., it should not introduce processing problems or product quality defects,

- the chemical nature of the waste, i.e., polymerized resin or completely cured cement cannot be recycled,

- no adverse contaminants in the waste, e.g., abrasive materials in friction material products.

Recycling of finished products or scrap may also be considered in certain applications, though they usually require crushing to some extent. Limitations of this application are somewhat similar to those for fine dust, though it should be noted that crushing equipment tends to generate high dust levels; again this implies the need for complete extraction systems together with efficient air filtering devices. Consequently, the overall benefit of product or scrap recycling, with regard to environmental asbestos emissions, is questionable.

The cost of fine dust recycling in most applications is likely negligible. However, the cost of a medium size crusher (capacity 2 tons per hour) including the dust collection system is reported to be around $US 1million (R.W. Lanting and J. den Boeft, 1980). This estimate does not take into account the cost benefit, if any.

8.2.4 Air cleaning devices

8.2.4.1 General implications

Due to the very large volumes of air which are employed in asbestos milling and manufacturing industries and exhausted through air filtering systems, particular attention must be paid to the quality and efficiency of air cleaning devices.

Some useful quantitative information was provided in a 1974 study (C.F. Harwood, P. Siebert, T.P. Blaszak, 1974) describing the distribution and capacities of dust collection systems among 21 asbestos plants (Table 8.2). In this study, for example, the baghouse air throughput quoted for the largest asbestos mine (Asbestos, Quebec), was 7.6 million m^3/hour, though the figure may be significantly higher at present operating conditions.

For France, the total installed capacity (1982) is reported to be about 3 million m^3/hour for the major asbestos manufacturing industries (D. Bouige, 1982). However, the installed dust collection capacities among the various manufacturing industries appear to be quite unevenly distributed when compared to the asbestos consumption rates for each industry sector (Figure 8.1). These data indicate that proportionally more dust extraction systems are required for certain industrial activities. For example, the friction materials industry and the textile industry are equally large users of air cleaning devices (installed capacity), while they are both relatively small asbestos consuming industries.

8.2.4.2 Classification of the various air cleaning systems

The air cleaning systems available are generally classified into four categories: cyclones, wet scrubbers, electrostatic precipitators and fabric filters. Their respective collection efficiencies for standard dusts have been extensively examined and Table 8.3 provides a useful indication of their respective performance.

While such a performance classification was not specifically established for asbestos fibre or asbestos containing dust, the general trends indicated in Table 8.3 are applicable for asbestos. Furthermore, the majority of cleaning systems currently in use by the asbestos industry are fabric filters, as all other devices have generally failed to achieve the level of performance required (G.S. Rajhans and G.M. Braggs, 1978) (R.W. Lanting and J. den Boeft, 1980) (D. Bouige, 1982).

However, it should be recognized that other devices can be used in conjunction with a fabric filter, performing the role of a pre-separator, (e.g., cyclones) or in applications where fabric filters cannot be used due to particular conditions, such as moisture content, fire risk, etc. It should also be noted that fabric filters can be very inefficient until a cake of dust builds up on the surface, which can take typically 30 mins.

Table 8.2

CAPACITY OF DUST COLLECTION SYSTEM

(I.I.T. Research Institute)

Capacity	Plants having stated Total Capacity		Baghouses in plants having stated Total Capacity	
m^3/min	N°	Percent	N°	Percent
< 142	1	4.8	19	21.6
143 - 283	1	4.8	27	30.7
284 - 566	---	----	31	35.3
567 - 849	---	----	4	4.5
850 - 1,416	4	19.0	2	2.3
1,417 - 2,832	2	9.5	4	4.5
2,833 - 5,663	8	38.2	1	1.1
> 5,663	5	23.7	---	---
TOTAL	21	100.0	88	100.0

Figure 8.1

ASBESTOS CONSUMPTION/DUST COLLECTION CAPACITY

(Association Française de l'Amiante - 1982)

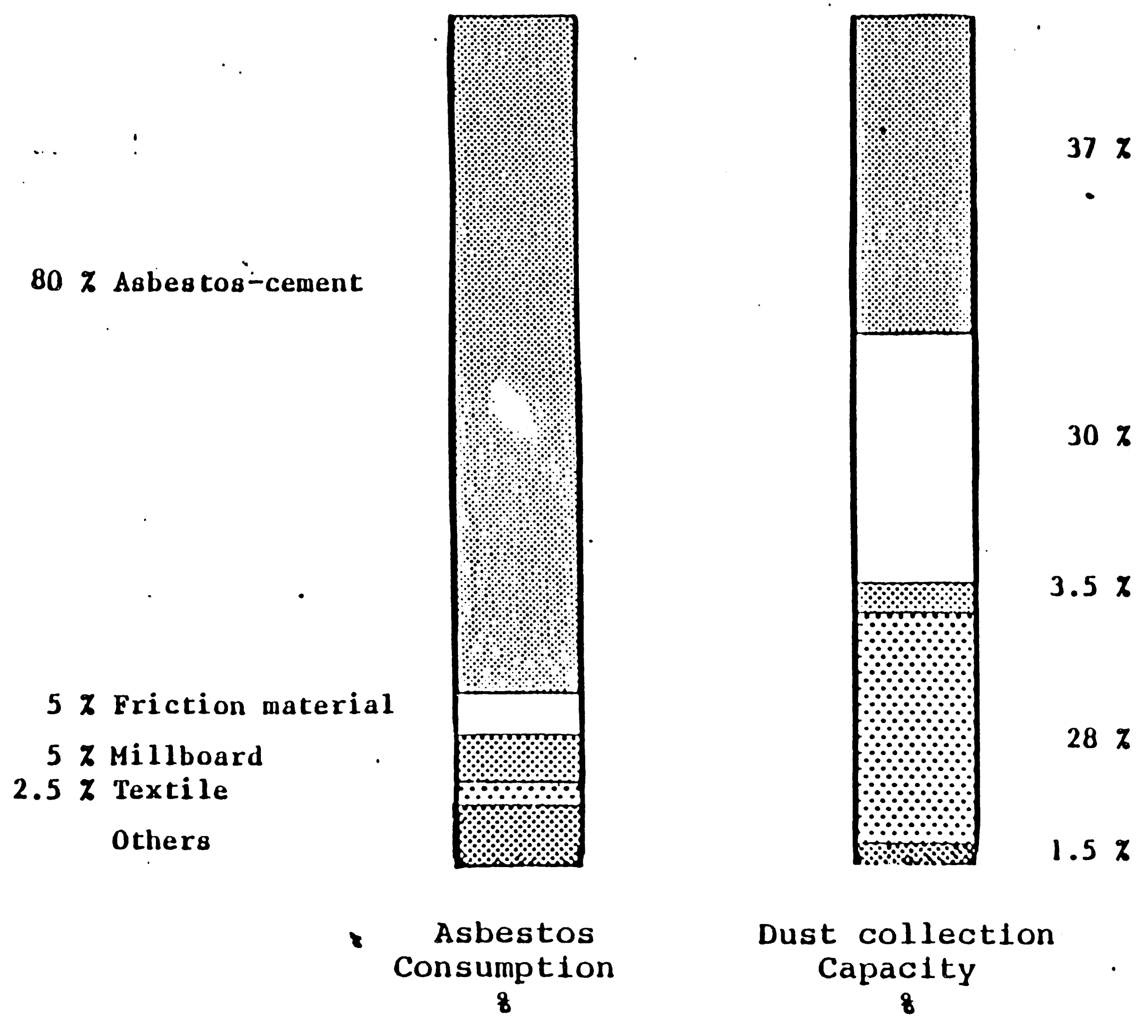


Table 8.3

TYPICAL COMPARATIVE EFFICIENCIES OF DUST COLLECTORS

(Handbook of occupational hygiene)

Type of Collector	Efficiency on a Standard dust 80 % < 60μ 30 % < 10μ 10 % < 2μ μm	Approximate efficiency at 10 μm	Approximate efficiency at 5 μm	Approximate efficiency at 1 μm
	%	%	%	%
High efficiency cyclones	84.2	85	67	10
Small multi-unit cyclones	93.8	96	89	20
Low pressure drop cellular collectors	74.2	62	42	10
Spray tower	96.3	96	94	35
Self-induced spray collector	93.5	97	93	32
Wet impingement scrubber	97.9	99	97	88
Venturi high-pressure drop scrubber	99.7	99.8	96.6	94
Dry electrostatic precipitator ...	94.1	98	92	82
Irrigated electrostatic precipitator	99.0	99	98	92
Fabric filter	99.8	99.9	99.9	99
Fabric filter with pre-coat	99.9	99.9	99.9	99.9

Source : Squires, B.J. "Removal of Particulate Matter from Industrial Airborne Discharges" International Conference on Total Environment Protection, London November 1972

8.2.4.3 Typical filtering equipment

A typical complete dust control system for the asbestos manufacturing industry is shown in Figure 8.2. It should be noted that such a configuration requires careful step by step engineering to be fully effective.

The basic construction of an air filtering device requires the inclusion of a self-cleaning mechanism to ensure that dust collected on the fabric material is periodically released, thus maintaining a constant pressure drop across the filter. Such a device is critical to preventing any reduction in air volume flow rate (extraction efficiency) and maintaining a constant level of capture for fine dust.

Several kinds of self-cleaning mechanisms are available, from the simple manual type to the automatic reverse air cleaning system.

However, whenever possible, the automatic cleaning mechanism is recommended as it is the best insurance that the equipment will be operating under almost permanently ideal conditions (Association Française de l'Amiante, 1982). On the other hand, purely manual shaking systems are not recommended as they are not sufficiently reliable, and experience demonstrates that the shaking operation itself is likely to expose workers to very high dust levels. In this case, the workers involved should be provided with full personal protection and measures are also required to fully control environmental emissions.

The filter fabric is an essential and likely most important part of the are filtering device. A large variety of materials are available and primarily two types are encountered: the woven type and the felted type.

With regard to filtering efficiency, natural fabric of the woven type is generally preferred, though natural and synthetic felted fabrics are equally effective (Air Cleaning Devices, 1982).

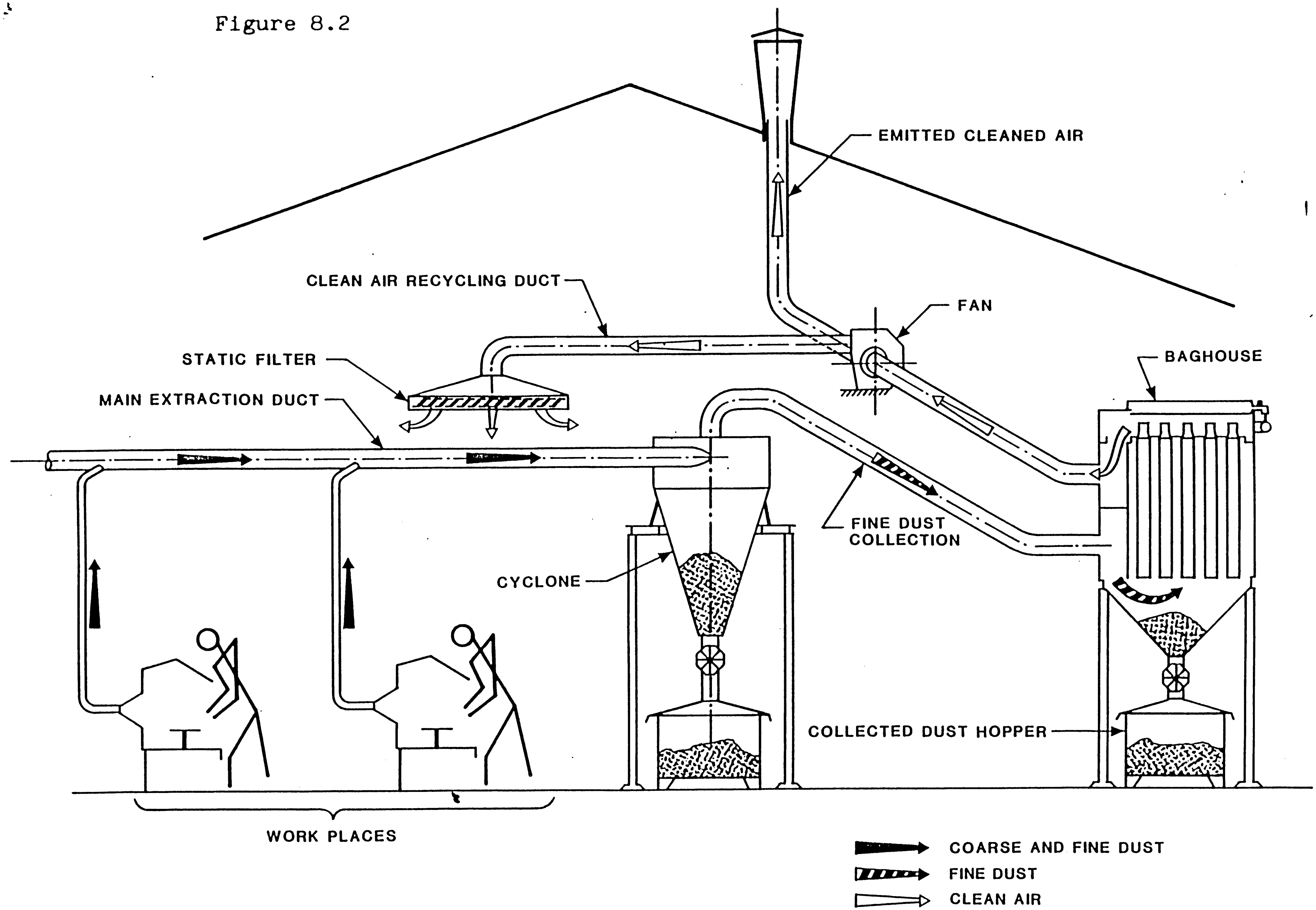
A typical distinction between woven and felted material is the filtration rating (air to cloth ratio) which can be two to three times higher for felted material (Association Française de l'Amiante, 1982) (Air Cleaning Devices, 1982). An optimum pressure drop should be selected for the dust involved and maintained constant, to the extent possible, during normal operating conditions. Typical values for fine dust are:

- Air to cloth ratio ($m^3/m^2/hr$) ... 35 - 160

- Pressure drop (mm/Wg) .... 50 - 150.

Hoppers and valves, which assist in the recovery of dust below the bag filters, require careful design to prevent any dust loss, blockage or air reentrainement during operation. With regard to environmental protection, this aspect is particularly important when filter bags are operating completely outside the factory walls.

Figure 8.2


EMITTED CLEANED AIR
CLEAN AIR RECYCLING DUCT
FAN
STATIC FILTER
BAGHOUSE
MAIN EXTRACTION DUCT
FINE DUST COLLECTION
CYCLONE
COLLECTED DUST HOPPER
WORK PLACES
COARSE AND FINE DUST
FINE DUST
CLEAN AIR

8.2.4.4 Air cleaning efficiency

Stack emission measurements taken on the basis of isokinetic sampling procedures can provide an indication of filtering efficiencies in the asbestos industry. Countries such as France, Germany (FRG) and Canada have introduced regulations that require compliance with specific emission standards.

For France (Ministère de l'Environnement et du Cadre de Vie, 1981), two limit values are being implemented for all the asbestos manufacturing industries:

- 0.1 mg/m^3 for pure asbestos

- 0.5 mg/m^3 for mixed dust.

In Germany (FRG), a single limit value of 0.1 mg/m^3 for asbestos fine dust is applicable in all instances.

On the other hand, Canada has opted for a fibre counting control procedure which limits stack emissions in mining and milling operations to less than 2 $fibres/cm^3$ greater than 5 micrometers in length.

For France, Germany and North America, some typical in-situ data on emissions have been reported that demonstrate the very high performance levels that can be achieved when using the best available technology (D. Bouige, 1982) (G. Guthner, 1982) (U. Teichert and K. Robock) (see Tables 8.4, 8.5 and 8.6).

To illustrate what can be accomplished, the Ministry of the Environment in France (Secrétariat d'Etat à l'environnement, 1983) lists the improvements made at a large friction materials plant where some 300,000 to 370,000 m^3 of air per hour are being exhausted. Since 1976, dust emissions have been reduced from 6.3 kg/hr to 0.038 kg/hr. This is a reduction of 165 times over a one-year period following the implementation of regulations. The total cumulated costs to achieve this reduction are estimated at $US 1.2 million (1983).

8.2.4.5 Cost of gas cleaning devices

Various procedures have been developed to calculate investment, operating and maintenance costs for gas cleaning devices (G.S. Rajhans and G.M. Braggs, 1978)(W.M. Vatavuk, R.B. Neverill, 1982)(U.S. Environmental Protection Agency, 1973).

This section will not attempt to review all the existing cost estimating procedures, but will provide an indication of costs and trends from recent data available for baghouse systems, the most frequent type of gas cleaning device encountered.

Table 8.4

CONTROL EFFICIENCY OF BAGHOUSES
ON ASBESTOS BRAKE LININGS MANUFACTURING PLANTS
(Association Française de l'Amiante)
Strasbourg Colloquium, October 1982

Origin of Dust	Capacity of baghouse (m3/hr)	Dust Concentration: baghouse entrance (mg/m3)	Dust Concentration: at exit equipment emission (mg/m3)
Bag opening (raw asbestos) and crushing	45,000	600 - 900	0.10
Bag opening (raw asbestos) and crushing	24,000	100	0.25
Manufacture	45,000	1,500 - 3,000 (before entering cyclone)	0.10
Manufacturing and finishing operations	45,000	1,500	0.10
Finishing operations	45,000	50	0.10
Finishing operations	10,000	600 - 900	0.10
Finishing operations	12,500	5,000 - 8,000 (before entering settling chamber)	0.45

Table 8.5

Stasbourg Colloquium, oct. 82
(Umweltbundesamt)

Process	Air to cloth ratio $m^3/m^2/h.$	Dust collect capacity $m^3/h.$	Emission mg/m^3	Emission f/cm^3 $L > 5$ µm
Working with asbestos cement	0.65	68,000	0.01	0.006
Carding machine for raw asbestos	1	28,500	0.03	0.01
Working with asbestos cement	1	44,000	0.01	0.03
Fiber screening	1	7,600,000	0.1	0.8
Fiber screening	1.1	510,000	0.06	0.05

Table 8.6

<u>Emission results from a typical German asbestos cement plant</u>

(4th International Conference on asbestos) - (Torino, May 1980)

Unit	Total Dust Conc. (mg/m³)	Asbestos Dust Conc. (mg/m³)
1.1	0.35	
1.2	0.30	0.02
1.3	0.25	
1.4	0.60	
1.5	0.9	
1.6	1.9	0.25
2.1	0.35	
2.2	0.65	
2.3	1.3	
2.4	2.1	0.13
2.5	0.1	

In an attempt to generalize cost estimates, Vatavuk and Neveril (1982)(G.S. Rajhans and G.M. Braggs, 1978) provide a graphical approach to the problem. Figure 8.3(a-e) presents these graphs with various options based on criteria such as standard or custom design, intermittent or continuous duty, pressure or suction operation, type of cleaning mechanism, and material of construction.

For example, using Tables 8.7 and 8.8 for bag costs and Figure 8.3(a-e) for baghouse costs, the authors arrive at a typical estimate of around $US 413,000 for a 170,000 m^3/hr dust collection device using stainless steel construction, insulation and fibreglass bags.

The Association Française de l'Amiante (D. Bouige, 1982) estimates investment costs for baghouses at 21 FF per m^3 air per hour (1981) which would result in a cost (1982) of $US 560,000 for the dust collection device in the previous example.

Lanting and den Boeft give typical investment costs for baghouses of 2.90 to 8.90 DM (1982) per m^3 air per hour which, as a mean value, is equivalent to about 6 DM or 17 FF* per m^3 air per hour.

In an actual case, for a 340,000 m^3/hr dust collection device Eternit A.G. Berlin (1982) (Table 8.9) indicates investment costs estimated at 2.222×10^3 DM, which compares well with the calculated 2.040×10^3 DM using the cost investment procedure above.

On the basis of these few examples, the different estimating procedures for investment costs can be considered in reasonably good agreement.

However, when viewing installation costs quoted by different authors, wide variations have been reported. Estimates of up to five times the purchase cost for baghouses are described for extreme cases (R.W. Lanting and J. den Boeft, 1980)(US EPA, 1973), though a mean value would probably be in the range of 1.5 to 2.0.

Operating and maintenance costs are difficult to estimate on a common basis as they are a function of such important parameters as recycling, electrical consumption cost, pressure drop, bag replacement, etc. However, it should be noted that these costs may be quite substantial under specifically unfavourable conditions, when these important parameters can act cumulatively on cost.

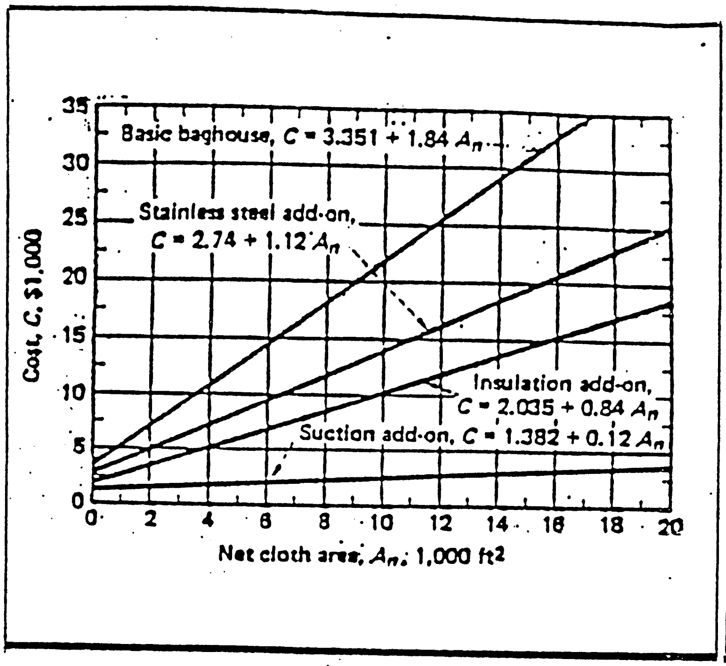
8.3 Substitution

Substitution of asbestos fibres or asbestos containing products has been proposed by some authorities as a possible means of "control" or a solution to the health problems associated with previous asbestos exposure, though primarily for the occupational setting. There is no question that

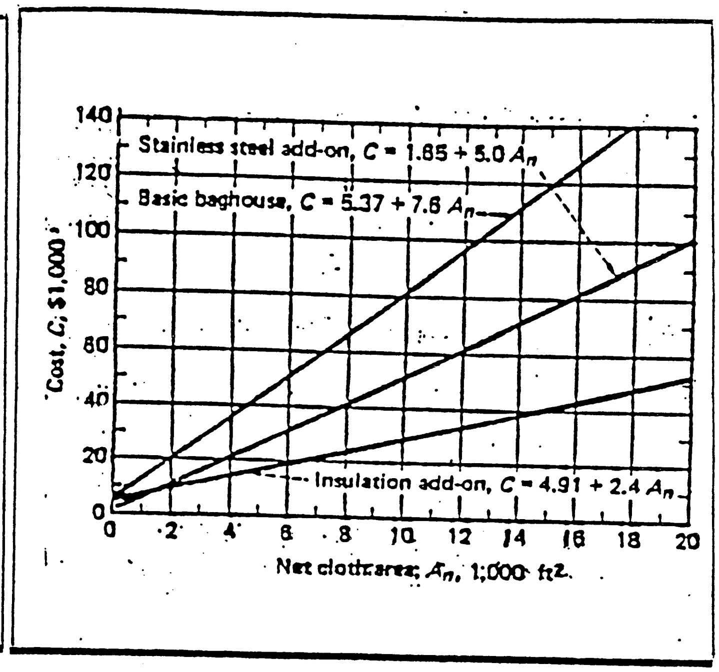
---

* Mean rate of exchange at the end of 1982.

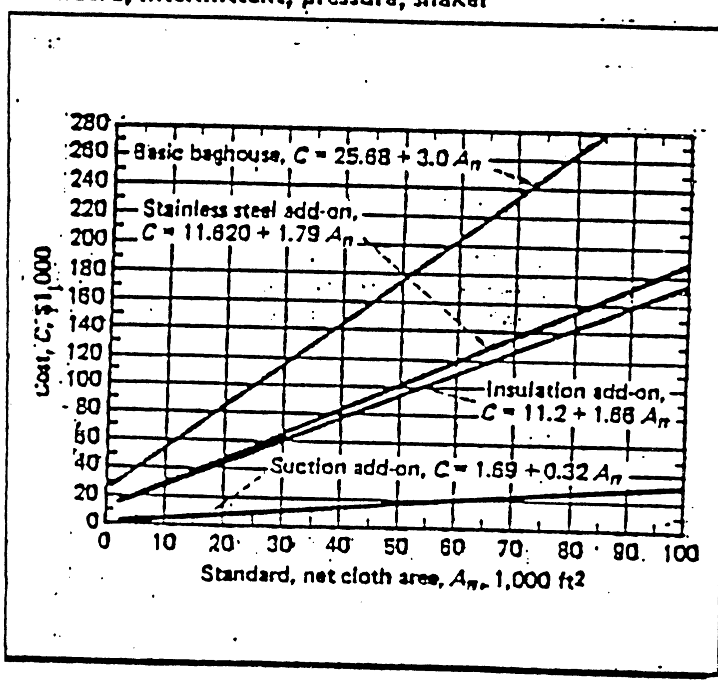
Figure 8.3(a-e) Installation Costs of Various Baghouses
(Vatavuk and Navaril, 1982)



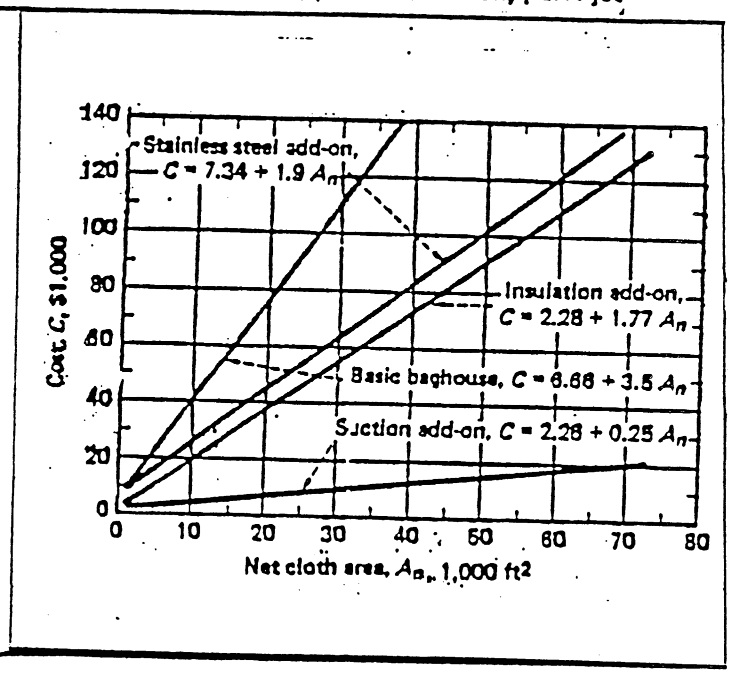
Standard, intermittent, pressure, shaker



Standard, continuous, pressure/suction, pulse-jet



Standard, continuous, pressure, reverse-air



Standard, continuous, pressure, shaker

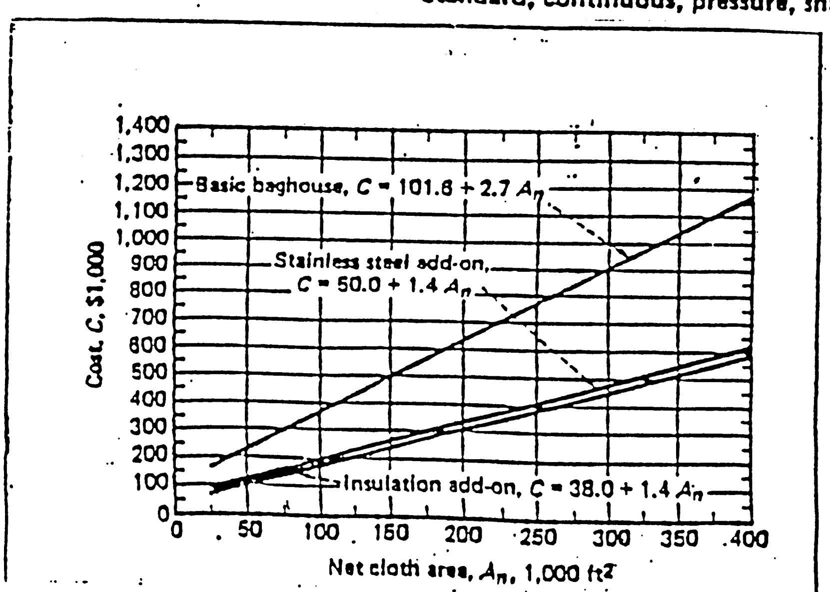


TABLE 8.7

Unit costs of filter bags made from seven representative Fabrics (Vatavuk and Navril, 1982)

/$/ft²/

Design	Cleaning mechanism		Dacron	Orlon	Nylon	Nomex	Fiberglas	Polyproplene	Cotton
Standard	Mechanical shaker	20,000 ft^2	0.40	0.65	0.75	1.15	0.50	0.65	0.45
	Mechanical shaker	20,000 ft^2	0.35	0.50	0.70	1.05	0.45	0.55	0.40
	Pulse jet		0.60	0.95		1.30		0.70	
	Reverse air		0.35	0.60	0.70	1.05	0.45	0.55	0.40
Custom	Mechanical shaker		0.25	0.35	0.45	0.65	0.30	0.35	0.40
	Reverse air		0.25	0.35	0.45	0.65	0.30	0.35	0.40

TABLE 8.8

Guide to approximate gross cloth area

(Vatavuk and Navaril, 1982)

Net cloth area, ft^2	Gross cloth area, ft^2
1-4,000	Multiply by 2
4,001-12,000	1.5
12,001-24,000	1.25
24,001-36,000	1.17
36,001-48,000	1.125
48,001-60,000	1.11
60,001-72,000	1.10
72,001-84,000	1.09
84,001-96,000	1.08
96,001-108,000	1.07
108,001-132,000	1.06
132,001-180,000	1.05
180,001 and up	1.04

TABLE 8.9

Costs of Fabric Filters in the Asbestos Cement Industry
(Eternit AG, Berlin, 1982)

Capital costs:	
Investment [10^3 x DM]	2.222
Based on:	
- exhaust gas flow rate [m^3/hr]	339,605
- installed capacity [KW]	650
Running costs:	
Electricity consumption*) [10^3 x DM/yr]	324.1
Filter material [10^3 x DM/yr]	92.7
Filter changes [10^3xDM/yr]	48.3
Other operation and maintenance [10^3xDM/yr]	29.0
Heat loss [10^3 x DM/yr]	210.0
Based on:	
- average operating time [hrs/yr]	3,700
- average replacement intervall of filters [yrs]	1.4
- heat loss [MWh/yr]	4.3

*) Based on an unit price of 0.178 DM/KWh.

alternative products are, and for that matter, always have been available for a number of asbestos containing products. Moreover, in recent years a variety of alternate fibrous materials have been developed that are proposed, or in some instances, have replaced asbestos fibre in certain product applications. While the development of substitutes for asbestos should be encouraged, it is important that there be thorough toxicological testing of such materials to ensure that they can be used safely.

8.4 References

Air Cleaning Devices, Handbook of Occupational Hygiene, Brentford Kluwer Publishing, 1982.

Asbestos International Association, Health and Safety Publication, R.C.P. N° 2, Catalogue of Tools for Working With Asbestos Cement Products on Site, London, 1983.

Asbestos International Association, R..C.P. N° 4, Asbestos Fibres, Packaging, Handling and Transportation, London, 1983.

Association Française de l'Amiante, Caractéristique Générales du Dépoussiérage dans l'Industrie de l'Amiante, Paris, 1982.

P. Borneman, Industrielle Anwendung Von Ersatzstoffen Fuer Asbest: Erfahrungen, Probleme, Perspective, Staub 40, 1980, p. 217.

D. Bouige, Emissions de Poussières dans l'Industrie de l'Amiante, UDI Berichte 475, Poussières Fibreuses, Colloque Strasbourg, Oct. 1982.

G.M. Bragg, The Technical Feasibility and Cost of Controlling Workplace Exposure to Asbestos Fibres, Study N° 7, Royal Commission on Matters of Health and Safety Arising from the Use of Asbestos in Ontario, Toronto, 1982.

G. Guthner, Stand Der Technik Bei Der Abscheidung Asbest-Haltiger Staeube, UDI Berichte 475, Faserige Staeube, Strasburg Colloquium, Oct. 1982.

C.F. Harwood, P. Siebert, T.P. Blaszak, Assessment of Particle Control Technology for Enclosed Asbestos Sources, ITT Research Institute, Oct. 1974.

A.A. Hodgson, Alternatives to Asbestos and Asbestos Products, Anjalena Publications Ltd., Berkshire (England), 1985.

International Labour Office, RESA (2) 1983/III Rev., Draft Code of Practice on Safety in the Use of Asbestos, Geneva, ILO, October 1983.

R.W. Lanting and J. den Boeft, Environmental Pollution by the Asbestos Industries, Problems and Proposals for Solutions, Nov. 1980.

J. Lebel, Quebec, Canada, in press, 1984.

Ministère de l'Environnement et du Cadre de Vie (France) - Service de l'Environnement Industriel - l'Industrie au Regard de l'Environnement : Industries de l'Amiante, Paris, mars 1981.

Preisliste BG 6, Bearbeitungs-Geraete Fuer Asbest-Zement Hochbau-Produkte, Eternit, Berlin, Sept. 1982.

Proceedings of the World Symposium on Asbestos - Montreal - May 1982, Canadian Asbestos Information Centre, Montreal, 1983, pp. 281-282.

G.S. Rajhans and G.M. Braggs - Engineering Aspects of Asbestos Dust Control, Ann Arbor Science, 1978.

Secrétariat d'Etat Auprès du Premier Ministre Chargé de l'Environnement et de la Qualité de la Vie (France). Direction de la Prévention des Pollutions, Note, Eternit Prouvy (nord).

Secrétariat d'Etat Auprès du Premier Ministre Chargé de l'Environnement et de la Qualité de la Vie (France), Direction de la Prévention des Pollutions, Note, Amiante : Un Exemple de Lutte Contre la Pollution, 8 juillet 1983.

M. Sittig, Pollution Control in the Asbestos Cement, Glass and Allied Mineral Industries, 1975.

U. Teichert - Ergebnisse Quellenbezogener Messungen Faser-Foermiger Teilchen In Der Aussenluft, UDI Berichte 475 - Faserige Staeube, Strasburg Colloquium, Oct. 1982.

U. Teichert and K. Robock, Measurement Technique Applied for Self-Control Within the German Asbestos Cement Industry, Fourth International Conference on Asbestos, Torino, May 1980.

U.S. Environmental Protection Agency, Control Techniques for Asbestos Air Pollutants, Pub. N° AP 117, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, Feb. 1973.

U.S. Environmental Protection Agency, Control Techniques for Asbestos Air Pollutants, Publication N° AP 117, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, Feb. 1973.

W.M. Vatavuk, R.B. Neveril, Estimate the Size and Cost of Baghouses, Chemical Engineering, March 1982.

9. SUMMARY AND CONCLUSIONS

For the past two decades, asbestos fibers and their associated health risk to workers and the general population have received much attention on the national and international level. This report has attempted to present the current state-of-the-art focussing on asbestos in the ambient air and its effects on the public at large. The issue is complex and the problem associated with trying to assess and regulate a generic pollutant, i.e. a class of fibers, is difficult. The task is further complicated by questions concerning the reliability of ambient and emission data; accurate analysis techniques are very costly and have rarely been used in the past. Even though it is well established todate that asbestos causes lung fibrosis (asbestosis) and/or carcinoma of the lung as well as mesothelioma at high exposure levels, it remains difficult to predict a risk of developing disease in the general public; and the mechanism(s) by which asbestos induces effects have not been established unequivocally.

In this report, most recent data on emission into the general environment and ambient concentration levels measured by generally accepted analysis techniques have been presented. Further, the current knowledge regarding asbestos induced health effects and the risk of developing disease to the public at large have been critically reviewed. Finally technically available control alternatives have been presented and their economic feasibility and impacts have been evaluated, in order to propose suitable policy action.

Asbestos in the Atmosphere

Asbestos has been defined as "a generic term for a number of hydrated silicates that, when crushed or processed, separate into flexible fibers made of fibrils", and includes serpentine and amphibole asbestos. Many of these minerals may occur in a non-fibrous form, in which case they should not be classified as asbestos. On the other hand, there is an impressive number of minerals other than asbestos that exhibit fibrous structure, similar in size range to asbestos. Asbestos constitutes only a small proportion of the fibrous content of ambient air. Because of its main chemical and physical characteristics, mainly its incombustibility and excellent tensile strength, asbestos has been known and used for over 4000 years. Currently, there are over 3000 industrial applications of asbestos fibers. As a result of abundant natural and antropogenic emission sources over a long history, it has became an ubiquitous pollutant present in all environmental media.

Asbestos is emitted from a large variety of industrial processes, ore preparation, mining, and natural sources such as asbestos containing rocks and soils. Asbestos emissions in different countries and at different sites depend strongly on the contribution from natural sources (i.e. local geology) and the stringency of emission standards enforced on the various industrial categories. In absence of proper emission control, the construction industry and removal of friable asbestos insulation are recognized as important emission sources. Even if the use of asbestos materials in construction has declined noticeably in recent years, building demolition and disposal of asbestos wastes may continue for some time to be significant sources of airborne asbestos. In countries or areas where asbestos ore is extensively mined and milled, these processes may constitute the largest emission source; especially because emission control from mining activities is difficult.

The continued implementation of workplace related and environmental legislation regulating asbestos emissions into air has significantly contributed to the improvement of the current emission situation. In most OECD countries, asbestos emissions have drastically been reduced over approximately the past ten years. This can be illustrated by the example of a large French friction product manufacturing plant having achieved a 165 times emission reduction over seven years. Today, national asbestos emission standards in OECD countries usually range around 0.1 mg/m^3.

Since asbestos is exceptionally resistant to thermal and chemical degradation, it persists unchanged in the environment over extended periods of time; it can therefore be transported over long distances.

Assessment of the magnitude of ambient asbestos concentrations has been limited by the analytical methods available. Different analysis techniques are used in the measurement of asbestos emissions, concentrations in the workplace and those in ambient air. The method of choice for the determination of asbestos in ambient air is transmission electron microscopy using direct transfer sample preparation techniques, which however, is a costly method requiring time and highly qualified personnel. Its use, especially in the past, has not been wide-spread and thus, only few reliable data of ambient asbestos levels are available. Comparison with data involving other analysis methods such as gravimetric measurements are extremely difficult and should be avoided.

Available data indicate asbestos concentration levels of generally less than 2 fibers/L (total) (instrumental detection limit) in remote and rural areas, while urban levels range up to 85 fibers/L (total) or 9 fibers/L ($>$ 5um) and are generally between 0 and 45 fibers/L (total) or 0 and 13 fibers/L ($>$ 5um). Concentrations in the vicinity of industrial sources are somewhat higher with values between 24 and 97 fibres/L (total) or 1.4 to 19.3 f/L ($>$ 5 um).

The Health Risk of Atmospheric Asbestos

The health hazards associated with exposure to high airborne levels of asbestos in the occupational environment have long been recognized. Prolonged exposure to elevated concentrations causes fibrosis (asbestosis), bronchial carcinomas, mesotheliomas of the pleura and peritoneum. Laryngeal cancer and malignancies of the gastrointestinal tract have also been shown to be associated with asbestos exposure but the degree of excess risk and the strength of the association are less than for lung cancer and mesothelioma. The risk of bronchial carcinoma in populations exposed occupationally to asbestos is increased at least additively and in some cohorts multiplicatively by cigarette smoking and on the basis of most available data, it has been suggested that the amphiboles are more potent in the induction of mesothelioma than is chrysotile. Available data from toxicological studies indicate that fibre dimensions are important determinants in the pathogenesis of asbestos-related disease.

On the basis of available toxicological and epidemiological data, it can be concluded with some certainty that there is a dose-response relationship for all of the main types of asbestos-related disease. It can also be concluded that the risk of asbestosis associated with exposure to the low levels of asbestos present in ambient air is probably negligible and that strategies to limit exposure of the general population should be based on consideration of the more significant risks of lung cancer and mesothelioma associated with inhalation of airborne asbestos.

There is evidence that the risk of mesothelioma is increased for family contacts of asbestos workers and for individuals who have lived near asbestos mines or factories; however there was no evidence of increased mortality due to lung cancer in an ecological study of females residing in the vicinity of chrysotile mining communities in Quebec (Siemiatycki, 1983) or in an inherently more sensitive cohort study of male residents in the vicinity of an amosite factory (Hammond et al., 1979). However, the power of these studies was limited. Few data concerning the exposure of the populations in these studies were presented, but it is likely that concentrations were considerably greater than they are today. On the basis of the results of an analysis of time trends in disease rates among males and females through 1980, it has been suggested that environmental exposure to asbestos contributed negligibly to the overall incidence of mesothelioma in the general population (Mc Donald, 1984). However, the sensitivity of this approach has yet to be evaluated.

Available epidemiological studies are not sufficiently sensitive to permit a precise determination of the cancer risks associated with exposure of the general population to asbestos in ambient air. These risks have been estimated through extrapolation of epidemiological data on exposure to the much higher levels of asbestos present in the occupational environment assuming linearity of the exposure-response relationship (lung cancer and mesothelioma) and incorporating a relationship between risk and time since first exposure (mesothelioma). For example, the Committee on Nonoccupational Health Risks have estimated that the lifetime risk of lung cancer and mesothelioma associated with average exposure to asbestos in ambient air varies from 170 per million (non-smoking female) to 448 per million (smoking male). However, there are numerous uncertainties associated with such estimates and they can serve only as a rough guide.

It is apparent though that reduction of exposure almost certainly lessens the risk of asbestos-related malignancies and it would be prudent, therefore, to minimize exposure of the general population through reduction of controllable emissions of asbestos by introduction and use of "best practicable" control technology.

Impacts of Asbestos Control and Proposed Strategies

There are several ways to reduce emissions of carcinogens such as asbestos to the environment. Methods can range from stringently controlling emissions to banning and substitution. While countries like Denmark and Sweden have implemented a ban of the use of asbestos except for essential applications, and some other countries like Switzerland and the United States are considering or developing similar regulatory action, many governmental bodies and countries including the Commission for European Communities, Canada and Japan currently regulate asbestos by limiting emissions to the lowest degree possible with the best technical means available. Countries adopting this control option devise emission limits and/or ambient concentration values according to the state-of-the-art of control technology. Such emission limits, however, only serve as guidance threshold values which could and should periodically be revised in accordance with best available technology.

Past experience in many OECD countries has shown that asbestos emissions from stationary manufacturing and processing sources can be reduced by add-on dust control equipment such as fabric filters, possibly in combination with mechanical cyclones as pre-cleaners. If best available control technology is applied and the control device is properly operated and maintained, control efficiencies in excess of 99 percent can be obtained, which translates into a hundred fold reduction in ambient asbestos levels. Fabric filters with pre-coat achieve an approximate efficiency of 99.9 percent for all fibre lengths 1 um. Costs for bag-houses are estimated between $US2.00 and 2.50 (1982) per m^3 air treated per hour. The technical and economic feasibility of best available control technology has, thus, been demonstrated by past experience, and it is therefore recommended that all asbestos milling, manufacturing and processing plants install fabric filters to control asbestos emissions into ambient air. In order to minimize the possible health risk, installation of baghouses should not only be required on new plants but also existing ones should be retrofitted.

Industrial emission sources that still remain relatively less controlled or uncontrolled in many countries, including some OECD countries, are mining and asbestos waste disposal. Portable dust collection systems, good process management using coarse dust producing tools as well as wetting techniques, for example, production rationalization and recycling of waste streams to the degree possible are recommended in order to improve the emission situation into air from these source categories.

Asbestos fibre substitution -- often considered a perfect solution to eliminating asbestos dust completely -- should be considered with caution. It should be borne in mind that the prerequisite for the health effects of asbestos is its fibrous structure. While chemical properties play an important role, any fibrous material which can generate respirable fibres also could have the potential to induce health effects comparable to asbestos. Before substitute fibres are introduced onto the market they should be carefully screened and tested for biological activity, with controls and regulations being implemented as appropriate.

Lastly, it should be remembered that any proposed policy to limit asbestos emissions to the lowest possible will only be effective if it is properly implemented. Such implementation requires periodic emission tests and ambient air sampling. Central laboratories with adequate technical analysis apparatus and skilled operators, who maintain strict quality control, are recommended for reliable analysis of samples.