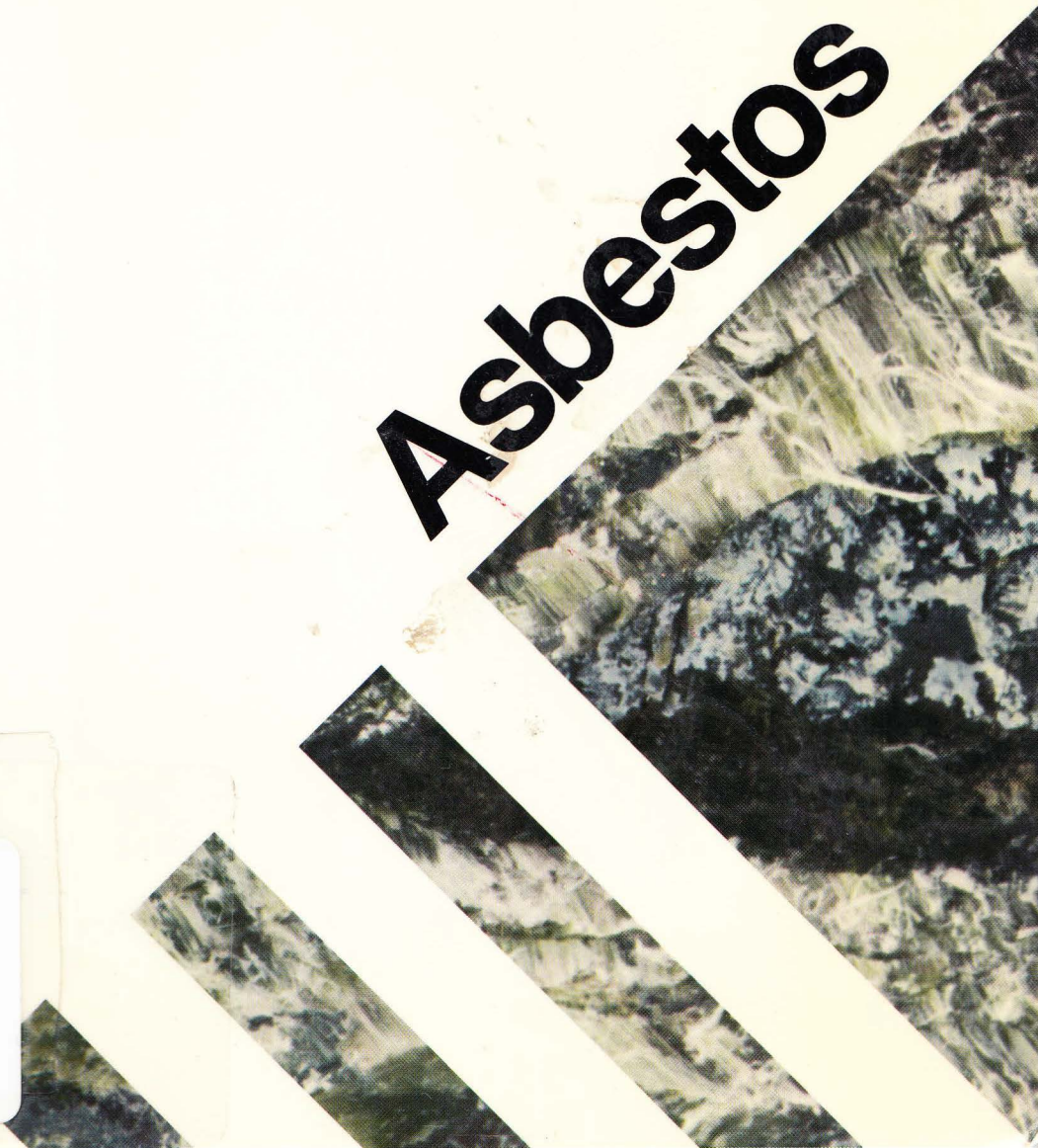
Canada

Asbestos



Asbestos

Contents

Chrysotile asbestos is found in cross fibre veins zigzagging through the host rock.

The mineral

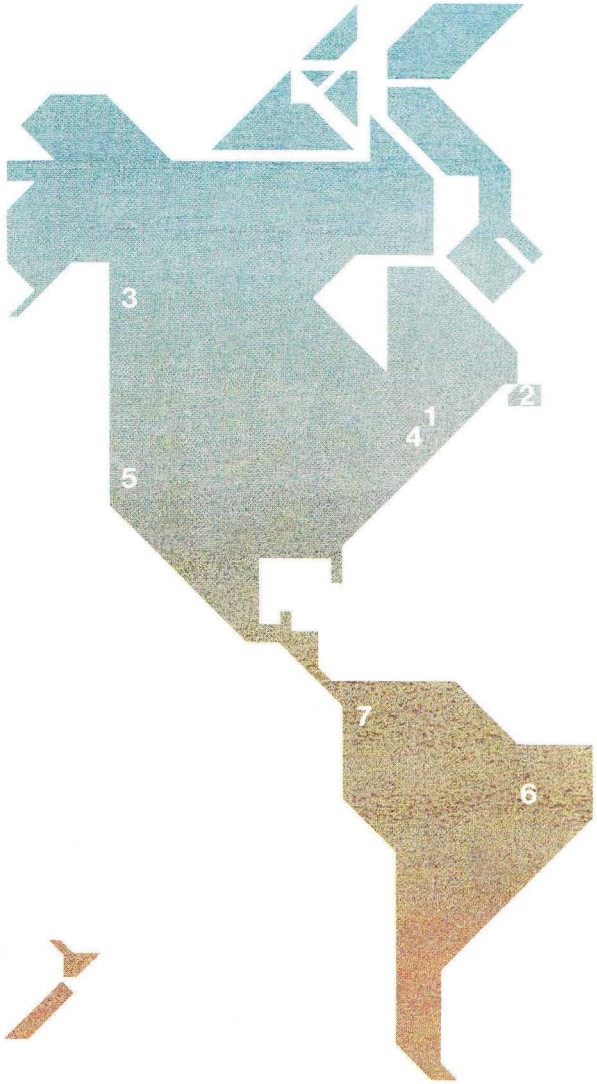
Asbestos, from the Greek work for unslaked lime, is the commercial name for a number of fibrous hydrated silicates that occur naturally in rock formations throughout the world. By some definitions as many as thirty varieties of asbestos exist, but only six are of commercial importance[1]. These are divided on the basis of mineralogical features into two mineral groups: the amphibole group, which includes actinolite, amosite, anthophyllite, crocidolite and tremolite; and the serpentine group, which includes the most abundant variety of asbestos by far, chrysotile.

Geologists believe that most asbestos, the variety chrysotile in particular, was formed far below the earth's surface under conditions of extreme pressure and temperature. Peridotite, a common host rock consisting of iron, magnesia and silica, was altered chemically and physically by heat and by waters that probably infiltrated slowly from the surface. These ground waters transformed the host rock into the magnesia-silica-water ($3MgO\text{-}2SiO_2\text{-}2H_2O$) mineral serpentine. During crystallization of these solutions in the openings of the host rock, veins of parallel fibres, between 1 mm and 40 mm in length, were formed. These veins constitute the most common form of asbestos. Although the occurrence of asbestos is frequent, concentrations sufficient to make commercial mining feasible are rare.

Numerous minerals other than asbestos exhibit fibrous structure, a number of which are classified as 'asbestiform'[2]. Asbestos and 'asbestiform' minerals may occur in igneous and metamorphic rocks, especially in such mineral deposits as nickel, chromium, copper and gold ores, and in granites, basalts and almost all silicates — in other words, in nearly two thirds of the earth's crust.

Commercially exploited asbestos deposits

1. Quebec (Canada)
2. Newfoundland (Canada)
3. British Columbia (Canada)
4. Vermont (U.S.A.)
5. California (U.S.A.)
6. Brazil
7. Colombia
8. Cyprus
9. Italy
10. Greece
11. Turkey
12. Yugoslavia
13. South Africa
14. Zimbabwe
15. India
16. Japan
17. Korea
18. China
19. Taiwan
20. U.S.S.R.

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Three types of asbestos fibre have commercial value: amosite** (bottom left), **crocidolite** (top left), **and chrysotile** (top and bottom right). **Chrysotile accounts for 95 percent of the commercial use of asbestos.

The common occurrence of fibrous minerals gives rise to the presence of fibres in the soil, water and air in regions devoid of any industrial activity associated with the extraction of these minerals. In fact, all mining operations, the working of quarries, construction of highways, tunnels, foundations and even ordinary erosion of rock and soils can cause the emission of fibrous dusts, including asbestos.

Today, only the largest deposits of asbestos are commercially exploited. Asbestos mining is conducted in Brazil, Canada, China, Colombia, Cyprus, Greece, India, Italy, Japan, Korea, South Africa, the U.S.S.R., Taiwan, Turkey, the United States, Yugoslavia and Zimbabwe.

Chrysotile, sometimes referred to as white asbestos, is the most important commercial variety and accounts for about 95 per cent of world production; amosite, crocidolite, anthophyllite and tremolite account for the remainder.

Open-pit mining operations.

Mining

In general, deposits that are mined contain about 5 per cent asbestos by weight. Consequently, the scale of today's commercial operations implies the handling of enormous volumes of rock and involves numerous processing stages that are required to separate the asbestos fibres and to produce various specifications for product manufacture.

Extraction

The preferred method of mining asbestos ore is by open pit, although deep deposits may dictate underground methods. Although technically less complex, open-pit mines require an extensive infrastructure, complex organization and a great deal of equipment to remove large quantities of waste rock and expose the ore, and to maintain an adequate supply of ore to the processing plant under all operating conditions. In Canada, asbestos mining companies have invested in the latest equipment and communication aids, and automation and remote control technology, to ensure the safety of workers and to protect the environment.

Once the overburden is removed the pit is carved into levels by blasting. The ore recovered during this operation is loaded into trucks by huge mechanical shovels and hauled to the primary crusher.

Underground, ore is mined by block caving. When blasted, the masses of rock fragment and collapse under their own weight and fall through vertical ore passes into haulage drifts. The ore is then hoisted to the surface and carried on conveyors to the processing plant. To ensure the safety of workers in the enclosed areas, powerful ventilation systems circulate and renew the air while filtering-out the dust.

Asbestos fibre processing through fully enclosed equipment.

Processing

Processing of the ore involves separation of asbestos from host rock by a series of mechanical operations. The ore is first crushed in a primary crusher and then reduced further in a cone crusher to free the asbestos from waste rock. Following the initial stages of crushing, the ore is passed through huge dryers to remove the entrained moisture and to prepare it for the recovery of the asbestos fibre.

After additional stages of crushing to further reduce the size of the ore, particles proceed onto vibrating screens where the action causes the asbestos to float above the rock. Air aspiration or suction then draws the fibres from the screens into cyclone collectors where they are then directed to hammer mills for further processing.

Milling is based on a process that removes the fibres by air. Consequently, to avoid the emission of fibres into the workplace and the environment, all processing machinery and conveying equipment is enclosed, and the entire mill building is maintained at a negative air pressure. In addition, all the air used in the process is filtered before being exhausted to the outside or recirculated to the mill building.

Classification and packaging

After milling, the fibres are graded by screening according to length and 'openness', or the fineness to which the fibre has been separated. On the basis of length and openness, fibres can be separated into 150 grades, each corresponding to a specific use in the manufacture of asbestos-based products.

The fibre is compressed to reduce volume, weighed and automatically bagged in paper or polyethylene bags, depending on the customer's specifications. In certain instances water soluble bags are used which can be incorporated directly into a slurry allowing the manufacturing process to avoid dust emission from bag opening.

Samples of asbestos fibre from bags leaving the processing plant undergo strict quality control to ensure that the fibres meet the appropriate standards and customer specifications. The Quebec Standard, a classification developed in Quebec, is the generally accepted international standard.

Automatic bagging of fibre.

To facilitate handling and to prevent emission of asbestos during transportation, the bags are stacked into 36-unit bundles. These are then entirely protected with one or more layers of plastic cover by an automatic shrink- or stretch-wrapping process before shipment in bulk or container.

Mine tailings

The very large accumulation of asbestos tailings near mines is of increasing interest as a potential resource for other industrial applications. Examples include: aggregates for asphalt, recovery of metals and magnesium compounds, manufacture of refractory sands and brick and the production of mineral wool insulation. Some of these applications are now in production.

Most Canadian companies have embarked upon revegetation programs to prevent erosion and dust emissions from tailing piles and for aesthetic reasons. Special techniques have been developed that encourage growth of grass and shrubs, and provide favourable conditions for establishing natural vegetation.

Being incombustible and heat resistant, asbestos affords ideal protection against fire.

Properties

The exceptional properties derived from the fibrous and crystalline structure of asbestos, as well as its chemical composition, make this natural fibre valuable in various industrial applications.

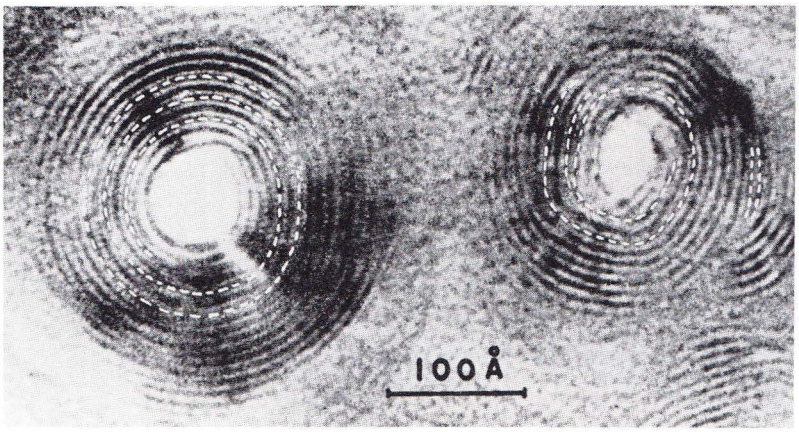
Chrysotile possesses an additional unique feature in that a fibre is really a bundle of thousands of agglomerated fibrils of magnesium silicate. The average diameter of a fibre used in industry varies from 0.1 µm to 1 µm.* Structurally, each fibre is much like a scroll of paper, somewhat hollow, and imparts absorbing and insulating properties.

The extreme fineness of these fibres results in a vast surface area, which produces fibre elasticity and high tensile strength. In fact, the tensile strength of an asbestos fibre is greater than that of steel with the same cross-sectional area. These physical characteristics, in conjunction with uniform chemical composition, impart many special physicochemical properties of industrial importance, such as:

- incombustibility,
- resistance to high temperatures,
- low thermal conductivity,
- resistance to strong chemicals such as alkalis and acids,
- resistance to microorganisms,
- resistance to wear, and
- electrical resistance.

(see table page 17)

* µm = micrometre or one millionth of a metre.



Structurally, a chrysotile fibre resembles a scroll of paper.

Physicochemical properties of different types of asbestos

Property	Chrysotile	Crocidolite	Amosite
	Hydrous magnesium silicate	Iron and sodium silicate	Iron and magnesium silicate
Chemical composition (essential elements in %)			
SiO_2	39.0	51	50.0
FeO	2.0	20	40.0
Fe_2O_3	1.5	18	—
MgO	40.0	1	6.5
Na_2O	—	6	—
H_2O	13.0	2	2.0
Diameter of fibril (μm)	0.020	0.080	0.100
Diameter of industrial fibre (μm)	0.1 to 1.0	1 to 2	1 to 2
Maximum length of fibres (mm)	40	70	70
Specific surface: Absorption of N_2 on industrial fibres (cm^2/g)	30 000-90 000	10 000-20 000	10 000-20 000
Tensile strength (MPa)	490-1961	706-2206	98-588
Flexibility-pliability	excellent	good	low
Density (g/cm^3)	2.55	3.37	3.45
MOHS hardness	2.5-4.0	5.0-6.0	5.0-6.0
Specific heat (J/g·°C)	1110	842	816
Deterioration temperature (°C)	450-700	400-600	600-800
Melting point of residue (°C)	1500	1000	1100
Chemical resistance to:	alkalis	acids	acids

Sources: Asbestos Information Centre (Great Britain); Comité spécial sur l'amiante (France).

Architectural use of asbestos cement.

Uses

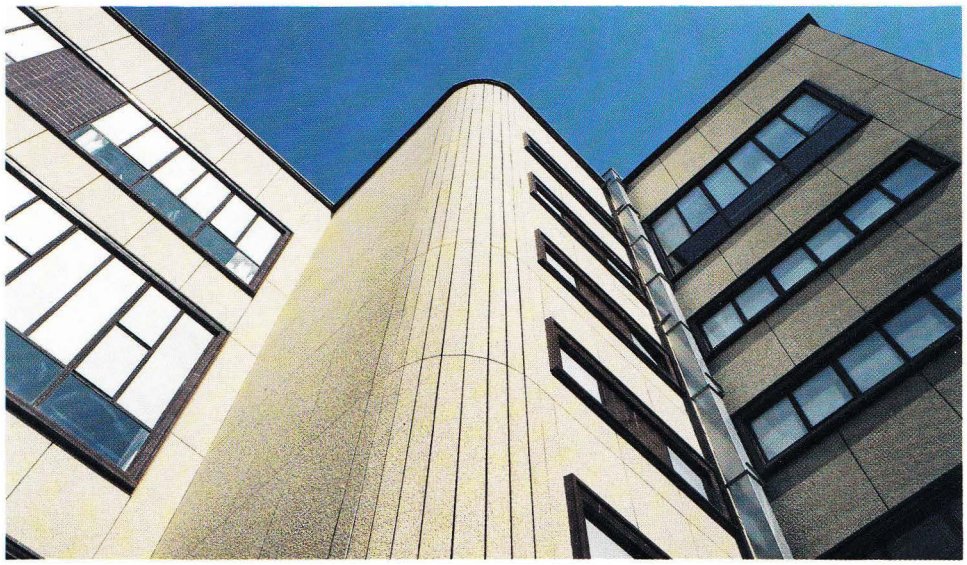
The major applications of asbestos are as follows: asbestos cement, representing about 70 per cent of world consumption; friction materials, representing some 15 per cent of consumption; and papers and felts as well as a large number of paints, sealants, asphalts and other products in which asbestos is an important additive. Most of today's product applications are confined to those uses where the fibre is effectively locked into a matrix, such as cement, plastic or resin.

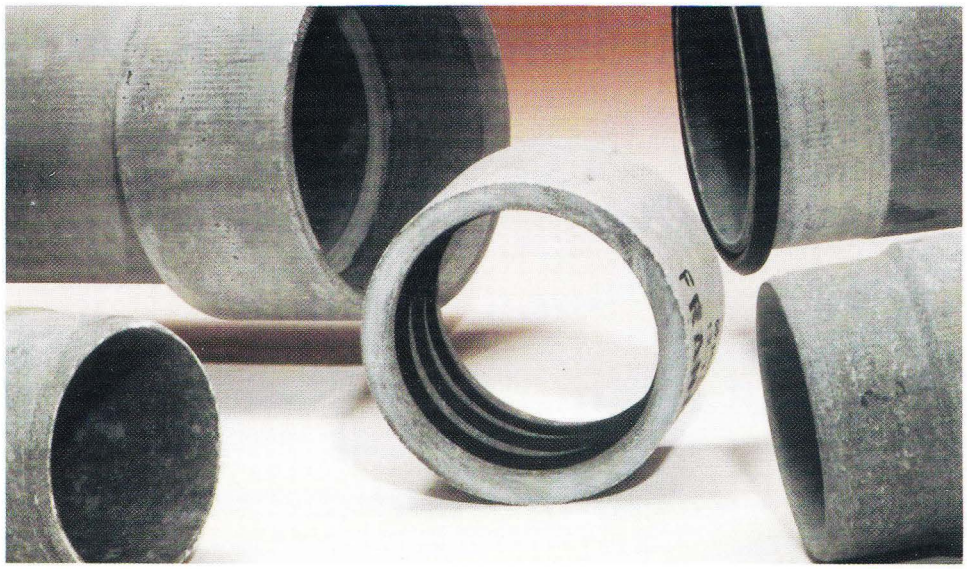
Asbestos cement

Asbestos cement is one of the most widely used construction materials in the world, thanks to the exceptional technical characteristics imparted to the cement by the asbestos. Made by adding 10 to 15 per cent by weight of fibre to water and cement, asbestos cement is renowned for its high tensile and compressive strength, flexural strength and corrosion resistance. Asbestos cement is crack resistant, fireproof, unaffected by wide temperature variations and, weighing only 70 per cent of an equivalent volume of prefabricated concrete, is a cost-effective product. In some countries manufacturers provide 50-year warrantees on asbestos cement products.

Chrysotile-reinforced cement is particularly well suited for many product applications, such as pipes, shingles, clapboards, flat and corrugated sheets, acoustic tile, window panels and curtain walls.

Today, one of the most common applications is in asbestos cement pipe, which is used for water supply, sewage, irrigation and drainage systems, as well as for air



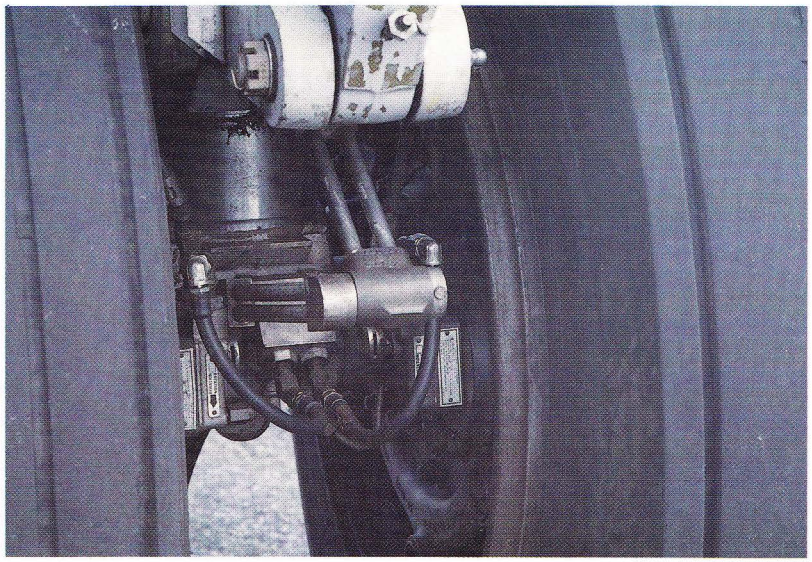


Asbestos cement sheets and pipes.

conditioning, ventilation and electrical conduits. Asbestos cement pipes withstand soil corrosion, mildew, termites, various chemicals and biological organisms, and are resistant to ground movement. Relatively light to handle, asbestos cement pipes can be assembled with flexible joints. They do not become encrusted internally and maintain a smooth bore, allowing good flow capacity throughout the service life, which can exceed 50 years. Asbestos cement pipes can be manufactured up to 2.5 m in diameter and 6 m in length, making for simple and economical installation.

Asbestos cement sheets are another important application and are used as building materials throughout the world. In the past, asbestos cement sheets were used almost exclusively in the construction of industrial and farm buildings, but the trend today is to produce material that is textured and coloured for use in public buildings, shopping centres, office towers and even in residential construction. Asbestos cement is also used in construction of airport buildings, since it does not interfere with the transmission of radar waves.

Finally, one of the major advantages of asbestos cement is its cost-performance ratio, which explains its growing use in developing countries. Although the asbestos fibre may have to be imported, the remaining raw materials, such as cement, are usually available locally. Moreover, asbestos cement technology is not particularly complex and requires relatively lower capital investment and significantly less energy input than, for example, the manufacturing of steel, cast iron and aluminum products.



Friction products

Because of its heat absorption properties and resistance to high temperatures and corrosion, chrysotile is unsurpassed as a fibre for friction materials in terms of technical quality and cost.

Friction materials can be made from resin-impregnated asbestos cloth or wound yarn into which metal wire is incorporated. Moulded friction materials, including disc and drum brakes and clutch facings for automobiles, are the most common products. These are made from a mixture of chrysotile (40 per cent), resin and other materials.

However, asbestos-based friction materials are also widely used in farm machinery and heavy equipment, in elevating devices and in many types of light industrial machinery.

Papers and felts

Asbestos papers and felts represent only 6 to 8 per cent of world consumption of medium-length fibres. However, they have found numerous applications in diverse areas such as furnace and boiler thermal insulation, electrical insulation for appliances and industrial equipment, muffler insulation, and for the protection of underground and marine piping systems. Special uses include electrofine paper for high electrical resistance and papers for diaphragms in cells for the electrolysis of brine.

Chrysotile imparts to papers and felts an exceptional resistance to temperature fluctuations, moisture, mildew and rot. For this reason, asbestos papers are widely used as underlay for vinyl or linoleum flooring, whereas asbestos felts are mainly used in roofing.

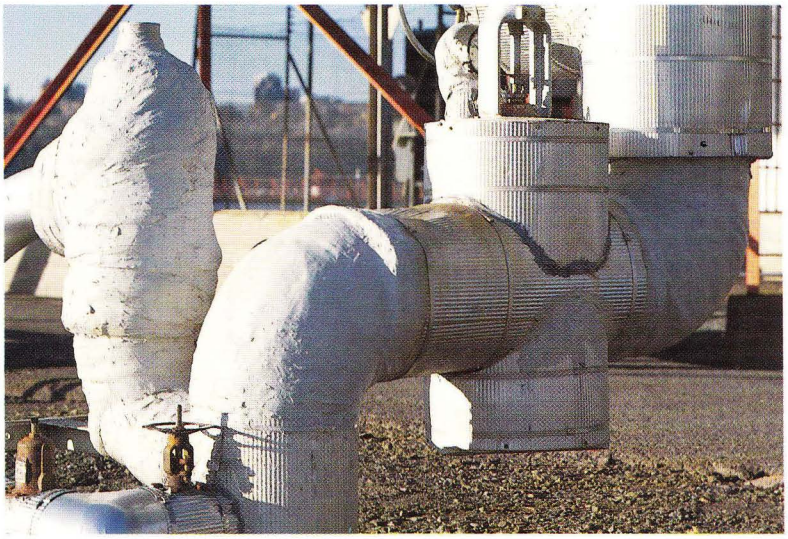
Additives

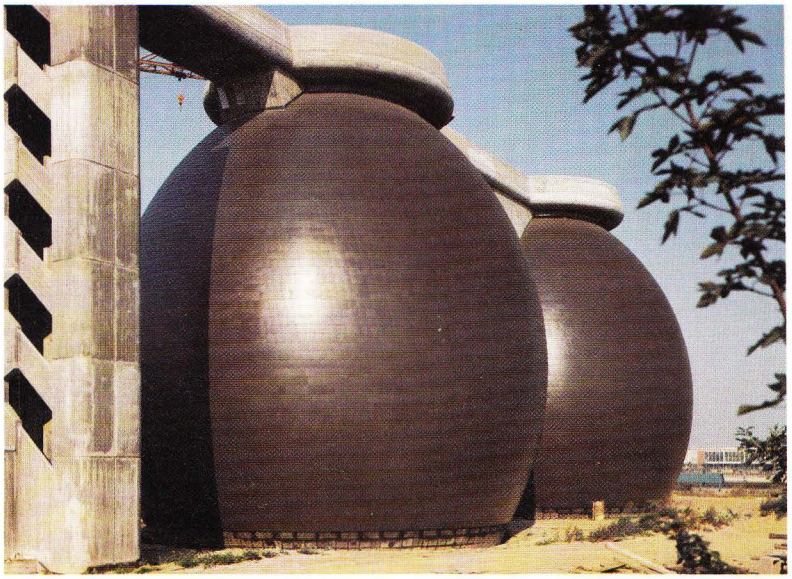
This category includes a broad range of products in which asbestos is used as an extender for reinforcement or as a low-cost filler.

Numerous products incorporate short asbestos fibres or asbestos residues to provide consistency, greater homogeneity, improved dimensional stability to heat, decreased electrical conductivity, greater tensile strength and lower production costs. Products in which asbestos is used as an additive include vinyl asbestos floor tiles, a wide range of plastic products as well as paints, caulkings and other composites.

Made of 15 per cent vinyl and a thermoplastic binder composed of 10 to 20 per cent asbestos, mineral additives and pigments, vinyl asbestos tiles are widely used as floor coverings in commercial and industrial buildings. The tiles are particularly resistant to fire, smoke, humidity and mildew. Comparative tests have also shown that vinyl asbestos tiles are far more durable than floor coverings that do not contain asbestos, particularly in areas of heavy traffic.

In high-tech applications, asbestos is compatible with most polymeric materials. This is why many industrial sectors, such as the automotive, electronic, chemical, aeronautic and aerospace industries, currently use plastics incorporating asbestos fibre. Asbestos fibre reinforced plastics are used in the chemical industry for tubing, storage tanks and other products where corrosion resistance is required. The dielectric properties of these composite plastics render them particularly useful in electrical wiring, circuit breakers, and household appliances. A sophisticated application relates to transmission of electromag-





Asbestos-based coating for insulation.
Asbestos cement shingles covering water storage tanks.

netic waves. Here, asbestos-reinforced plastics are used in the manufacture of domes which protect high-speed radar detectors and high-powered antennas in aerospace communications.

The addition of asbestos to asphalt results in coating products that are impermeable to water and resistant to wear and cracking in cold temperatures. In liquid or paste form, containing between 2 and 15 per cent asbestos in solvent-diluted or water-emulsified asphalt, these products find applications primarily as sealers and coatings for roofing, and as corrosion protection for metallic surfaces. Mixed with aggregates and binder, asbestos-reinforced asphalt makes a highly resistant road surface.

Asbestos cement shingles used in roofing.

Health monitoring of asbestos workers includes lung x-rays.

Asbestos and health

For over 50 years the health effects of asbestos have been the subject of much more intensive scientific and medical study and research than those of any other material involved in the manufacture of industrial products. The findings of these studies have led to the development and implementation of controls, both technical and medical, to minimize the inherent risks associated with the use of asbestos.

The three main diseases that have been associated with the inhalation of asbestos dust are: pneumoconiosis, lung cancer and mesothelioma. Other types of cancer have been attributed to asbestos exposure, although the evidence at present is inconclusive[3,4].

On the other hand, there has been no convincing evidence of a relationship between the ingestion of fibres that may be present in drinking water, and a higher-than-expected incidence of gastrointestinal cancer in the general population. Moreover, animal-feeding studies with several varieties of asbestos have not increased the incidence of cancers. Consequently, experts agree that there is no apparent relationship between the ingestion of asbestos fibres and gastrointestinal cancer.

Pneumoconiosis

As in any pneumoconiosis, asbestosis, the form associated with the inhalation of asbestos dust, is characterized by a fibrosis (scarring) of the lung, which leads to a progressive inability to transfer oxygen from the lungs to the blood. In reducing lung capacity, pneumoconiosis causes respiratory difficulties, shortness of breath and a dry cough. Diagnosis is made by clinical and X-ray examinations.

Pneumoconiosis is primarily an occupational disease caused by the prolonged inhalation of high levels of mineral, metal or plant dusts; well known examples being iron, silica, coal and asbestos.

In 1977, the *Comité spécial sur l'amiantose* (Special Committee on Asbestosis) of the Workmen's Compensation Commission of Quebec published the results of a two-year detailed study on virtually every asbestos worker in Quebec. After a review of the medical records of some 6785 workers in mines and processing plants, the study established that 2.3 per cent of these workers suffered from various degrees of asbestosis[5].

As all the cases of asbestosis were found in workers who had been exposed for more than 20 years, and in some instances, for more than 40 years, at a time when dust levels were very high and uncontrolled, the Quebec Commission concluded that with the stringent dust controls currently in place, this form of pneumoconiosis is a disease of the past[6]. Conclusions in a report (1985) for the United Kingdom Health and Safety Commission by Sir Richard Doll and Dr. Julian Peto are similar[7].

Lung cancer

Lung cancer is a malignant tumour of the bronchial tubes and may be associated with a number of factors, some related to personal lifestyle, diet and smoking for example, or to occupation.

The risk of lung cancer in asbestos workers has been the subject of a number of epidemiological studies in different sectors of this industry. One of the best known studies, and one of the first to have some measurement data on dust levels in the past, was undertaken in Quebec over a

14-year period and included a cohort of some 11 000 asbestos workers from the region of Thetford Mines, Quebec. Conducted under a program of McGill University (Montreal) and sponsored by the Government of Canada in cooperation with the Government of Quebec, this study was directed by Professor Corbett McDonald and is recognized internationally as a critical contribution to the epidemiology of asbestos.

This study established that the risk of disease was significantly higher for those workers with the greatest exposure to asbestos dust in the workplace, particularly for asbestosis, lung cancer and other respiratory diseases[8].

After examining the history of workers exposed to a wide variation of dust levels, this research established that risk of disease increased with increasing levels and duration of exposure. However, the authors of this study calculated that the risk of lung cancer for these asbestos workers, if regularly exposed to levels of 1 f/cm^3 of air,* would be equivalent to the personal risk of smoking two cigarettes per week[8].

On this question of risk, the Ontario Royal Commission on Asbestos states: *"We find in the cases of chrysotile mining and milling and of general chrysotile manufacturing that the disease risk associated with chrysotile exposure under a 1 f/cm^3 control limit, effectively enforced, involves a projected mortality rate well below the mortality rate that results from industrial accidents in all Ontario manufacturing. It therefore falls well within the bounds of a societally acceptable industrial risk"*[9] .

* Asbestos fibres greater than 5 μm in length and less than 3 μm in diameter with length at least three times greater than the diameter.

Most of the asbestos industry is now striving to achieve a dust level of 1 f/cm^3. It is important to recognize that nowhere outside the workplace do the levels of exposure to airborne asbestos fibre reach or come close to 1 f/cm^3. Measurements taken in the ambient air indicate that asbestos levels are generally 1000 times less than this occupational standard.

On the other hand, epidemiological studies of workers engaged in textile manufacture have demonstrated that the risk of lung cancer is much higher in this industry than in other asbestos-processing sectors[10]. This differentiation in risk according to industrial activity led the Ontario Royal Commission on Asbestos to conclude that the type of industrial process influences the dimensions of the fibres released into the air, and thus the hazard faced by workers[11].

A committee of experts, convened in 1984 by Health and Welfare Canada, similarly concluded that there are important variations in the risk associated with exposure to asbestos in different types of industries[12].

Asbestos and tobacco

As the risk of lung cancer is also closely associated with smoking, many epidemiological studies on asbestos attempt to separate and measure the influence of each factor in contributing to the incidence of this disease. In the case of asbestos miners and for those workers in the highest exposure category, heavy smokers were found to have a standardized mortality ratio* from lung cancer

*Standardized mortality ratio: the relationship between the observed mortality rate in the group studied and the expected rate, where the latter is determined from the actual mortality rate of the general population.

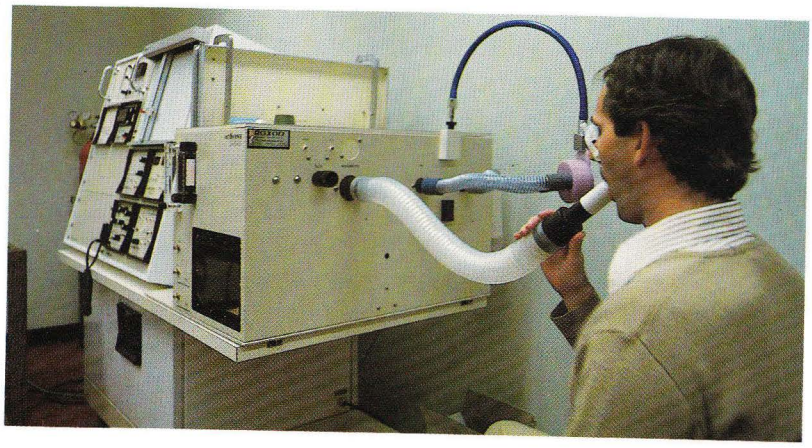
that was four times that for nonsmokers[8]. The Ontario Royal Commission on Asbestos stated that smoking may multiply the lung cancer risk by five for asbestos-exposed workers.

This synergistic effect between smoking and asbestos exposure on the incidence of lung cancer had been noted in a study of insulation workers in the United States. Dr. W. Nicholson (Mount Sinai School of Medicine) in commenting on this study stated: *"For 2066 nonsmokers, only two lung cancers were identified over a six-year period: 179 were observed in 9590 men with a history of cigarette smoking"*[13]. Indeed, calculations based on American Cancer Society data suggest that smoking increases the risk of lung cancer by a factor of ten, and exposure to asbestos dust, by a factor of five. In practice, this implies that for asbestos workers, the risk of lung cancer is very closely related to smoking. In fact, the 1985 report by Doll and Peto for the U.K. Health and Safety Commission concludes that the risk to non-smokers is relatively small even after quite heavy asbestos exposure[14].

Now that the importance of this interaction is well recognized, a number of asbestos operations have implemented programs encouraging workers to stop smoking and, in some instances, forbid smoking at the workplace.

Mesothelioma

In 1960, mesothelioma attracted scientific scrutiny in South Africa, when clusters of cases were found among persons working in crocidolite asbestos mines or living in the vicinity of these mines[15]. However, this malignant tumour of the lining of the body cavities (pleural, peritoneal, pericardium, rarely at other sites), remains a relatively rare disease. In Canada, for example, the inci-



Air samples are taken at regular intervals for dust monitoring at work sites. Medical surveillance of workers.

dence of mesothelioma in the general population during the 1970s was estimated at about 8 per million for men and 2.5 per million for women, with the incidence increasing for men[16]. Based on reviews of various studies, a variable percentage of mesothelioma cases in the general population are not related to any known history of occupational exposure to asbestos. These cases are: in Canada, 40 per cent; the United States, 70 per cent; Italy, 80 per cent; South Africa, 13 per cent; Great Britain, 37 per cent; and Netherlands, 28 per cent[17]. It should be noted that diagnosis of mesothelioma is difficult because it can occur at various sites and can resemble other tumours.

Epidemiological studies of different groups of asbestos workers have shown that the latency period for mesothelioma is between 15 and 40 years, and that the risk is similar in smokers and non-smokers.

It has also been observed that there are more cases of this disease in workers in the industries using the amphibole asbestos varieties, crocidolite and amosite, than for workers exposed only to chrysotile in mines. In the McDonald study, no significant excess risk of mesothelioma was detected among workers in chrysotile mines and manufacturing plants in Quebec, where the incidence of mesothelioma accounted for only 0.2 per cent of deaths, or 11 cases in 50 years[8].

On this subject, the Report of the Committee of Experts convened by Health and Welfare Canada concluded: *"Differential risks of mesothelioma associated with exposure to various fibre types have been observed in populations engaged in mining and milling, manufacture of textiles and friction materials and in the production and assembly of gas mask filters. In terms of both absolute numbers of mesotheliomas and these tumours expressed as a percentage of excess lung cancer in the study popu-*

lations, substantially greater risks have been associated with crocidolite and possibly amosite exposures than with exposure to chrysotile alone, both in mining and manufacturing. Populations exposed to mixed fibre types have an intermediate risk. This evidence emerges when all *available studies are taken into account."*[18].

Biological effects

Scientific evidence on the biological response of the human organism to asbestos fibre exposure has demonstrated that not only is the level and duration of exposure important, but so is fibre type and industrial process. The association of mesothelioma with fibre type, notably the amphibole varieties, is described above. The report of the Ontario Royal Commission has broken new ground in relation to fibre dimension: *"What these observations all tend to indicate is that there is indeed an association between type of industrial process and fibre dimension, and because of this, there is accordingly an association between industrial process and disease. A consideration of fibre dimension thus serves to assist in explaining the differing disease incidence in various industrial cohorts and has served to assist in explaining the differing incidence at least in mesothelioma among asbestos workers exposed to different fibre types. In our judgement, a consideration of fibre dimension also serves to reconcile the otherwise conflicting animal and epidemiological evidence on fibre type"*[19].

The Commission goes on to say: *"... we conclude from all of this evidence that the pathogenicity of asbestos is primarily a function of fibre dimension. We also conclude that the amphiboles, and especially crocidolite, are more likely to be of hazardous dimensions than chrysotile. Moreover, the significance of fibre dimension in the pro-*

duction of disease has implications for fibre substitutes for asbestos. To the extent that man-made mineral fibres are long and thin in dimension, their use may also pose a health risk"[20].

Fibre chemistry and surface properties, the Commission states, *"have yet to be shown to be as important as fibre dimension in determining disease."* On the other hand, *"... the evidence which does exist... points to a similar conclusion as the evidence on fibre dimension: namely, that chrysotile tends to be less hazardous than the amphiboles"*[20]. Thus the Commission specifically concludes: *"The asbestos fibres which are most likely to cause adverse health effects when inhaled are long and thin. "Length" and "diameter" are, of course, relative phenomena: fibres are measured in microns, one micron being one-millionth of a metre. The hazardous asbestos fibres are those which would be longer than 5, perhaps longer than 8 microns, and thinner than 1.5 or perhaps 0.25 microns"*[22].

Importance of dose-response relationship

Merely establishing that a relationship exists between exposure and biological effect is not sufficient to understand the problem and to identify possible solutions. It is necessary first of all to measure the various degrees of exposure and their corresponding effects on health, and then to determine the nature of the relationship between these two factors, i.e. a dose-response relationship. Only then would it be possible to evaluate the degree of risk and to determine whether an absolutely safe threshold exists.

On this subject, the report of the Ontario Royal Commission on Asbestos states that the analysis of most epidemiological studies conducted on asbestos confirms the existence of a dose-response relationship for the main dis-

eases associated with these mineral fibres. Furthermore, extrapolations from high exposure levels in the past indicate that the increased risk of lung cancer for asbestos workers following 50 years exposure would be only 1 per cent for exposure levels varying from 0.04 f/cm^3 for textile workers, to 5fcm^3 for miners[23]. On the other hand, it should be noted that it is virtually impossible to measure the risk associated with low levels of exposure because of statistical uncertainty; consequently researchers must proceed by extrapolation to determine the theoretical risk from exposure to the low levels currently encountered. There now exists sufficient scientific evidence to confirm that, with the present controls in modern plants, except possibly in certain textile mills, any excess risk associated with chrysotile exposure at these low levels will be difficult or impossible to detect scientifically[24].

The threshold concept

The concept of a threshold implies that there exists a certain level of exposure below which exposure is absolutely safe as the body's defence mechanisms can cope with the applied dose or exposure. If this were so and if the threshold were known, it would be sufficient merely to limit exposure to below that level and no disease would result. Consequently, the existence of a threshold implies a level of exposure above zero at which there is absolutely no adverse health effect.

In the case of asbestos (and all carcinogens for that matter), the prudent approach has been to assume that any exposure involves some degree of risk as the assessment of disease risk at low levels of exposure is very uncertain. This uncertainty has also been interpreted as "the no safe level" concept: in order for the health effects and consequently the risk to be zero, exposure must be zero. In

other words, for there to be no asbestos-related diseases, there should be no asbestos. While seemingly logical, such a statement taken to its extreme loses sight of the fact that every activity in life entails some degree of risk.

Moreover, given the common occurence of these natural mineral fibres throughout much of the earth's crust, zero exposure to asbestos can never be achieved.

The concept of acceptable risk and establishment of a safe standard

The United States National Institute of Occupational Safety and Health defines what could be an acceptable risk as a measured level of exposure which involves a risk that is recognized and accepted by society. Accordingly, the *"acceptability of a risk depends upon a social value judgement made by the affected parties or by the legislature or by society as a whole"*[25]. In assessing the acceptability of a risk, the Ontario Royal Commission on Asbestos referred to a comparison with other workplace risks. In any such evaluation, it is essential to remember that "no human activity can be risk-free", as emphasized by the report of the Royal Society of the United Kingdom[26].

There are inescapable judgements that need to be made when assessing the acceptability of a workplace risk. Data from scientific studies can only establish a numerical risk, whereas the resulting decisions are based on a number of factors and need to be taken at the social and political levels. The factors recommended by the Ontario Royal Commission include a combination of relative risk, cost-benefit analysis and best technology.

With regard to best available technology and ongoing technological progress, every available means, both technical and regulatory, should be used in order to achieve

the lowest possible dust levels in the workplace and thus to minimize risk. Nevertheless, through rigorous regulation and stringent enforcement of the levels of chrysotile fibre in the workplace, the associated risks are low relative to other occupational factors and therefore acceptable[27].

Status of research

"Epidemiology is concerned with the study of the distribution and determinants of disease prevalence in humans"[28]. It is the science that allows the establishment of a cause and effect relationship between diseases and lifestyle factors, such as tobacco and alcohol consumption, and occupational factors, particularly those concerning exposure to toxic substances.

The most powerful analytical technique in epidemiological studies is the cohort study which consists of tracing the largest possible number of workers exposed to a particular hazard and analyzing the causes of death. The death rate per cause is then compared with the predicted death rate per cause for a control population standardized to take account of the death rates in specific age groups, etc. The first number (observed in the cohort) divided by the second (expected from the control) gives the standardized mortality rate or SMR.

A relatively new science, epidemiology has substantially improved its techniques and methods but, like all statistical sciences, it requires extensive resources and time to complete a study. Consequently, few powerful studies are available.

Concurrent with epidemiological studies, other research is being carried out to better define risks and to discover more effective methods of prevention. These projects fo-

cus essentially on the refinement of fibre measurement methods, and on fibre properties and their associated biological effects.

In addition, these investigations on asbestos are benefiting from advances made in the field of cancer research, particularly in regard to the mechanisms through which carcinogens affect cells. Once these mechanisms are better understood, it may be possible to define a threshold for biological and pathological response to mineral fibres.

Asbestos cement used in the construction of a residential complex.

Asbestos and the public

Given that because of its natural occurrence asbestos is present to some extent almost everywhere, it has been estimated that stopping all industrial activity associated with asbestos would result in little change in the number of fibres in the air or water on a global basis[29, 30].

Asbestos in the environment

It is estimated that during a normal lifetime, a person could inhale about 23 billion fibres of asbestos from the general environment. This ubiquitous presence of asbestos, as measured by electron microscopy, is also evident from autopsies performed on individuals never exposed to asbestos in the workplace and who did not reside in the proximity of any asbestos operation. In one such study, an analysis of pulmonary tissues in randomly selected subjects of routine autopsies revealed the presence of about one hundred asbestos fibres per gram of tissue[31]. Consequently, most residents of urban areas inhale and retain some asbestos fibres as a matter of course[32].

Several studies have been conducted to determine the relationship between asbestos fibres in the environment and the incidence of cancer.

One epidemiological study focussed on 1779 people not occupationally exposed, but living less than 1 km from an amosite plant in Paterson, New Jersey. The study concluded that this population did not exhibit any significant excess cancer risk[33].

Along similar lines, an ecological* study in Canada by J. Siemiatycki[34] was conducted on the female population in the mining towns of Asbestos and Thetford Mines,

* An ecological study is where exposure is assessed for populations rather than individuals.

Quebec. Before the introduction of strict control measures by the mining companies in the 1960s, the population studied had been exposed to concentrations of fibre sufficiently high that dust would accumulate on balconies and cars, necessitating its removal. Despite such high levels of exposure found in these asbestos mining towns, which undoubtedly represent some of the highest non-occupational exposures, the mortality rate (of the female population) was not significantly higher than for the whole of Quebec. Although a slight excess mortality from lung cancer could not be ruled out statistically, the female population studied in these two towns did not exhibit any overall excess mortality.

In 1984, Health and Welfare Canada published the results of an investigation into the possibility of health effects from the ingestion of asbestos in drinking water on the populations of 71 Canadian municipalities[35]. Samples of drinking water from each municipality were analyzed using a transmission electron microscope. All samples were found to contain some asbestos and 5 per cent of the samples contained approximately 10 million fibres of chrysotile per litre. Conclusions indicated that the death rate resulting from all types of cancer was not excessively high for people living in the two cities with the highest amounts of asbestos in the drinking water.

The Ontario Royal Commission on Asbestos came to a similar conclusion when it noted that there was *"no reason for public concern"* over the health effects of asbestos through ingestion. As a result, the Commission stated that it was not necessary to regulate the amount of asbestos in water, food or beverages as no significant increase in disease could be related to the ingestion of the fibres[36].

Safety of asbestos products currently on the market

With most products currently on the market, such as household electrical appliances, cement products and asbestos-reinforced plastics, the asbestos fibres are sealed within a matrix so that fibres cannot be emitted into the atmosphere under normal use.

A study conducted in Austria to determine the influence of weathering on the deterioration of asbestos cement and consequently fibre release, made a comparison of the concentration of asbestos in the ambient air in communities where the roofs were made of asbestos cement as compared to the concentrations in communities with no asbestos cement roofs. This study concluded that the average concentration of asbestos fibres in the ambient air of communities with asbestos cement roofs was still below the analytical detection limit of 0.1 fibres per litre[37].

In the United States, emissions of asbestos dust from automobile brake systems have been measured in numerous tests simulating actual average wear. Ninety such tests demonstrated that the release of asbestos in the form of fibrous asbestos dust represented only 0.3 per cent of the asbestos contained in the linings. Heat generated by braking transformed 99.7 per cent of the asbestos into particles of olivine and forsterite[38].

On the other hand, the use of loose asbestos such as in insulation applications, or lightly bound asbestos in products where the fibres can be easily released under normal use, has been discontinued or prohibited, because of the difficulties associated with dust control in such products and applications.

Asbestos insulation

Although certain applications such as sprayed-on asbestos have been discontinued, this material is still found in older buildings. When such buildings undergo renovation or are demolished, precautions must be taken to control and minimize dust and thus reduce the risk of exposure to workers and to the public[39].

Measurements of the concentration of fibres in the ambient air of such buildings has shown that the public has not been exposed to higher levels of asbestos except in a few special cases where the insulation was badly deteriorated or had been disturbed[40]. Moreover, the concerns over this form of asbestos insulation in schools have little scientific basis as measurements have shown that fibre levels were no higher inside these schools than in the ambient air outside. Fibre levels in ambient air are usually some 1000 to 10 000 times lower than the levels permitted under current occupational regulations[41].

After having reviewed a number of studies including two specifically prepared for the Ontario Royal Commission on Asbestos, the Commission concluded that asbestos insulation in buildings rarely gives rise to asbestos dust emissions and, where they do occur, the levels are generally no higher than in the ambient air outside.

The hypothetical cancer risk that such exposure places on the public is clearly minimal when compared to other risks faced in every day life. The Ontario Royal Commission calculated that even if fibre levels in a building were ten times those usually encountered in ambient air, the chances of developing a fatal cancer after 10 years exposure would

be *"less than 1/50 the risk that death would come from commuting ten miles (16 kms) by auto to and from that building daily for the same period"*[42].

On this basis, the Ontario Royal Commission concluded that there is no need to remove asbestos insulation when it is in good condition. On the other hand, if the insulation has been damaged the chances of dust emission are higher and in these situations, the Commission recommends that the insulation be sealed or removed, taking all the necessary precautions to protect the workers as well as the building occupants.

In the 1985 report by Doll and Peto for the U.K. Health and Safety Commission[43], the authors state that exposure (40 hours per week for 20 years) to the levels measured in asbestos insulated buildings in the U.K. would amount to a lifetime risk of one per 100 000. For comparison, the authors noted that non-smokers exposed to cigarette smoke for 7 hours per week run a lifetime cancer risk of 90 in 100 000.

In recent years, hundreds of millions of dollars have been spent in North America on removal of asbestos from buildings; however, in the Ontario Royal Commission's opinion, with a few exceptions, this work *"was not justified"* on the grounds of lowering the risk to occupants[44].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Responsibility of those involved in establishing an acceptable risk level

The role of scientists

The role of scientists in the debate on asbestos and health has been succinctly defined by Dr. Corbett McDonald when, in his testimony before the Ontario Royal Commission on Asbestos, he stated: *"...if you want a scientific estimate of risk, you measure the concentrations and you apply your dose-response relationships, and that tells you what you should expect. And there is no better scientific answer than that."*[45]

This statement recognizes that the prime responsibility of scientists is to assemble and analyze the medical, statistical and epidemiological data required to determine the effects of asbestos on health. As long as research cannot scientifically establish a level of exposure above zero for which there is no effect on health – that is, an absolutely safe threshold – scientists cannot be categorical on either the existence of such a threshold or on the safety of regulatory standards that are based on extrapolation of data. In other words, the role of the scientist is to provide the estimates of risk on which decision making is based.

Dr. Julian Peto at the World Symposium on Asbestos went on to say: *"A scientist is no better qualified than anyone else to decide whether a risk of 1 in 1000 or 1 in 10 is acceptable; his job is to determine whether the risk at a particular level is in fact 1 in 1000 or 1 in 10"*[46]. Moreover, as long as a broad scientific consensus is lacking on the quantitative relationship between risk and exposure, society will not have the necessary information to determine what direction to take in regulations, what working conditions should be adopted within the asbestos industry, or the need for substitutes.

Scientists play a paramount role, as compared to other groups involved in the asbestos issue. They are capable of assessing as objectively as is possible, the risks associated with asbestos; consequently, a concensus within the scientific community on this issue is essential for society.

Industry's position

Today, industry is aware that asbestos, like other raw materials if misused, can be hazardous to health. Consequently, it is the industry's responsibility to implement all available technical controls so that workers can handle asbestos safely and that the protection of the environment is ensured.

The increasingly stringent regulation of asbestos both in the workplace and in the general environment has led to the use of the best available technology for dust control in asbestos processing and product manufacturing operations. Indeed, dust control and working conditions approach the best in any industry today[47].

To the extent that measures are technically possible, operations and plants in the industry are striving to reduce dust levels even more. Given the current state of scientific evidence, the industry must look to society for guidance as to societally acceptable standards. Such was the origin of the 2 f/cm^3 standard adopted some years ago. More recent advances in technology and improved work practices have made a 1 f/cm^3 level attainable in most sectors of the industry.

The industry claims that asbestos should not be singled out, but viewed as one of many hazardous substances. At the World Symposium on Asbestos, Jean Dupéré stat-

ed industry's position concerning asbestos substitutes: *"...legislation and regulations worthy of a responsible, fair and equitable society must demand the same guarantees, impose the same rules and apply the same high standards to the production and use of mineral fibres, synthetic fibre and other substitute products, as to the production and use of asbestos."*[48]

The worker's position

At the international level, the trade union movement has yet to agree on a common position in the matter of the regulation of asbestos.

According to the assessment of risk followed by the major American and European worker federations, all exposure above zero entails a significant and unreasonable risk for workers. On this basis, these federations maintain that the use of asbestos should be banned. They advocate the mandatory replacement of asbestos by other materials, or a moratorium on the use of asbestos until such time as scientific data allow more precise assessment of the associated risks[49]. Conversely, equal attention is now being given to the potential risks from substitute fibres.

On the other hand, workers more directly involved in the asbestos industries have adopted a less extreme position and have moved closer to the industry perspective in the areas of dust control, medical surveillance, work practices in general, the withdrawal of dangerous products and applications, and the replacement of asbestos by substitutes offering equivalent technical performance that have been shown to be safe.

Concurrently, representatives of the labour movement are increasingly concerned over the health hazards of all

Implementation of safe work practices.

dusts, particularly those from silica, cotton, flax, lead, coal and other industrial materials, and have started to promote more controls and stringent regulations on the presence of all dusts in the workplace.

More generally, the labour movement considers one of the main problems to be the inconsistent enforcement and haphazard adherance to regulations and work practices. Consequently, workers are calling for greater vigilance on the part of government and the industry in this regard.

In this context, the International Labour Office in 1983 developed a Code of Practice on Safety in the Use of Asbestos which recommends the establishment and enforcement of very stringent control measures and work practices when dealing with asbestos[50].

The choice for governments

Given the divergence of opinions over the use of asbestos, and in the absence of a scientific consensus on quantifying the potential hazard or even on the existence of a safe exposure threshold, governments must still make decisions that are acceptable to all of society. Such decisions have to take into account all of the factors – health and safety, scientific, economic and political – regarding the use of asbestos. In terms of legislation, governments should also be aware of the indirect impact of a specific regulatory approach to comparable economic sectors. It is quite likely that most regulatory measures on asbestos will have considerable influence upon the approach adopted for controlling other hazardous materials.

In this context, it is apparent that only the systematic control of asbestos at all stages of its use can permit society to take full advantage of the technical and economic qualities of asbestos, while at the same time minimizing any potential risks.

Indeed, systematic controlled use of asbestos is favoured and has been endorsed by many international agencies such as the World Health Organization (WHO), the International Standards Organization (ISO), the United Nations Economic Council for Europe, the International Labour Office (ILO) and the Organization for Economic Cooperation and Development (OECD). This position has also been adopted by the Commission of the European Communities in its workplace directives on asbestos and it is the basis for Canada's approach to the regulation of asbestos.

Banning

An extreme option, banning, is advocated by those who maintain that as any asbestos exposure will pose some risk, conditions should be changed so that there can be no exposure and therefore no risk. Such a measure, if implemented, would have the sole effect of halting the commercial use of asbestos. It would not change the reality that naturally-occuring asbestos fibre is omni-present in the soil, water and air.

The banning option, in addition to imposing significant social and economic costs, would not bring about a zero-risk environment: *"Desireable though it may be in principle, the idea of totally eliminating risk is not attainable in the real world... Absolute freedom from risk is not obtained in other aspects of occupational health and safety. Accordingly, we do not believe that absolute freedom from risk is an appropriate criterion for asbestos fibre control. The appropriate criterion must include a weighing of relative risks..."*[51].

Should the principle of zero-risk become established in occupational and environmental regulations, it would have serious implications for society as it tries to regulate and control all the hazardous substances that are part of daily life.

Substitutes for asbestos

One option suggested as a solution to the asbestos 'problem' involves the progressive replacement of asbestos with materials or products considered less hazardous but offering similar technical advantages.

This route has been taken in the case of certain products such as friable insulation materials where normal handling

would generate unacceptably high and uncontrollable dust emissions. On the other hand, for most important asbestos applications, research to date has not been able either to demonstrate the harmlessness of substitute fibrous materials nor has it developed a "miracle fibre" technically equivalent to asbestos for its many applications.

Moreover, to have equivalent technical performance, mineral fibre substitutes must have fibrous natures and physical properties similar to asbestos. Synthetic fibres currently on the market have been designed to duplicate asbestos as closely as possible. Understandably, many may prove to have comparable biological effects but, unlike asbestos, in most instances they are neither controlled nor regulated and exposure risks are not known.

The biological effects reported in recent years from experimental studies show that most naturally-occurring and man-made fibrous materials, proposed as substitutes for asbestos, are biologically active.

Clearly, the evidence to date suggests the view that the replacement of asbestos, particularly by other fibrous materials, should not proceed without scientific evaluation of the "harmless" or "less harmful" biological nature of these alternatives. As noted by the Ontario Royal Commission: *"We consider it better to regulate a known hazard rigorously than to compel the use of substitutes whose hazardous nature, being unknown, is not subject to regulation to a similar degree of rigour"*[52].

Thus, the process of substitution which follows the philosophy of "if it is not asbestos it must be safer" is not in the interests of the health and safety of workers. If health and safety is the prime concern, the evidence suggests that the prudent approach is to control and regulate all respirable fibrous materials to the same degree as for asbestos.

The Canadian position: control of asbestos

As there is no certainty about the relevance of banning or of systematically replacing asbestos with substitutes, an approach has been developed that takes into account the question of health effects as well as the cost-benefit aspects of asbestos use. This approach calls for the controlled use of asbestos, a solution that appears to meet with the approval of the large majority of those involved.

In 1981, the Canadian government adopted a position* on asbestos that was agreed to in principle by all the provinces of Canada. This position recommends the systematic control and implementation of safety measures for all aspects of asbestos use. These recommendations, which permit the continued use of asbestos without excessive risk, could be a model for all fibre producers and users. Indeed, the standardization of regulations for asbestos, as for other materials considered hazardous when improperly used, is the only way to ensure equal safety for all, everywhere.

*See following chapter for text.

Current approach to the regulation of asbestos in Canada

Asbestos is a useful industrial material having many important and essential applications. Asbestos is the collective term for naturally ocurring mineral silicate fibres of the serpentine and amphibole groups. For practical purposes the types of fibre that are most important are chrysotile of the serpentine group, and crocidolite and amosite of the amphibole group. Chrysotile, the variety commercially produced in Canada, accounts for over 90 per cent of all asbestos mined.

Exposure to airborne asbestos dust is recognized as a hazard to health: pulmonary fibrosis (asbestosis), malignancies of the lung and possibly of the gastrointestinal tract, and mesothelioma are effects that can result from asbestos dust inhalation. The risk of developing asbestos-related diseases is dependent upon the concentration of fibres in the inhaled air, the duration of exposure and the type of fibres. Crocidolite, amosite, or chrysotile dust exposure can cause lung cancer and the risk is greatly increased by cigarette smoking. Crocidolite and amosite have been reported to be associated with mesothelioma more frequently than chrysotile, thus suggesting that the risk of mesothelioma after exposure to crocidolite and amosite may be higher.

As knowledge has increased about the health hazard posed by astestos dust, concern has risen in business and government to protect workers and the public. Manufacturing equipment and techniques have been developed that can radically decrease the degree of contamination of the atmosphere in mine, mill and factory. More precise sampling and measuring procedures are being developed for routinely monitoring the concentration of asbestos fibres in the atmosphere.

Occupational health

Existing Canadian regulations concerned with occupational exposure to asbestos dust require that atmospheric contamination within the work place be limited to a time-weighted average of 2† fibres or less per cubic centimetre (f/cm^3)* of air.

Some jurisdictions have, or are planning, more stringent controls on amphiboles than for chrysotile and indeed the use of crocidolite has been banned by regulatory authorities in some provinces. When appropriate, regulations are revised in the light of new knowledge.

The 2† f/cm^3 occupational standard was adopted to protect workers from asbestosis and is based upon the acceptance of a minimal risk of developing this disease. Dose-response relationships at such a level of exposure have not been sufficiently established to enable the assessment of risk of development of cancers. It is expected, however, that the lower the level of exposure, the less the risk of developing cancer. Regulations concerned with occupational exposure to asbestos should require the use of the best available control technology in equipment and work practices.

Environmental control

The asbestos dust level in the general environment is so much lower than in occupational settings that there appears to be little or no risk to the public. However, in com-

† Health and Welfare Canada has recommended that this limit be lowered to 1 f/cm^3.

* Fibres counted are those greater than 5 μm in length.

parison to the general environment, somewhat elevated levels of exposure to asbestos dust may occur in the neighbourhood of industries emitting asbestos, and during the utilization or disposal of certain materials containing asbestos.

Federal regulations require that air that is exhausted from asbestos mines and mills to the environment should not contain more than 2 f/cm^3 at the point of emission. It is intended that these regulations will be extended to manufacturing industries.

Canadian authorities are working with the asbestos mining, manufacturing and related industries as well as municipal authorities to achieve better control on the disposal of wastes containing asbestos.

In the past, sprayed asbestos fibre has been used for fireproofing and other purposes, and subsequently has been found to release fibres to the atmosphere. This practice is no longer used in Canada.

There is no evidence currently available to suggest that there is any risk from the consumption of food and drink that may adventitiously contain asbestos. In the case of water supply for human consumption, it has been found that minute concentrations of asbestos have long existed in some localities, but studies to date have not found excess mortality count from diseases related to asbestos fibres in the drinking water of those districts.

In general the greatest concern about the health effects of asbestos has been, and still is, posed by airborne concentrations of asbestos fibres in the workplace.

Consumer products

Human exposure to asbestos dust as a result of consumer product use by the general public appears generally to be very low. Canadian government regulation of asbestos-containing products has therefore been directed at controlling exceptional cases where a potential hazard has been found to be present: in wearing apparel, certain products used by children, drywall joint cements, wall-patching compounds and artificial decorative ash (for fireplaces). It is planned to prevent the sale to other than industrial users of free asbestos fibre and dry powder products that contain it.

Although Canadian fibre producers are currently using warning labels, it is planned that such labels on packaging for asbestos fibre will be made mandatory. If appropriate, such labels will be extended to some manufactured products containing asbestos offered for sale to the public, in particular those that may emit fibres during installation.

Further research will be undertaken in Canada on existing products to determine the degree of fibre emission associated with installation and wear; products that cannot be used safely will have to be improved or withdrawn from commerce.

Substitutes

Because of the unique properties of asbestos, this material has found wide application in industrial as well as consumer usage. It is recognized that in some instances no suitable substitutes for asbestos are available at this time.

Canada recognizes that in some applications other less hazardous materials can be used in place of asbestos to achieve the same results. Canada also recognizes that substitutes for asbestos fibre in certain applications may pose risk to the health of workers and the public. A research program should be encouraged to establish their relative safety.

Transportation

Handling and transportation of packages of free asbestos fibre are potentially hazardous activities, but the hazard can be minimized through appropriate practice and regulation. Proposed Canadian legislation follows generally the United Nations' recommendations for the transport of dangerous goods. Similar requirements have been adopted by the U.S. Department of Transport and are being proposed by the International Maritime Consultative Organization.

Summary

In conclusion, workers and the public in general can be protected from the risks associated with asbestos dust exposure through suitable product design as well as enforcement of appropriate regulations on occupational health, environmental control, sale and use of products, handling and transportation of asbestos.

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