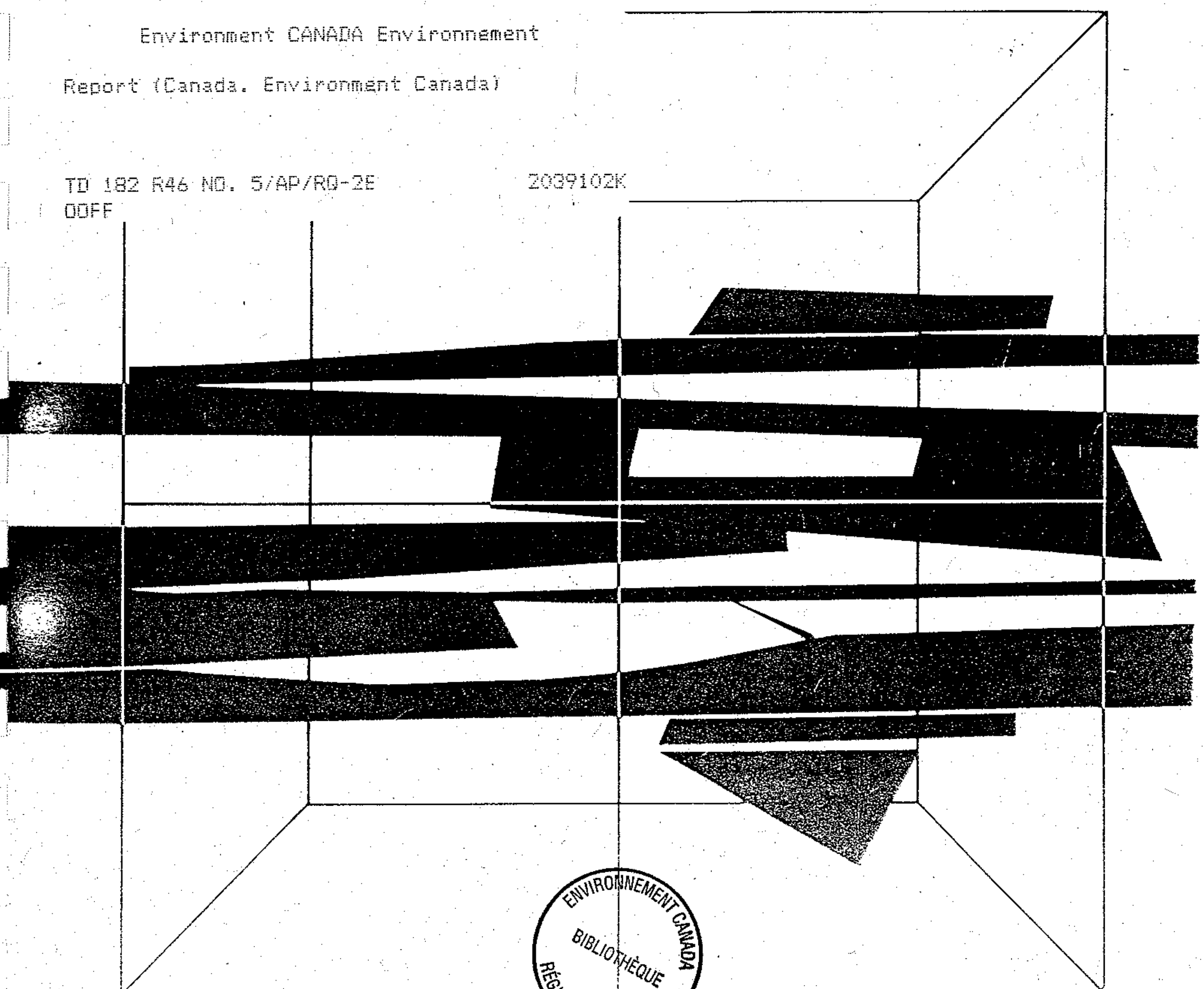
Ambient Air Asbestos Survey in Québec Mining Towns Part 2 — Main Study

Report EPS 5/AP/RQ-2E



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AMBIENT AIR ASBESTOS SURVEY IN QUÉBEC MINING TOWNS PART 2 - MAIN STUDY

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ABSTRACT

In 1984, asbestos air pollution levels were monitored continuously for 12 successive four-week periods in Asbestos (2 sites), Thetford-Mines (3 sites) and Black-Lake (2 sites) in the asbestos-mining region of Québec. These sites were located in the centre of each mining town - usually on the roof of a school. By way of comparison, the same types of samples were taken at a site in Montreal and at another site in a rural area (St. Etienne).

The four-week samples were collected on a membrane filter (Millipore®, surface area 400 cm^2, pore size 0.45 μm) with a "Connecticut Lo-Vol" air sampling instrument, operating at a flow rate of 110 l/min. and filtering approximately 5,000 m^3 of air through each membrane.

Only the concentrations of asbestos particles longer than 5 microns were measured by analytical transmission electron microscopy (ATEM). The type of asbestos and the shape and size distributions of the particules were also determined. The filters were prepared for microscopy by a method referred to as the "indirect method", involving low temperature ashing of part of the filter, ultrasonic treatment of the ash and transfer to electron microscope grids. This protocol was developed during a preliminary methodological study (Report EPS-3/AP/RQ-1E).

The mean levels for Montreal/St. Etienne, Asbestos, Thetford-Mines and Black-Lake were respectively 0.9, 52.5, 73.7 and 188.7 asbestos particles/litre. A significant seasonal effect was noted in the mining region where the levels increased in the spring and fall. These two peaks can be partially explained by weather conditions and the activities of the mining companies. No such seasonal effect was noted for Montreal or St. Etienne.

The vast majority of the asbestos particles encountered were of the chrysotile variety, but some tremolite fibres were also found in the mining region, especially in Thetford-Mines. The asbestos particles measured were between 5 and 20 microns long. In Montreal and St. Etienne, only individual chrysotile fibres were present. In the mining region, 13.5 % of the chrysotile particles were in bundles or aggregates of fibres, and 14.1 % of the asbestos particles were of such dimensions that they could have been visible with the phase-contrast optical microscope. The average concentration of optically visible fibres was 0.026 fibres/cm^3 in Black Lake, 0.010 fibres/cm^3 in Thetford Mines and 0.007 fibres/cm^3 in Asbestos.

In our view, this is the first study which attempts to systematically mesure

asbestos pollution levels near mines and mills. The measured levels were distinctly higher than the urban background pollution level.

RÉSUMÉ

Durant l'année 1984, dans la région des mines d'amiante du Québec, les niveaux de pollution atmosphérique par l'amiante ont été mesurés en continu pendant 12 périodes successives de 4 semaines, à Asbestos (2 emplacements), Thetford-Mines (3 emplacements) et Black-Lake (2 emplacements). Ces points d'échantillonnage se trouvaient au coeur des villes minières, le plus souvent sur le toit des écoles. À des fins de comparaison, les mêmes types de prélèvements ont été réalisés à un endroit à Montréal et à un autre dans une région rurale (Saint-Étienne).

Les prélèvements effectués pendant 4 semaines ont été réalisés sur une membrane filtrante (Millipore® de 400 cm^2 avec mailles de 0,45 µm) avec un échantillonneur de type "Connecticut Lo-Vol", opérant à 110 l/mn et collectant environ 5000 m^3 d'air sur chaque membrane.

Seules les concentrations des particules d'amiante plus longues que 5 microns ont été mesurées par microscopie électronique à transmission. Le type d'amiante ainsi que les distributions morphologiques et granulométriques des particules ont également été déterminés. Les membranes ont été préparées pour l'observation microscopique par une méthode dite "indirecte", comprenant l'incinération d'une partie de la membrane et le traitement des cendres aux ultrasons avant leur montage sur grilles. Ce protocole a été mis au point lors d'une étude méthodologique préliminaire (rapport SPE 3/AP/RQ-1F).

Les niveaux moyens s'élevaient à 0,9 part. d'amiante par litre pour Montréal-Saint-Étienne, 52,5 part. d'amiante par litre pour Asbestos, 73,7 part. d'amiante par litre pour Thetford-Mines et 188,7 part. d'amiante par litre pour Black-Lake. Un effet saisonnier important a été décelé dans la région minière, avec deux pics au printemps et en automne. Les variations des conditions météorologiques et de l'activité des compagnies minières permettent en partie d'expliquer ces deux pics. À Montréal et Saint-Étienne, un tel effet saisonnier n'a pu être observé.

La grande majorité des particules d'amiante recontrées était constituée de chrysotile, mais des fibres de trémolite ont également été trouvées dans la région minière, notamment à Thetford Mines. La longueur des particules d'amiante mesurées se situait entre 5 et 20 microns. À Montréal et Saint-Étienne, seules des fibres individualisées de chrysotile étaient présentes. Dans la région minière, 13,5 p. 100 des particules de chrysotile avaient la forme de faisceaux ou d'agrégats de fibres, et 14,1 p. 100 des particules avaient des dimensions suffisantes pour être visibles en microscopie optique de

contraste de phase. Les concentrations moyennes de fibres visibles sous le microscope optique équivalaient à 0,026 fibre par cm^3 à Black Lake, 0,010 fibres/cm^3 à Thetford Mines et 0,007 fibres/cm^3 à Asbestos.

Cette étude constitue, à notre avis, la première tentative de mesure systématique de la pollution par l'amiante au voisinage des mines et moulins. Les teneurs mesurées sont nettement plus élevées que la pollution de fond urbaine.

TABLE OF CONTENTS

		Page
ACKNOWLEDGEMENTS		IV
ABSTRACT		V
RÉSUMÉ		VII
LISTE OF FIGURES		X
LISTE OF TABLES		XI
1	INTRODUCTION	1
2	SAMPLING PROGRAM	4
3	SELECTION OF AN ANALYTICAL METHOD	15
4	ANALYSIS OF ASBESTOS CONTENT OF MEMBRANE FILTERS	20
5	RESULTS	23
5.1	Chrysotile Concentrations	23
5.2	Size and Shape Distribution of Chrysotile Particles	28
5.3	Tremolite Fibre Concentrations	35
5.4	Total Suspended Particulate Matter	35
6	DISCUSSION	39
6.1	Methodological Aspects	39
6.2	Characteristics of Pollution in Regions Studied	39
6.3	Other Studies on the Subject	40
6.4	Health Implications of Environmental Exposure to Asbestos	42
7	CONCLUSIONS	44
References		47

LIST OF FIGURES

		Page
Figure 1	Evolution of U.S. consumption and Canadian exports of asbestos	2
Figure 2	Eastern Townships	5
Figure 3	Location of sites 722, 723, 725, 732 and 736 in Thetford-Mines and Black-Lake	6
Figure 4	Location of sites 706 and 709 in Asbestos	7
Figure 5	The 3 sites in Thetford-Mines	10
Figure 6	The 2 sites in Black-Lake	11
Figure 7	The 2 sites in Asbestos	12
Figure 8	Connecticut Lo-Vol sampler and accessories	13
Figure 9	Transmission electron microscopic analysis of particles sampled on Millipore® membrane filter. Stages in the preparation of grids by direct and indirect methods	16
Figure 10	Preliminary methodological study	18
Figure 11	Granulometric matrix used to distribute dimensions	21
Figure 12	Seasonal variations in asbestos air pollution	30
Figure 13	Examples of seasonal variations in mining town region	31
Figure 14	Size distribution of fibres, bundles and aggregates	33
Figure 15	Mining town sites classified by chrysotile and total dust concentrations	38

LIST OF TABLES

		Page
Table 1	Regulatory articles aimed at controlling ambient asbestos (USA)	3
Table 2	Address, elevation and location of the 9 sampling sites	8
Table 3	Dates (month, day) from beginning to end of the 12 sampling periods in 1984	14
Table 4	Volumes (m^3) of air filtered through each membrane	24
Table 5	Chrysotile concentrations by periods and sites	25
Table 6	Chrysotile concentrations - Annual means by site and region	26
Table 7	Chrysotile concentrations - Means by period for all mining region sites	27
Table 8	Meteorological data	29
Table 9	Size and shape distribution of chrysotile particles - Size categories for all mining region sites	32
Table 10	Mean percentages of chrysotile particles classified as bundles or aggregates, by sampling period	32
Table 11	Mean concentrations of total suspended particulate matter by period and site	34
Table 12	Mean concentrations of total suspended particulate matter per period for all mining region sites	36
Table 13	Annual concentrations of total suspended particulate matter	37
Table 14	Recommended air quality standards for asbestos	45

1 INTRODUCTION

Since 1979, asbestos consumption has decreased considerably - especially in Europe and the United States. However, asbestos producers have found other markets elsewhere. During the past three years, asbestos consumption has stabilized in Western countries at 2 million tons, 40 % of which comes from Canada (Figure 1). In 1984, the world production of asbestos was around 4 millions tons.

In 1979, the World Health Organization placed asbestos in the first group of the 14 chemical substances with demonstrated carcinogenic properties (1). In the industrialized countries, regulations have been drawn up to control the occupational exposures. These regulations generally set standards for exposure, provide for medical supervision of workers, and prohibit certain applications. Although considerable research has been carried out in this field, asbestos is still a subject of concern because of the scientific community's uncertainty about the required degree of protection against exposure, technical difficulties involved in measuring airborne asbestos concentrations, problems in setting up control programs and the heritage of uncontrolled exposures in the past (2, 3).

Over the past ten years the asbestos problem has extended from the workplace to the general environment. In major urban centres, there is a measurable background level of asbestos pollution. Although this level is generally low and uniform (4), some areas may show higher concentrations (5). The three typical areas most likely to be polluted by asbestos are the areas close to asbestos industries (6), the homes of asbestos workers (7), buildings insulated with asbestos (8). There are three main sources of asbestos in the environment: asbestos mines and factories, from which emissions are intense but localized and controllable; asbestos products, the use and degradation of which yield emissions that are probably less intense but more difficult to control because they are more numerous and widely dispersed; and naturally occurring asbestos deposits (9). To limit emission of asbestos into the ambient air, the United States began introducing a comprehensive legislation program (Table 1) in 1971.

In 1983, Environment Canada decided to proceed with a systematic study of ambient asbestos concentrations in the mining towns of Thetford-Mines, Black-Lake and Asbestos. Few data were available on the subject until then: only 21 short-term samplings have been analysed by Dr. Graham Gibbs and his team in 1980; the levels obtained for asbestos were between 170 and 11,000 ng/m^3 (17). The objective of the new study was to mesure the asbestos pollution levels over a complete year (1984) at seven sites in mining towns and at two control sites, one in Montreal and the other in a rural area (St. Etienne).

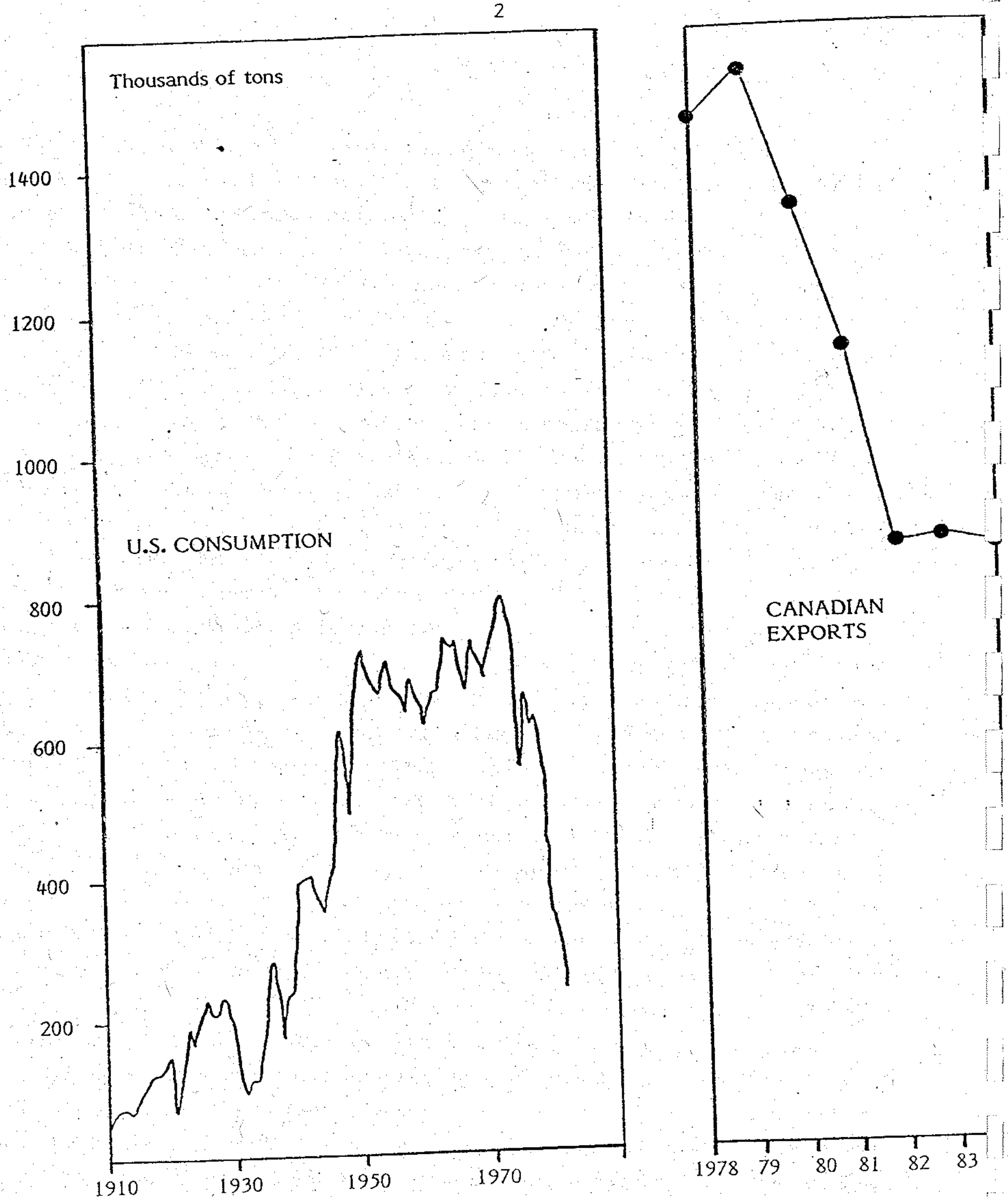


Figure 1
Evolution of U.S. consumption and Canadian exports of asbestos

The fact that epidemiological research had already been done on the residents of the mining towns constituted another interest for the project (12-15). Thus, the measurements results on pollution levels could be integrated into a larger context with inference on dose-effect relationship at low asbestos-exposure levels.

TABLE 1 REGULATORY ARTICLES AIMED AT CONTROLLING AMBIENT ASBESTOS (from US Federal Register, since 1971)

	Number of rules and regulations
ENVIRONMENTAL PROTECTION AGENCY	
Clean Air Act	12
Federal Water Pollution Control Act	8
Toxic Substances Control Act	20
CONSUMER PRODUCT SAFETY COMMISSION	
Consumer Product Safety Act	10
DEPARTMENT OF TRANSPORTATION	
Hazardous Materials Transportation Act	4
FOOD AND DRUG ADMINISTRATION	
Federal Food, Drug, and Cosmetic Act	7
Total	61

2 SAMPLING PROGRAM

Figure 2 is a map of the Eastern Townships showing the location of the mining towns of Thetford-Mines, Black-Lake and Asbestos. Thetford-Mines and Black-Lake are part of the same mining complex (Figure 3), but Asbestos is located about 180 km further southwest (Figure 4). Environnement Québec has been operating a sampling network in the mining regions since 1974. Its purpose is to monitor total suspended particulate matter and dust-fall (31). A Connecticut Lo-Vol sampler was installed at each of the seven sites in the network. The reference numbers, elevations, addresses and locations of the sites are indicated in Table 2 (including two reference sites). The relation of these sites to potential emission sources can be seen in Figures 3 and 4. The two sites in Asbestos (No. 706, 709) were located east of the Jeffrey open-pit mine; one was on the roof of a community centre and the other one was on the roof of a school. Two of the three sites in Thetford-Mines (No. 722, 723, 725) were located on the roof of schools, one of which, i.e. No. 723, St. Noel School, was the furthest away from the pollution sources. In Black-Lake, St. Louis School (No. 732) and the Post Office (No. 736) were selected, being respectively 1 and 2 km from Société Asbestos Ltée tailing dump. Except for site No. 725 (skating rink on Notre-Dame St. in Thetford-Mines), all the sites were located in the centre of the mining towns - usually on the roof of public buildings or schools. Figures 5 to 7 show photographs of the seven sites.

Two control sites were selected: one in Montreal in the St. James Market, Ontario St. E., and the other one in a rural area in St. Etienne (Table 2).

A Connecticut Lo-Vol sampler (32) was installed at each site (Figure 8). The air enters the Connecticut Lo-Vol Sampler through the rectangular space between the upper part of the metal frame and the roof. The frame protects the upper rectangular compartment, which contains the membrane filter (Millipore®, surface area 400 cm^2, pore size 0.45 µm). A rotary vane pump is operating at a flow rate of 110 l/min., which is controlled by an orifice. A temperature compensating gas meter records the volume of the air sampled. Since the gas meter is located on the pumping line between the pump and the membrane filter, it operates under negative pressure. However, laboratory tests showed that the readings would not be affected. Each Connecticut Lo-Vol was equipped with an exhaust system to eject the filtered air at a distance so as to prevent "turnover" which would lead to an underestimation of pollution levels. With this sampler it is possible to collect an accumulated sample on the same Millipore® membrane filter over one-month period. This sampler had been recommended by Dr. Graham Gibbs and his

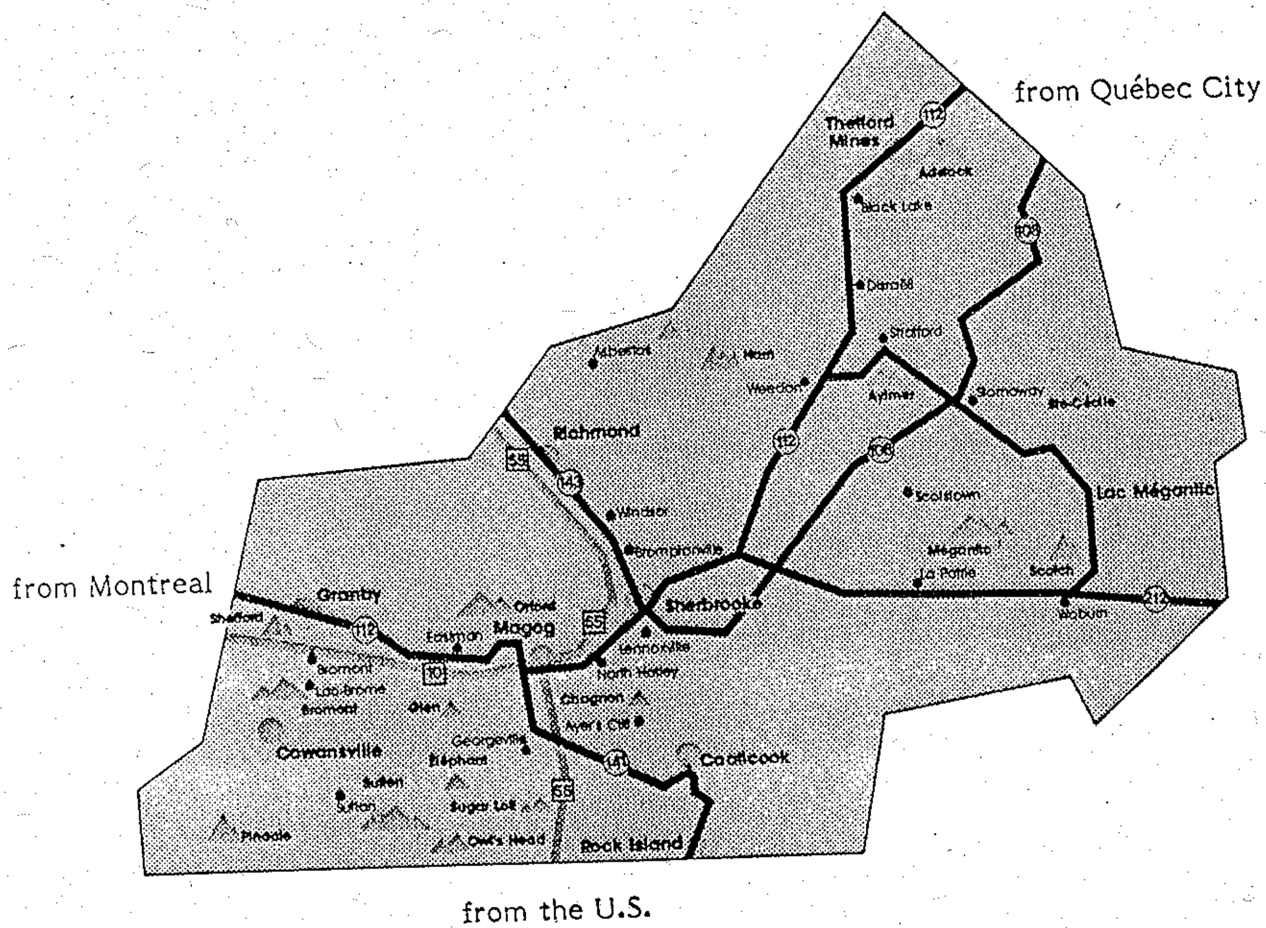
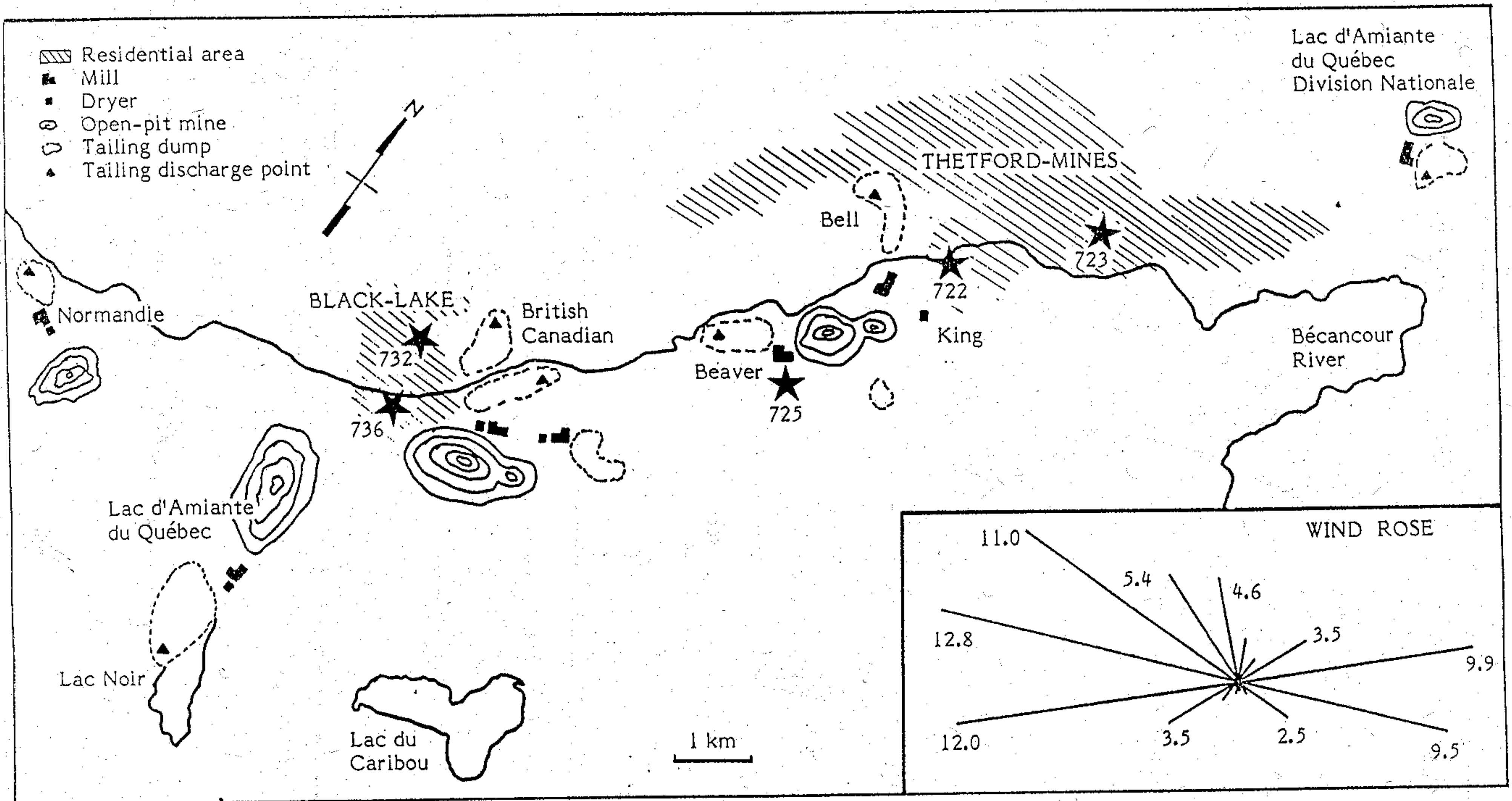
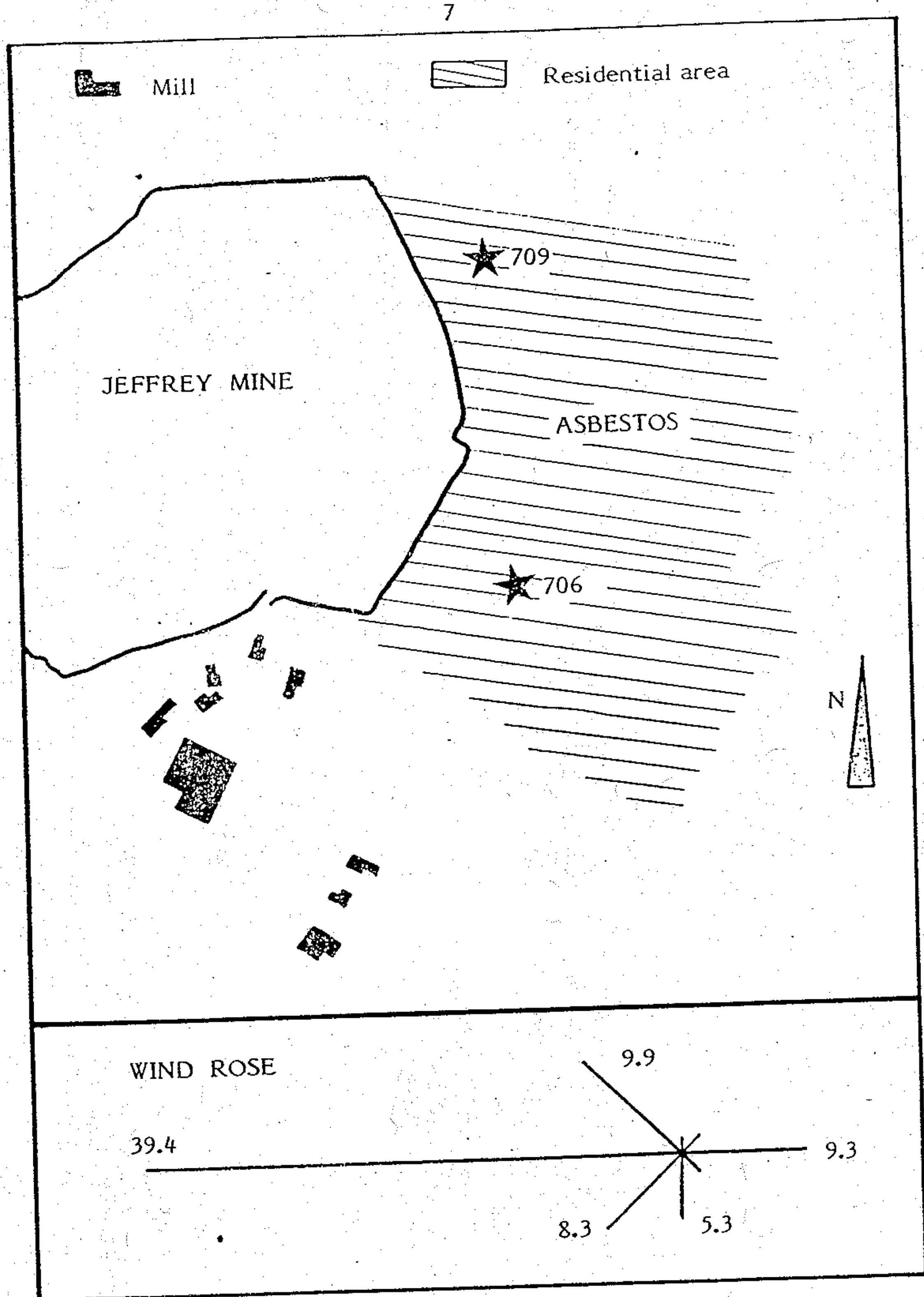


Figure 2
Eastern Townships



The average frequency (%) of wind directions during the period of the study is shown on the wind rose. The average wind speed (10 km/hr.) varied little with the direction.

Figure 3
Location of sites 722, 723, 725, 732 and 736 in Thetford-Mines and Black-Lake



The wind rose indicates the average frequency of wind direction in 1984.

Figure 4
Location of sites 706 and 709 in Asbestos

TABLE 2 ADDRESS, ELEVATION AND LOCATION OF 9 SAMPLING STATIONS

Station number and elevation	Location
ST. ETIENNE	
No. 000 (4 m)*	135 Dupuis St.
MONTREAL	
No. 012* (13 m)	St.James Market, 1125 Ontario St. E.
ASBESTOS	
No. 706 (8 m)*	Community Centre, Olivier Blvd. - 0.35 km southeast of Jeffrey open pit - 1.00 km northeast of mill No. 5 - 1.25 km northeast of mill No. 6
No. 709 (5 m)*	Sacré-Coeur School, Saint-Luc Blvd. - 0.35 km east of Jeffrey open pit - 1.90 km northeast of mill No. 5 - 2.15 km north of mill No. 5
THETFORD-MINES	
No. 722 (10 m)*	Trade School, Fabrique St. - 6.25 km southwest of Lac d'amiante du Québec, National Division - 0.75 km northwest of Bell mill - 1.6 km southwest of Bell waste dump - 1.6 km north of Beaver mine - 1.0 km north of King mine
No. 723 (22 m)*	St-Noel School, 8th Avenue. - 4.4 km west of Lac d'Amiante du Québec - 2.8 km east of Bell mill - 3.25 km southeast of Bell tailing dump - 2.8 km northwest of King mine - 4.6 km northwest of Beaver mine
No. 725 (7 m)*	Notre Dame St. skating rink. - 0.5 km south of Beaver mine - 2.5 km northwest of British Canadian No. 2 tailing dump - 3.0 km northwest of British Canadian No. 2 mill
BLACK-LAKE	
No. 732 (9 m)*	St-Louis School, St-Louis St. - 1.0 km west of British Canadian No. 1 tailing dump - 2.5 km southeast of British Canadian No. 1 mill - 5.0 km east of Normandie - 4.0 km north of Lac d'Amiante du Québec

TABLE 2 ADDRESS, ELEVATION AND LOCATION OF 9 SAMPLING STATION (cont'd)

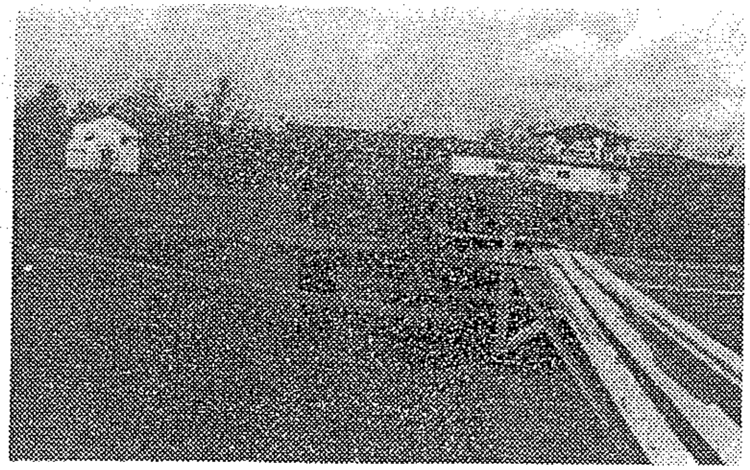
Station number and elevation	Location
No. 736 (4 m)*	Post Office, Port St. - 2.0 km south of British Canadian No. 1 tailing dump - 1.25 km west of British Canadian No. 1 mill - 3.0 km northwest of British Canadian No. 2 tailing dump - 2.5 km northwest of British Canadian No. 2 mill - 5.3 km east of Normandie - 4.5 km north of Lac d'Amiante du Québec tailing dump - 3.0 km north of Lac d'Amiante du Québec mill

* The elevations in metres are indicated under the site numbers.

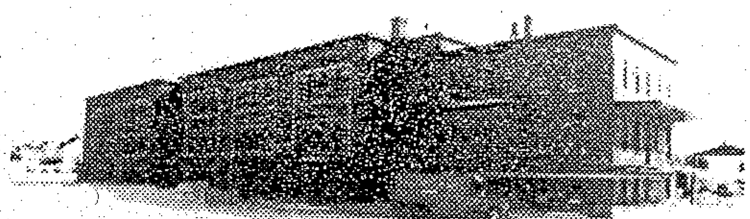
team following a pilot methodological study (19). It has the double advantage of long te sampling and of reducing the number of membrane filters to be analysed.

Continuous sampling was carried out at each site for 12 successive four-we periods from January 17 to December 19, 1984. The membrane filters were replaced the end of each of the periods on the dates indicated in Table 3; about 5,000 m^3 of ai (from 4,504 to 5,792 m^3) was passed through each membrane filter. At times installation and recovery of the membrane, the flow rate was measured with a rotamete and the pumping line was checked for any leakage with a Magnehelic® gauge. In all, or 8 membranes were defective and could not be analysed. For each of the 12 periods, a blank membrane filter was transported in its cassette but was not inserted into a sample

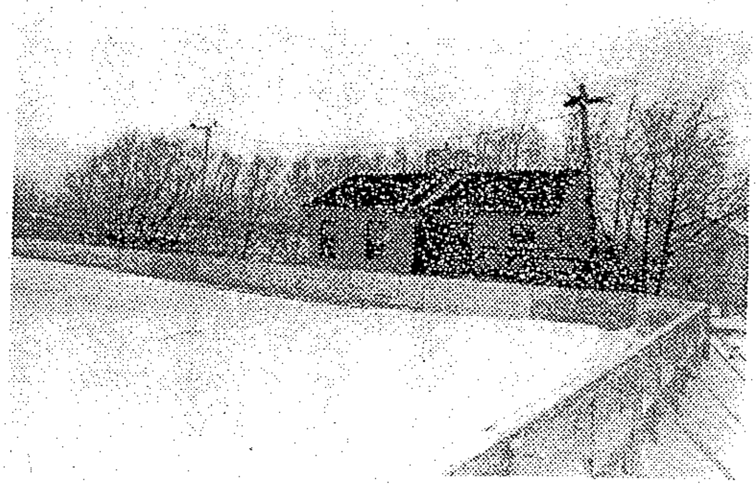
Environnement Québec continued to operate its sampling network throughou the study. It was possible to obtain data on total suspended particulate matter for all t sites except No. 000 in St. Etienne. Total suspended particulate matter was collected high-volume samplers, operating 24 hours every six days. Dust-fall gauges were als installed at all sites except Montreal and St. Etienne. Meteorological data includi minimum and maximum temperatures, height and duration of precipitation, ground snow and wind speed and direction, were recorded at Thetford-Mines and Asbestos. Wind ros for the Thetford-Mines and Asbestos regions are shown in Figures 3 and 4. Arithmetic means were calculated for ground snow, wind speed and total precipitation for each of t 12 periods of the study.



722 Trade School



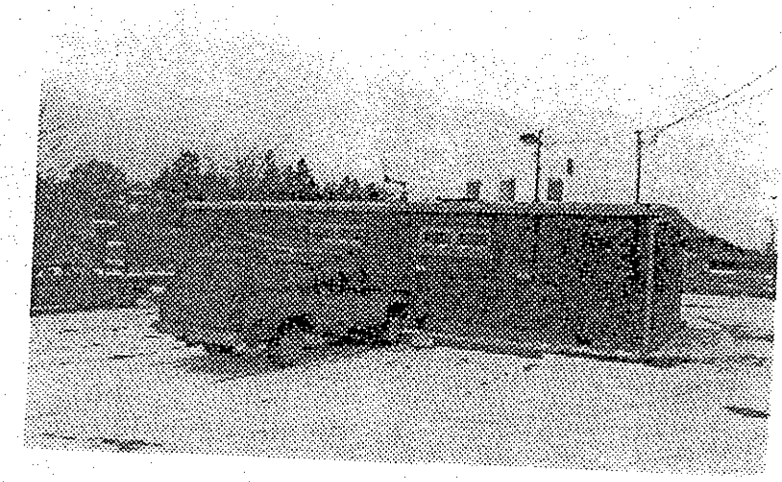
723 St. Noel School



725 Skating rink

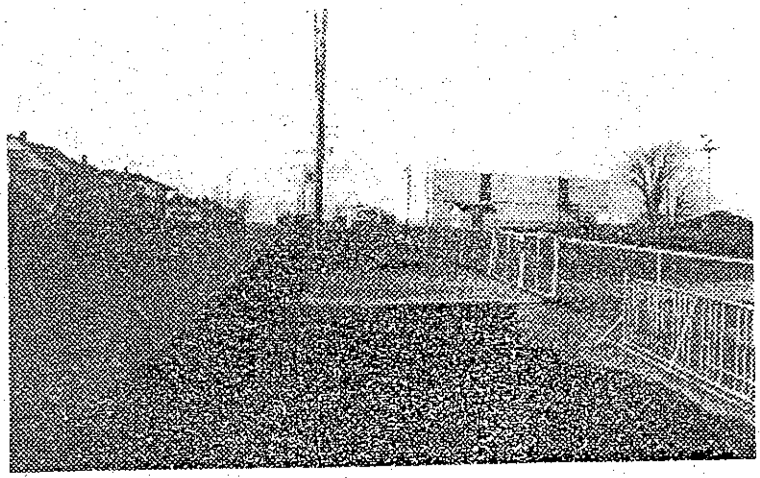
Figure 5
The 3 sites in Thetford-Mines

732 St. Louis School

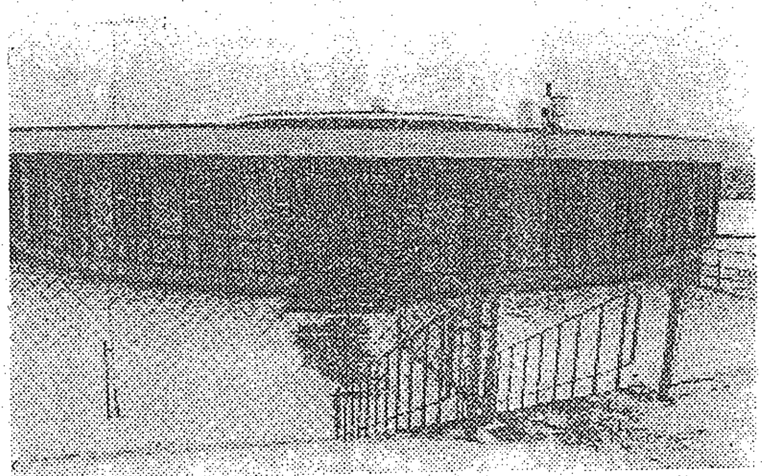


736 Post Office

Figure 6
The 2 sites in Black-Lake

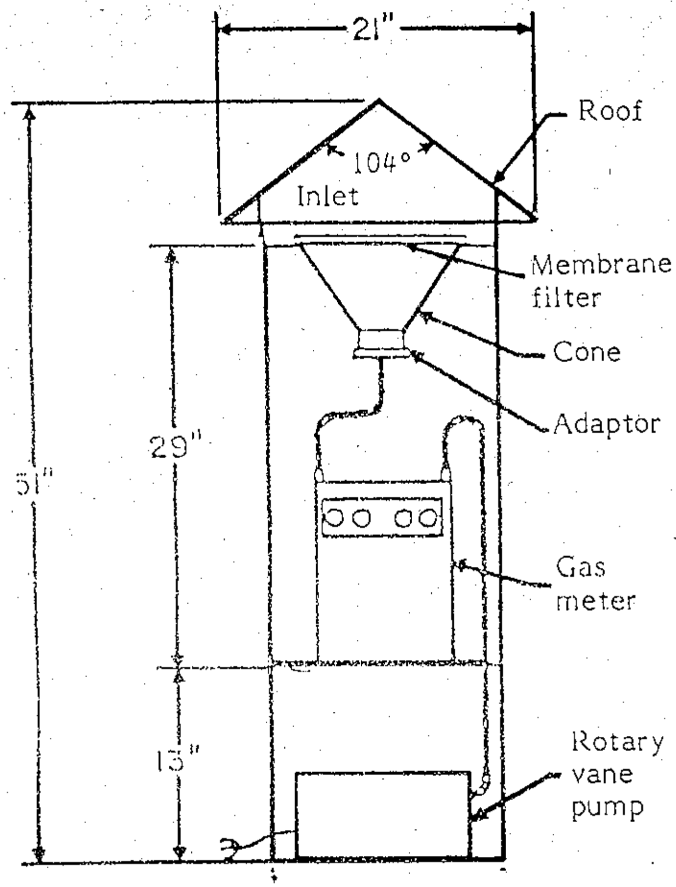


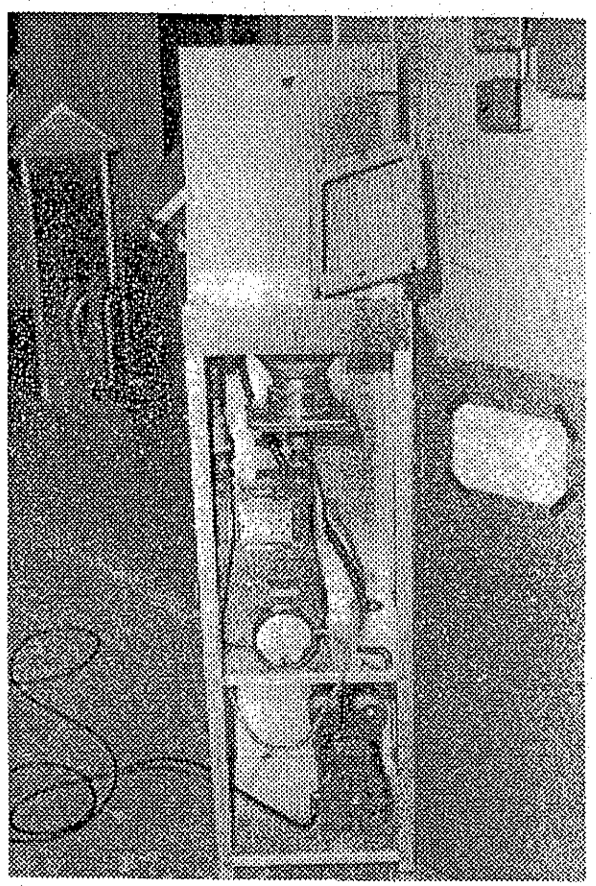
706 Community Centre



709 Sacré-Coeur School

Figure 7
The 2 sites in Asbestos





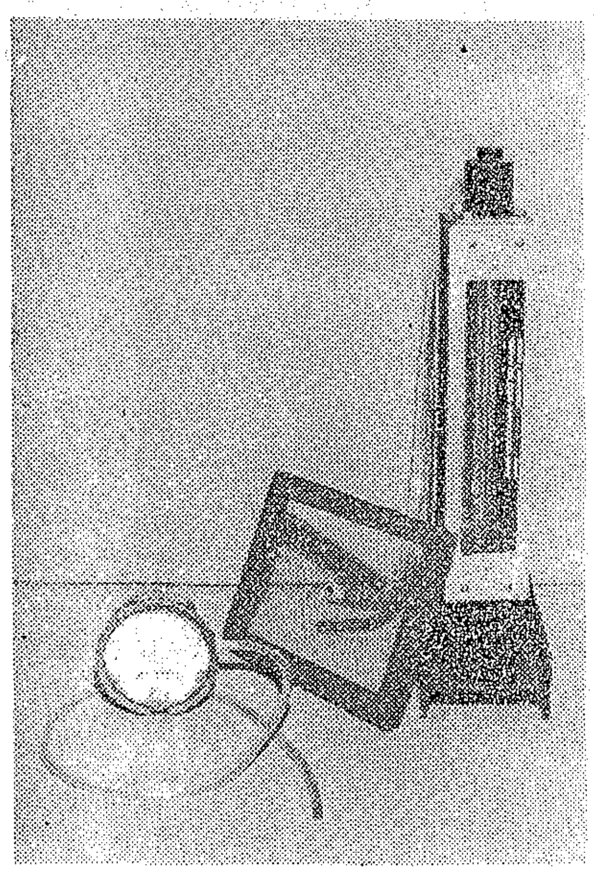


Figure 8
Connecticut Lo-Vol sampler and accessories
(Magnehelic® gauge, flowmeter)

TABLE 3 DATES (MONTH, DAY) FROM BEGINNING TO END OF THE 12 SAMPLING PERIODS IN 1984

Station No.	Period 1	2	3	4	5	6	7	8	9	10	11	12
000 (St. Etienne)	01-30 02-13	02-13 03-12	03-12 04-09	04-09 05-07	05-07 06-04	06-04 07-03	07-03 07-30	07-30 08-27	08-27 09-24	incident	10-22 11-19	11-19 12-17
012 (Montreal)	01-30 02-13	02-13 03-12	03-12 04-09	04-09 05-07	05-07 06-04	06-04 07-03	07-03 07-30	07-30 08-27	08-27 09-24	09-24 10-22	10-22 11-19	11-19 12-17
706 (Asbestos)	01-31 02-14	02-14 03-13	03-13 04-10	04-10 05-08	05-08 06-05	06-05 07-04	07-04 07-31	07-31 08-28	08-28 09-25	09-25 10-23	10-23 11-20	11-20 12-18
709 (Asbestos)	01-17 02-15	02-14 03-13	03-13 04-10	04-10 05-08	05-08 06-05	06-05 07-04	07-04 07-31	07-31 08-28	08-28 09-25	09-25 10-23	10-23 11-20	11-20 12-18
722 (Thetford-Mines)	01-18 02-15	02-15 03-14	03-14 04-11	04-11 05-09	05-09 06-06	06-06 07-05	07-05 08-01	08-01 08-29	08-29 09-26	09-26 10-24	10-24 11-21	11-21 12-19
723 (Thetford-Mines)	01-18 02-15	02-15 03-14	03-14 04-11	04-11 05-09	05-09 06-06	06-06 07-05	07-05 08-01	08-01 08-29	08-29 09-26	09-26 10-24	10-24 11-21	11-21 12-19
725 (Thetford-Mines)	01-18 02-15	02-15 03-15	03-15 04-11	04-11 05-09	05-09 06-06	06-06 07-05	07-05 08-01	08-01 08-29	08-29 09-26	09-26 10-24	10-24 11-21	11-21 12-19
732 (Black-Lake)	01-18 02-15	02-15 03-15	03-15 04-11	04-11 05-09	05-09 06-06	06-06 07-05	07-05 08-01	08-01 08-29	08-29 09-26	09-26 10-24	10-24 11-21	11-21 12-19
736 (Black-Lake)	01-17 02-14	02-14 03-13	03-13 04-10	04-10 05-08	05-08 06-06	06-06 07-05	07-05 07-31	07-31 08-29	08-29 09-26	09-26 10-24	10-24 11-21	11-21 12-19

3 SELECTION OF AN ANALYTICAL METHOD

Ambient asbestos can be measured by analytical transmission electron microscopy (ATEM), which is the unanimous choice of the experts for this purpose (20). However, there is still some doubt as to the best way to prepare Millipore® membrane filters before ATEM analysis. Two possibilities exist (Figure 9):

1) The "direct method", which involves collapsing the membrane filter and then replicating its surface within a carbon coated film (21, 22).
2) The "indirect method", which involves ashing part of the membrane filter and then treating the ash with ultrasound in a water bath and mounting it on ATEM grids with an appropriate distribution density for a better microscopic description of the particles (23).

According to the proponents of the direct method, this is the only method which allows reproduction of the original size distribution of the airborne asbestos fibres - a factor of prime importance in evaluating health hazards (24). Its detractors, who doubt the feasibility of large-scale application of a method that requires an optimal loading, fear a loss of particles during the preparation, and denounce the argument that determination of size distribution of asbestos dust particles will allow to predict their biological effects. Indeed, the scientific importance of fibre size is far from understood and no expert would risk making a definitive conclusion based on the particle size distribution of airborne asbestos. Any study that failed to measure the size of dust particles would doubtless be open to criticism, but extreme care must be exercised when interpreting or using these data.

The proponents of the indirect method guarantee its feasibility and recall that it has been used in most of the previous studies on this suject (25). Its detractors mention, without being able to substantiate their claim, that this method alters the original size distribution of the asbestos particles and hence cannot be used to determine numerical concentrations.

Therefore, it was decided to conduct a prior study of the two methods, testing them on membranes taken from the sites. In early 1984 (January 16 - April 19), 17 samples were taken on membrane filters at Thetford-Mines, Black-Lake and Montreal with a Connecticut Lo-Vol sampler, which was operated at a flow rate of 110 l/min. Sampling was done with periods shorter than a month in order to reduce the filtration density to 1 m^3/cm^2, a value deemed optimal for the direct method. The results of the methodological study (26) can be summarized as follows:

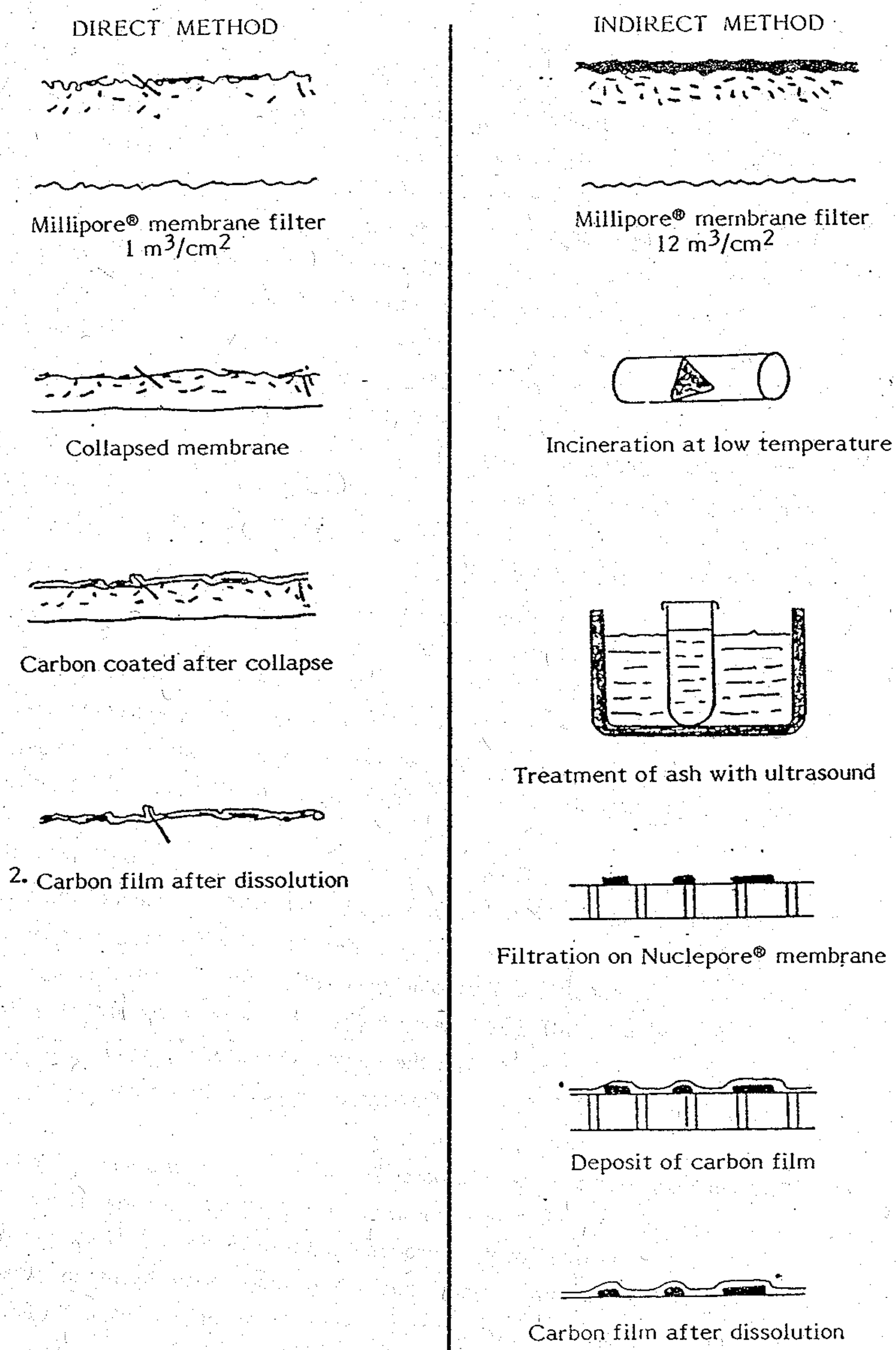


Figure 9
Transmission electron microscopic analysis of particles sampled on Millipore® membrane filter. Stages in the preparation of grids by direct and indirect methods.

a) The direct method has a low success rate (35 %). Even at what is considered the optimal filtration density, i.e. 1 m^3/cm^2, some membrane filters are too heavily loaded with dust and this causes the fragile carbon replica to break.

b) The preparations obtained through the direct method are difficult to observe by ATEM because of their filamentous texture.

c) About 90 % of fine chrysotile fibrils are missed under the microscope in the direct method. It is thought that these fine fibrils are hidden by the filamentous texture o that they penetrated the membrane filter and are lost during the dissolution of the filter (27). However, the larger fibres, which probably do not penetrate the mem brane, can be detected by both methods (Figure 10).

d) Under these conditions, the direct method yields low fibre counts and therefor concentrations with a wide confidence interval; furthermore, it does not make fc restoration of the original size distribution of the asbestos dust because of the selective loss of fine fibrils.

e) The feasibility of the indirect method is confirmed.

f) Since chrysotile particles may show complex morphologies in samples collected ne emission sources, it is difficult to calculate their mass under the microscope. Further, the determination of gravimetric concentrations involves more statistic variations than the determination of numerical concentrations. Hence, gravimetric concentration appears to be more difficult and less reliable than numerical conce tration (28).

g) In the indirect method, it seems that a light treatment of less than 10 minutes in low-energy ultrasonic bath (20,000 Pa, 50 kHz) does not produce sufficient breakdo to artifically increase fibre concentrations by a substantial margin (29). However over longer periods (2 hrs. ultrasonic treatment), the fine fibril concentrations can multiplied by a factor of 3. Nevertheless, the effects of ultrasonic treatment ar considerably less important than the consequences of losing fine fibrils in the dir method (Figure 10). The concentrations of large fibres do not vary with the duratic of ultrasonic treatment.

h) The indirect method makes it possible to detect fine and short fibrils of chrysot which are by far the most common, usually representing about 90 % of t particles. In a normal counting procedure, these fibrils therefore monopolize 90 % the microscopist's time - time that could have been spent in providing a mo accurate description of the shape and size of longer particles. To obtain signifi values for these particles, a size-selective analysis must be done, ignoring sh

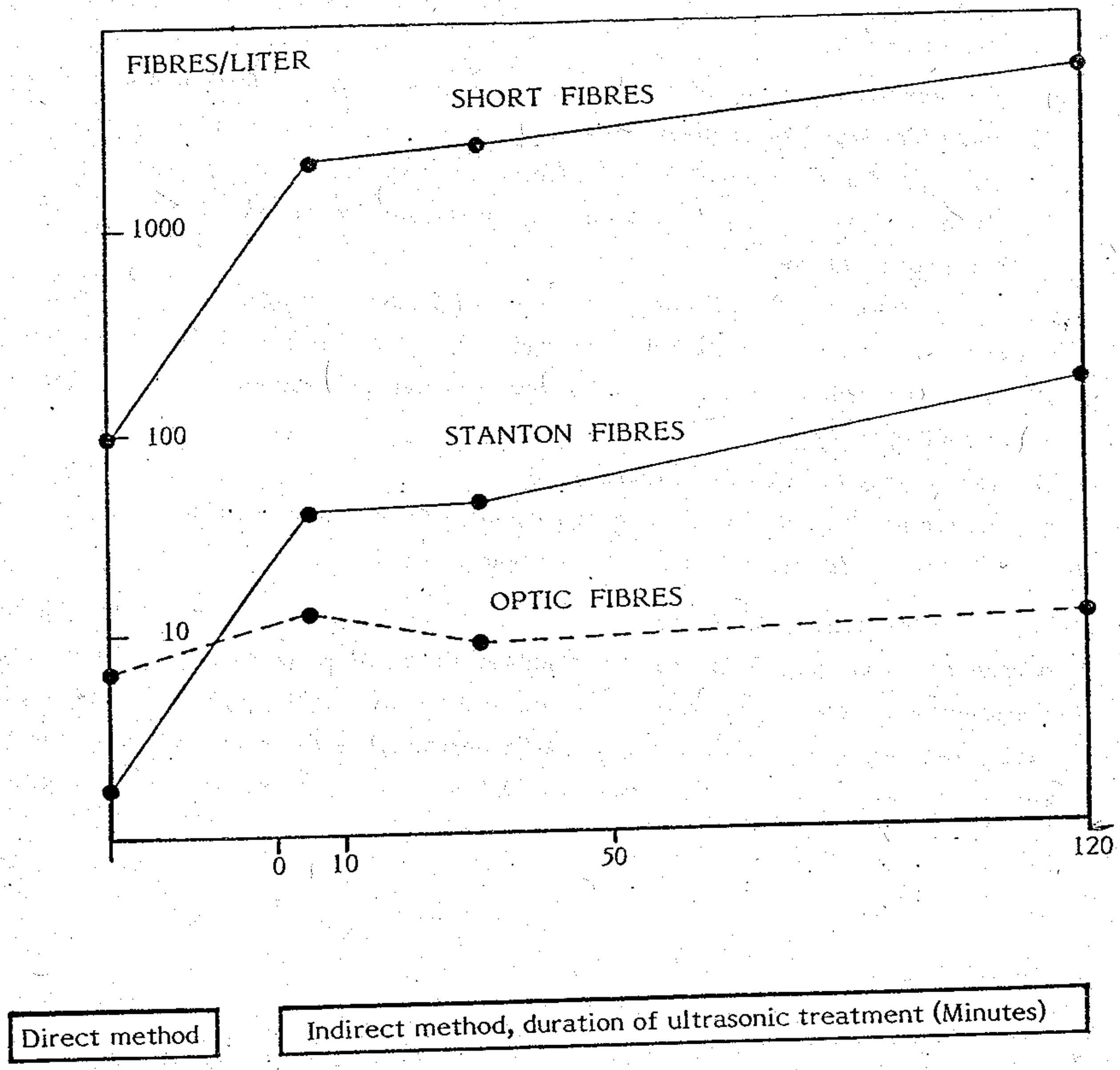


Figure 10
Preliminary methodological study
Comparison of average numerical concentrations measured by direct and indirect methods on 4 membrane filters from the mining region.

fibrils under 5 microns. The choice of the 5-micron limit represents a harmonization with standard optical microscopy procedures for measuring levels of exposure at the workplace (30).

i) The selective counting of fibres longer than 5 microns by ATEM offers, from a purely analytical standpoint, many advantages, including better visibility, easier identification, fewer variations between different microscopists and increased speed.

j) From a scientific standpoint, many arguments could be advanced in favour of the long fibre option (30).

Based on the various conclusions of the methodological study, it was decided to use the indirect method for the main study. The main features of this method are:

a) Continous sampling on the same membrane filter for four weeks using a Connecticut Lo-Vol operating at a flow rate of 110 l/min.;

b) Short ultrasonic treatment (7 minutes);

c) Expression of numerical concentrations and size and shape distributions;

d) Selective counting of particles longer than 5 microns.

Note: In this report, when references are made to measurements with the optical microscope, concentrations are expressed in fibres/cubic centimetres. Concentrations measured with the ATEM are expressed either in asbestos particles/liter, asbestos fibres/ liter or either in micrograms (or nanograms) of asbestos per cubic meter. An asbestos fibre is defined as an asbestos particle with a length/diameter ratio greater than 3:1.

4 ANALYSIS OF ASBESTOS CONTENT OF MEMBRANE FILTERS

Using analytical transmission electron microscopy (ATEM), the following parameters were determined for asbestos particles longer than 5 microns:

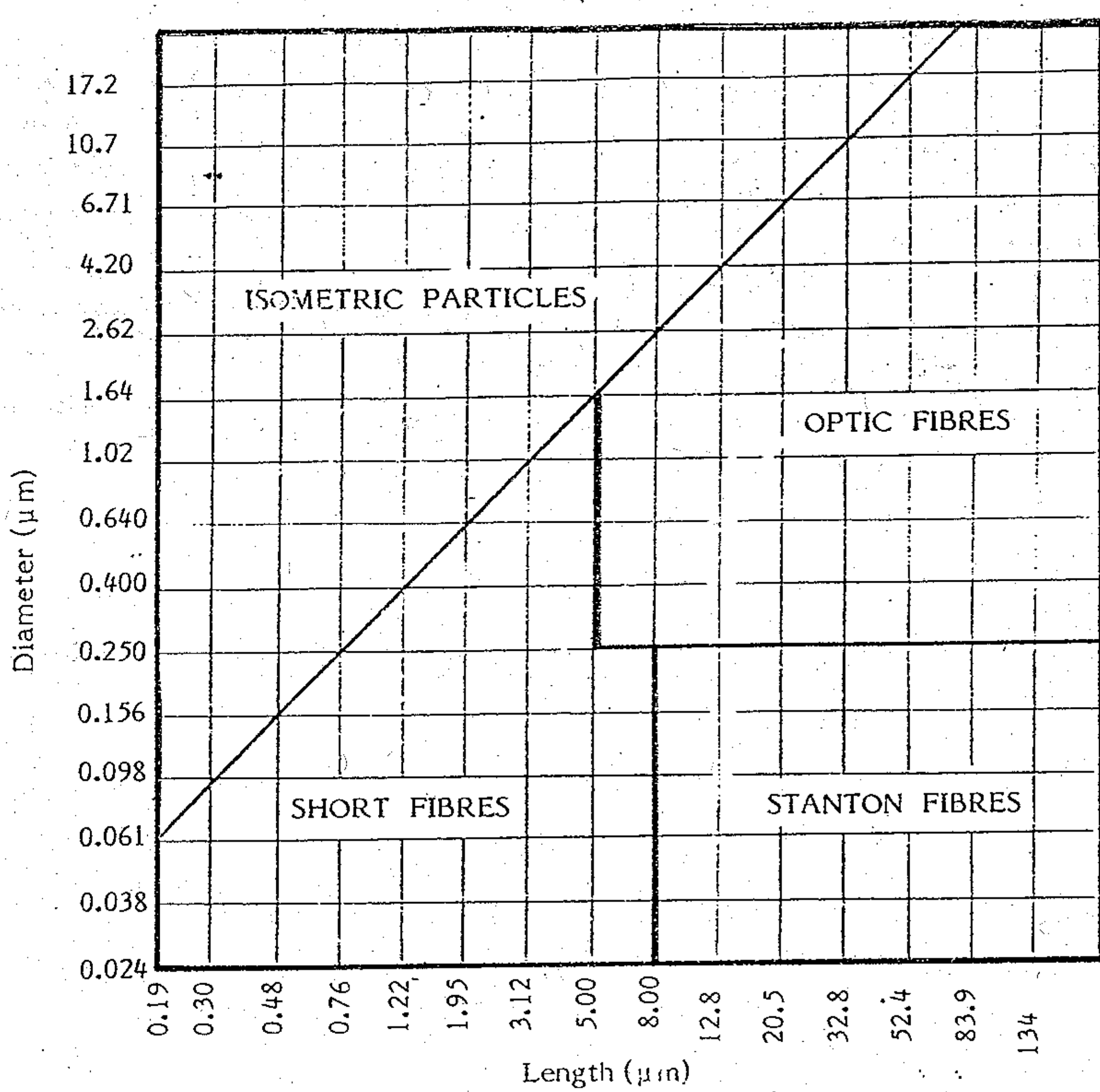
- mineralogical type
- numerical concentration
- shape classification
- size distribution.

In order to prepare the ATEM grids from each membrane filter, five portions measuring 1 cm^2 were cut from randomly chosen locations of the filter, that is, the equivalent of about 50 m^3 of filtered air. They were then separately placed, sampling side down, on the wall of a 100 ml, wide-mouthed glass bottle, which was introduced into the chamber of a low-temperature oxygen plasma asher. The asher operated through the night. In the morning, the vacuum of the asher chambers was broken very gently so that the ash would not be sucked out of the bottles. The bottles were then filled with 100 ml of ultra-clean water (Millipore-Q®) so as to wet the entire surface of the walls. They were then immersed in an ultrasonic bath at approximately 20,000 Pa, 50 kHz, for 7 minutes. The physical characteristics of the ultrasonic treatment (ultrasonic generator, volume of water in bath, type of bottle, placement of bottles in bath) were kept constant throughout the study. The pressure and frequency of the ultrasound were measured using a microphone probe.

After the ultrasonic treatment, one-fifth of the suspension (20 ml), or about 10 m^3 of air, was filtered through a polycarbonate Nuclepore® membrane (filtration area 10 cm^2, pore size 0.2 μm). Using the conventional replica technique (23), the particles retained on the surface of the Nuclepore® filter were carbon-coated, and the carbon film transferred to copper ATEM grids (200 mesh). Five grids were prepared, replicating the upper part of the filter in five random locations.

The grids were examined in the transmission mode (80 kV, 10,000 x) by means of a JEOL 100 CX® electron microscope, equipped with an energy-dispersive X-ray analyser (EDXA) PGT System IV® for chemical microanalysis. Only particles longer than 5 microns were considered. The analysis was terminated when at least 100 chrysotile particles had been counted, or the detection limit of 0.5 particle/liter reached.

The chrysotile particles were identified either on the basis of their particular shape, or on the basis of their EDXA spectra. Little use was made of electron diffraction. For the other fibres, the EDXA spectra were systematically stored on diskettes and subsequently compared with standard spectra from reference fibres (33).



The fine graduation is constituted by 225 (15x15) dimensional classes, the limits of which are in geometric progression.

The matrix is divided into four blocks:

ISOMETRIC PARTICLES. - Particles with a length/diameter ratio of less than 3. Particles with a ratio greater than 3 are called fibres.

OPTIC FIBRES. - Fibres longer than 5 microns and wider than 0.25 micron. They are theoretically visible under the phase-contrast light microscope. They serve as the basis for industrial health regulations.

STANTON FIBRES. - Fibres longer than 8 microns and finer than 0.25 micron. They have the greatest carcinogenic potential in Stanton's model.

SHORT FIBRES. - Particles not included in the above three blocks.

Figure 11
Granulometric matrix used to distribute dimensions

Each fibrous particle was classified according to the following shape criteria: individual fibres, bundles of fibres and aggregates of fibres. The dimensions of each particle were measured directly on the screen using an eyepiece graticule specially designed to measure fibre diameter to the nearest 0.03 µm, or a system of two concentric circles 10 and 50 mm in diameter drawn on the screen. The concept of coil dimension was used for bundles and aggregates; each particle was located in an imaginary rectangle whose sides represented its length and diameter. Size distributions were obtained by means of a matrix of 225 dimensional classes, grouped into 4 blocks having pre-established meanings (Figure 11).

5 RESULTS

Two types of asbestos were found in the samples collected in the mining towns: chrysotile (largely predominant) and tremolite (only about 0.5 to 1 %). Chrysotile was the only type of asbestos found in Montreal and St. Etienne.

5.1 Chrysotile Concentrations

The term "chrysotile particle" will be used in this report to describe fibres, bundles and aggregates of chrysotile. The concentrations of chrysotile particles longer than 5 microns are reported in Table 5; they vary from 0.5 fibre/l (the detection limit) to 1,158 fibres/l.

These concentrations have been analysed by site, region and sampling period. Three statistical indicators have been selected: the geometric mean, the geometric standard deviation and an arithmetic mean estimator, in case of log normal distribution (34).

The annual means per site and region are reported in Table 6, which shows clearly the differences between the mining region sites and the control sites. The levels measured in Montreal and St. Etienne were very close. In the mining region, the levels measured in Black-Lake were on average three times greater than those in Thetford-Mines and Asbestos. The most polluted site was Black-Lake (No. 735); the least polluted site was Thetford-Mines (No. 723), a site located far from the emission sources. Sites No. 732 and 736 in Black-Lake were surrounded with emission sources (Table 2, Figure 3). It will be noted that geometric standard deviations, albeit generally greater than 2, remain relatively small. The geometric standard deviation for Asbestos (2.9) is lower than that for Thetford-Mines (5.7). This is probably due to the fact that the emission situation in Thetford-Mines is more complex. The two sites in Asbestos are near the single open pit. The sites in Thetford-mines are more scattered and are subject to many and varied influences.

The statistics per period for all mining region sites are reported in Table 7. The statistics per period for the control region have not been calculated because of the small number of sites (n = 2) and the small number of fibres counted, leading to concentrations associated with large confidence interval. The data in Table 7 are reported graphically in Figure 12, which illustrates a clear seasonal effect, with peaks in April and October and troughs in the winter months and in July. The meteorological data (Table 8) and the variations in the activities of the mining companies may partially explain this

TABLE 4 VOLUMES (m^3) OF AIR FILTERED THROUGH EACH MEMBRANE

Station No.	Period 1	2	3	4	5	6	7	8	9	10	11	12
000 (St. Etienne)	-*	5466	5271	4894	-	5011	4649	4784	4845	-	4753	4708
012 (Montreal)	5201	-	-	4867	4751	4867	4518	4698	4785	4869	4947	4945
706 (Asbestos)	-	5475	5071	5003	4894	4955	4504	4768	4768	4811	4897	4961
709 (Asbestos)	-	5165	5005	4866	5792	4958	4541	4664	4675	4758	4800	4833
722 (Thetford-Mines)	5413	5405	5190	5081	4732	5183	4568	4814	4963	4989	5047	5068
723 (Thetford-Mines)	5176	5192	4994	4825	4675	4946	4601	4725	4796	4851	4967	5028
725 (Thetford-Mines)	-	5441	4951	5056	4962	4881	4545	4548	4627	9260?	4717	6139?
732 (Black-Lake)	5309	5468	4959	4963	4828	5045	4625	4725	4826	4890	4992	5033
736 (Black-Lake)	5505	5459	5093	5134	5195	4943	4463	4859	4811	4870	4915	4962

*-: Inadequate sampling.

TABLE 5 CHRYSOTILE CONCENTRATIONS BY PERIODS AND SITES[1]

	Period											
Station No.	1	2	3	4	5	6	7	8	9	10	11	12
000 (St. Etienne)	-*	0.5	> 0.5	1.1	-	0.6	> 0.5	> 0.5	0.6	-	> 0.5	> 0.6
012 (Montreal)	> 0.5	-	-	1.9	0.6	1.1	1.2	> 0.5	> 0.5	5.7	> 0.5	1.1
706 (Asbestos)	-	11.2	28.4	20.0	33.5	47.8	37.7	189.1	150.1	38.1	11.9	3.4
709 (Asbestos)	-	8.6	24.4	45.7	25.9	98.1	38.0	242.9	169.8	30.4	20.2	8.1
722 (Thetford-Mines)	10.8	7.2	64.8	187.6	76.6	208.7	103.1	115.1	73.9	379.2	63.6	15.4
723 (Thetford-Mines)	2.2	4.8	28.9	159.5	4.2	17.9	22.3	36.4	37.3	23.4	14.5	12.7
725 (Thetford-Mines)	-	8.5	86.2	92.7	575.4	160.7	45.7	17.7	43.7	177.2	68.8	17.7
732 (Black-Lake)	27.6	25.4	1112.4	414.2	239.6	75.7	46.9	34.1	139.1	229.6	21.7	25.9
736 (Black-Lake)	60.1	33.7	385.8	1158.0	369.8	139.4	57.7	148.2	149.3	441.1	79.0	30.9

[1] Number per liter of chrysotile particles longer than 5 microns.
*-: Inadequate sampling.

TABLE 6 CHRYSOTILE CONCENTRATIONS(1)
ANNUAL MEANS BY SITE AND REGION

Station No.	Number of samples	Geometric Mean	Geometric Standard Deviation	Estimated Arithmetic Mean*
000 (St. Etienne)	9	0.6	1.3	0.6
012 (Montréal)	10	0.9	2.2	1.2
706 (Asbestos)	11	29.8	3.1	47.6
709 (Asbestos)	11	37.2	3.3	57.5
722 (Thetford-Mines)	12	64.2	3.4	107.9
723 (Thetford-Mines)	12	16.7	3.1	26.8
725 (Thetford-Mines)	11	61.5	3.3	102.3
732 (Black-Lake)	12	86.2	3.7	153.2
736 (Black-Lake)	12	141.4	3.1	223.4
000 and 012 (St. Etienne and Montreal)	19	0.7	1.9	0.9
706 and 709 (Asbestos)	22	33.3	2.9	52.5
722, 723 and 725 (Thetford-Mines)	35	39.9	5.7	73.7
732 and 736 (Black-Lake)	24	110.4	3.4	188.7

1 Number per liter of chrysotile particles longer than 5 microns.
* From technique of Oldham, *Biometrics*, 1965, No. 213, p. 235-239.

TABLE 7 CHRYSOTILE CONCENTRATIONS(1)
MEANS BY PERIOD FOR ALL MINING REGION SITES

	Period											
	1	2	3	4	5	6	7	8	9	10	11	12
Number of samples	4	7	7	7	7	7	7	7	7	7	7	7
Geometric mean	14.1	11.3	90.0	142.9	75.7	84.1	45.5	77.8	93.7	109.1	30.7	13.4
Geometric Standard Deviation	4.1	2.0	4.3	3.9	5.7	2.3	1.6	2.7	1.9	3.5	2.2	2.1
Estimated Arithmetic Mean*	24.8	13.7	173.2	255.0	174.3	109.6	49.8	111.7	110.1	182.6	39.2	16.6

[1] Number per liter of chrysotile particles longer than 5 microns.
* From technique of Oldham, *Biometrics*, 1965, No. 213, p. 235-239.

pattern. The activities of the mining companies, the total precipitation and the average wind speed for each of the 12 sampling periods are shown on the three curves in Figure 13. A comparison of Figures 12 and 13 would warrant the following associations:

- The minimum winter pollution with the presence of ground snow and reduced mining activities;
- The July minimum with reduced mining activities, high precipitation, and low wind velocities; and
- The April maximum with a resumption of mining activities and high wind velocities.

The fall maximum is harder to explain. During this period, there was little mining activity and the wind velocity was low. However, precipitation was also low.

No asbestos particles longer than 5 microns were detected on the 12 blanks analysed.

5.2 Size and Shape Distribution of Chrysotile Particles

Table 9 shows the size and shape distribution of chrysotile particles for all samples collected in the mining region. It will be recalled that we separated the particles into three morphological categories (fibres, bundles, aggregates) and four dimensional classes (short, Stanton, optic, isometric) (Figure 11). The data in Table 9 is based on the analysis of 5,443 chrysotile particles. In all, 86 % of the particles had a typically fibrous morphology. The majority of fibres were placed in the Stanton category. Because of their cylindrical shape, bundles were mainly placed in the "optic" category and aggregates in the isometric category. Table 9 also indicates the average dimensions (length/diameter) of the seven groups of particles.

Figure 14 shows the distribution of chrysotile particles in the granulometric matrix. Schematically, it could be said that the vast majority of lengths are in the 5 - 20 micron range. The diameters of fibres, bundles and aggregates are respectively in the (0.04 - 0.25 µm), (0.4 - 2 µm) and (2.5 - 10 µm) ranges.

The size and shape distribution of chrysotile particles did not vary significantly with the sites. A seasonal variation was observed in that the percentages of particles classified as bundles or aggregates were higher for the first two sampling periods (Table 10). This observation, which is concomitant with the presence of ground snow, has not been explained.

In the control regions (Montreal and St. Etienne), the distribution was different.

TABLE 8 METEOROLOGICAL DATA

	Period											
	1	2	3	4	5	6	7	8	9	10	11	12
					Total precipitation (mm)							
Thetford-Mines	75	90	33	82	120	105	216	75	66	60	91	
Asbestos	31	86	35	97	114	93	172	86	89	46	69	
					Ground snow (cm)							
Thetford-Mines	104	74	95	1	0	0	0	0	0	0	0	
Asbestos	45	18	7	0	0	0	0	0	0	0	0	
					Average wind speed (km/hr.)							
Thetford-Mines	7.9	?	13.9	14.7	11.3	9.7	9.4	7.6	8.8	7.3	10.5	9.5
Asbestos	10.5	12.9	12.6	13.4	16.7	11.5	8.1	9.9	13.6	12.2	13.5	10.5

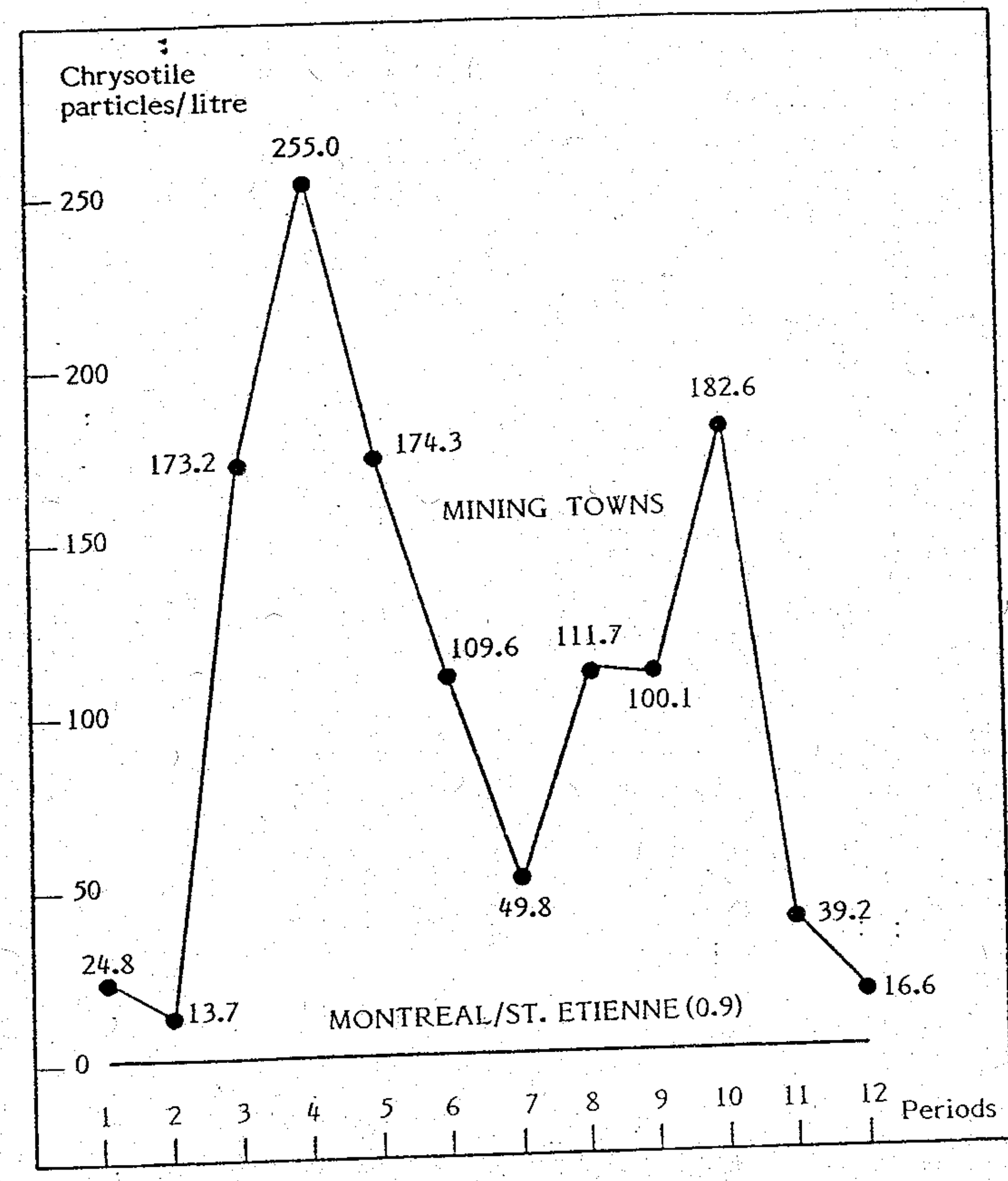


Figure 12
Seasonal variations in asbestos air pollution

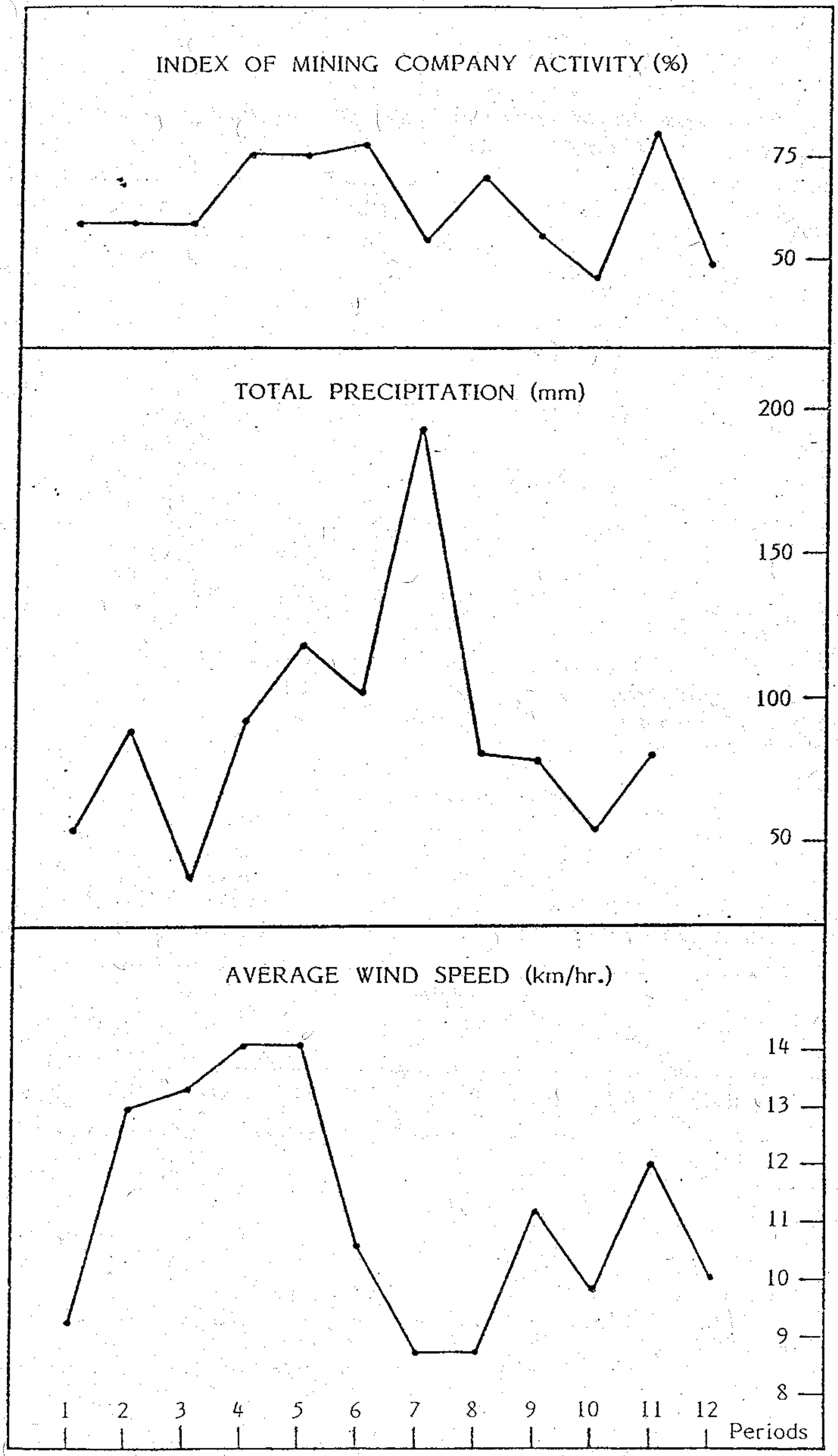


Figure 13
Examples of seasonal variations in mining town region

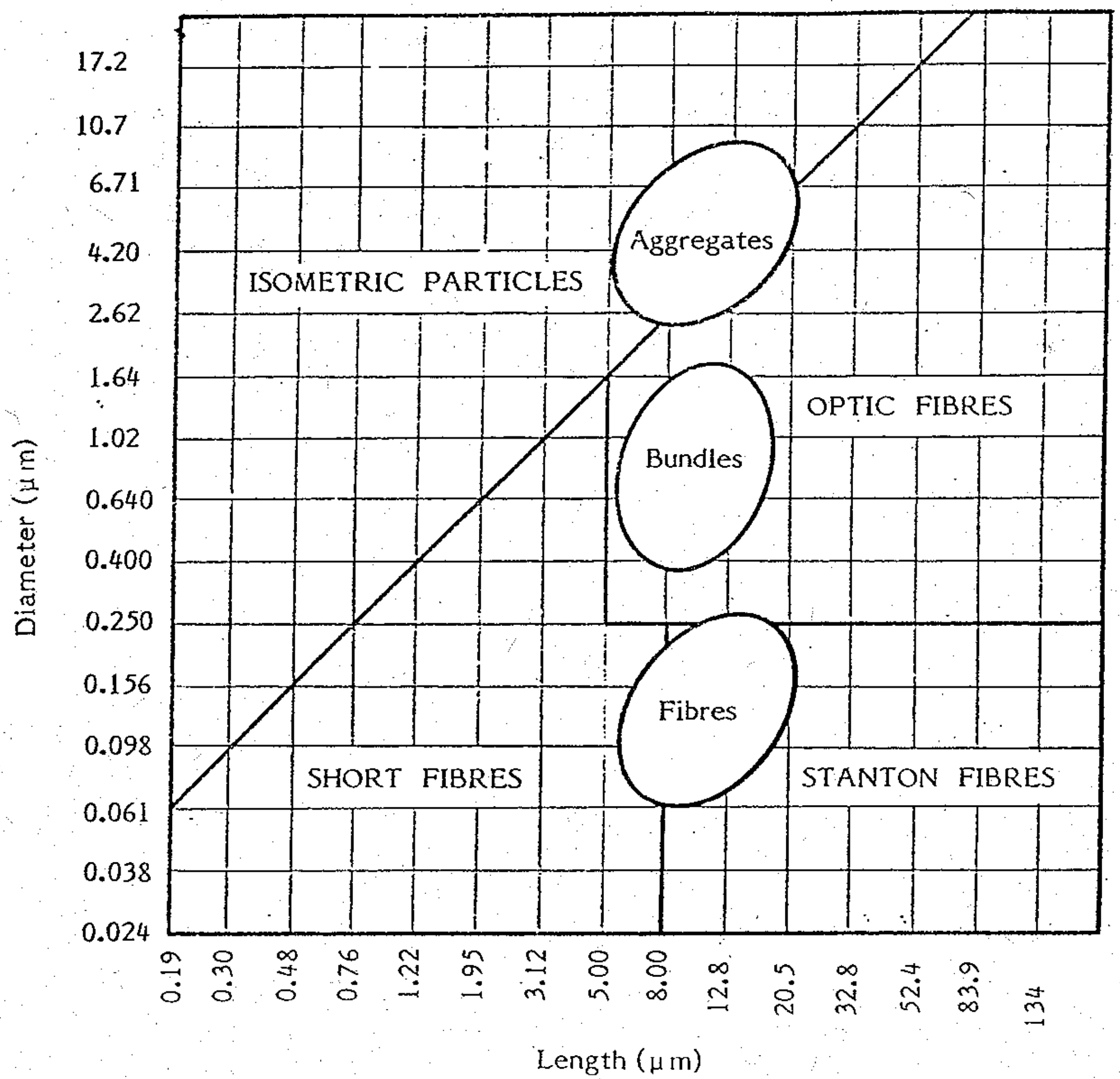
TABLE 9 SIZE AND SHAPE DISTRIBUTION OF CHRYSOTILE PARTICLES SIZE CATEGORIES(1) FOR ALL MINING REGION SITES

Shape Categories(2)	Short	Stanton	Optic	Isometric	Total
Fibres	32.5 % (6.8 µm/ 0.06 µm)*	47.7 % (13.3 µm/ 0.14 µm)	6.3 % (11 µm/ 0.33 µm)		86.5 %
Bundles			7.1 % (12.9 µm/ 1.3 µm)	0.6 % (9.5 µm/ 3.9 µm)	7.7 %
Aggregates			0.7 % (14.8 µm/ 3.3 µm)	5.1 % (9.5 µm/ 5.2 µm)	5.8 %
Total	32.5 %	47.7 %	14.1 %	5.7 %	

* Average length/Average diameter.
(1) See text and Figure 11 for explanation.
(2) See texte for explanation.

TABLE 10 MEAN PERCENTAGES OF CHRYSOTILE PARTICLES CLASSIFIED AS BUNDLES OR AGGREGATES, BY SAMPLING PERIOD

Period											
1	2	3	4	5	6	7	8	9	10	11	12
48.3	37.3	16.0	10.1	7.1	14.5	16.2	11.3	10.1	8.5	10.6	10.3



(The elipsoids contain about 95 % of total particles measured on all the membrane filters of the mining town region.)

Figure 14
Size distribution of fibres, bundles and aggregates

TABLE 11 MEAN CONCENTRATIONS OF TOTAL SUSPENDED PARTICULATE MATTER BY PERIOD AND SITE

Station No.	Period 1	2	3	4	5	6	7	8	9	10	11	12
012 (Montreal)	35	77	45.5	46	55	70	61	71	24	34.5	37	57.5
706 (Asbestos)	40	29	19.5	17	33	51	31	43	27	27	21	43.5
709 (Asbestos)	36	52	28	24	36	52.5	26	43	23	29	22	44
722 (Thetford-Mines)	29	24	33	35.5	32.5	49.5	29	45	34.5	49.5	43	21
723 (Thetford-Mines)	32	17	37	38	33	45.5	37	41	28	42	33	20.5
725 (Thetford-Mines)	23	21	15.5	38	38	38.5	36	29.5	26	30.5	33	14
732 (Black-Lake)	39	37	62	65	48	55	41	48	43.5	35.5	27	20
736 (Black-Lake)	29	41	46	40	41	51	23	41	40	31	34	21

[1] Micrograms per cubic meter.

Only fibres were found. Their average length was 7.9 µm and their average diameter 0.06 µm.

5.3 Tremolite Fibre Concentrations

Tremolite particles were detected in certain samples collected in the mining regions. They were always individual fibres and were on average larger than chrysotile fibres, with an average diameter of 0.53 µm, and an average length of 9.2 µm. The tremolite fibre counts were too low to warrant statistical analysis for each site and period. Mean tremolite concentrations by mining region were respectively 1.5 fibre/l in Thetford-Mines to 0.9 fibre/l in Black-Lake, and 0.2 fibre/l in Asbestos.

5.4 Total Suspended Particulate Matter

Table 11 shows the concentrations in $\mu g/m^3$ of total suspended particulate matter as measured by Environnement Québec using the high-volume sampler method. Although an examination of the overall data for each sampling period and for all mining region sites does not suggest a major seasonal variation, the concentrations were slightly lower in winter and slightly higher in spring (Table 12). Table 13 shows the concentrations per site for all sampling periods. Montreal shows the highest figure. In the mining region, Black-Lake had the highest average. However, the differences between the sites were less marked for total suspended particles than for chrysotile (Figure 15).

The total dust-fall was not considered because it was not measured in the control regions (Montreal and St. Etienne), and in the mining region many results were missing. The results on hand indicate greater dust-fall in Black-Lake and Asbestos (3.3 tons/km^2/month) than in Thetford-Mines (2.3 tons/km^2/month), with a peak in June and trough in winter.

TABLE 12 MEAN CONCENTRATIONS(1) OF TOTAL SUSPENDED PARTICULATE MATTER PER PERIOD FOR ALL MINING REGION SITES

	Period											
	1	2	3	4	5	6	7	8	9	10	11	12
Number of samples	35	34	24	28	34	28	34	34	27	28	33	25
Geometric mean	32.9	28.8	24.8	38.8	31.5	44.8	34.3	35.6	30.1	33.6	30.5	24.4
Geometric standard deviation	1.3	1.9	2.6	2.0	1.9	1.6	1.6	1.7	1.5	1.4	1.6	1.7
Estimated arithmetic mean*	34.2	35.4	35.5	47.9	37.6	49.8	37.8	40.3	32.7	35.5	34.1	27.7

1 Micrograms per cubic meter.
* From technique of Oldham, *Biometrics*, 1965, No. 213, p. 235-239.

TABLE 13 ANNUAL CONCENTRATIONS(1) OF TOTAL SUSPENDED PARTICULATE MATTER

Station No.	Number of samples	Geometric Mean	Geometric Standard Deviation	Estimated Arithmetic Mean*
012 (Montreal)	53	51.7	1.7	58.9
706 (Asbestos)	55	31.2	1.6	34.9
709 (Asbestos)	51	33.0	1.6	36.7
722 (Thetford-Mines)	52	33.9	1.8	39.7
723 (Thetford-Mines)	51	28.6	1.9	35.0
725 (Thetford-Mines)	51	26.0	1.8	30.8
732 (Black-Lake)	54	39.2	1.7	44.9
736 (Black-Lake)	50	35.9	1.7	41.3

1 Micrograms per cubic meter.
* From technique of Oldham, *Biometrics*, 1965, No.213, p. 235-239.

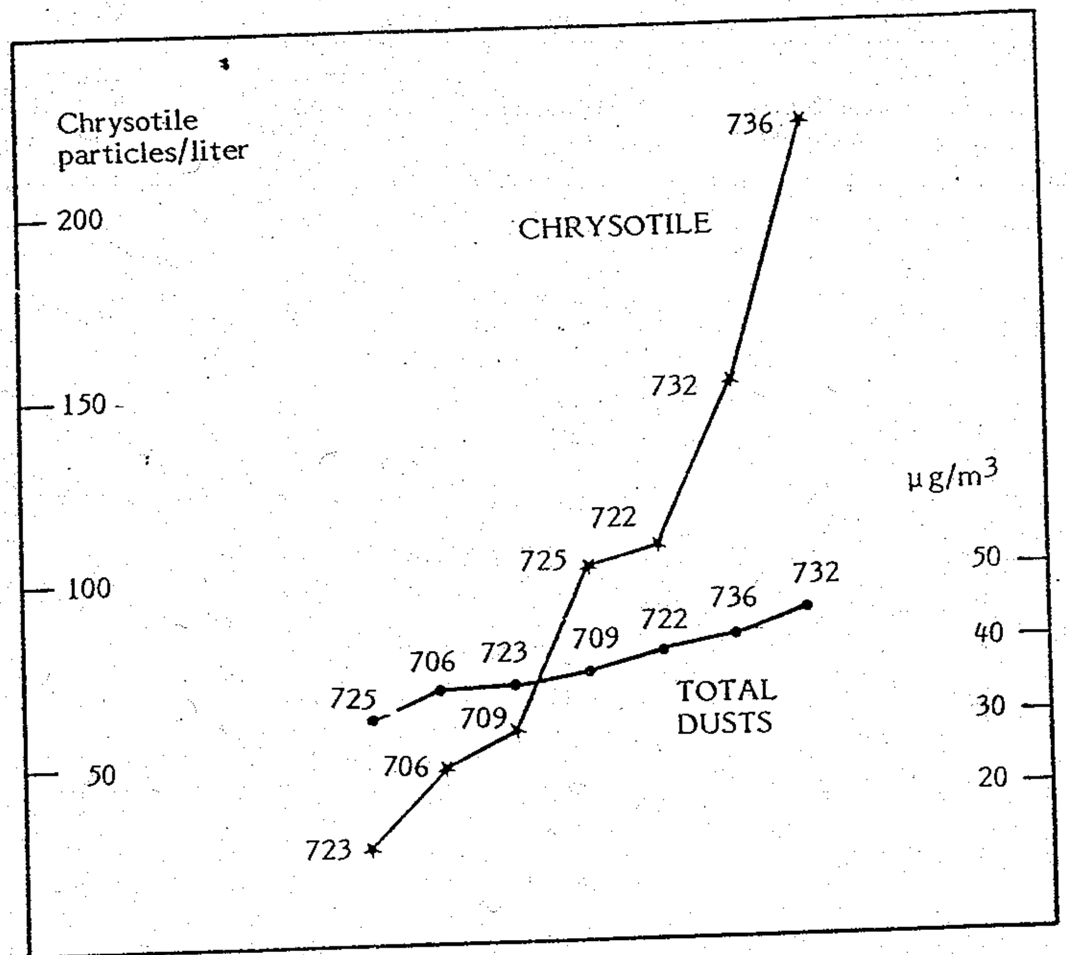


Figure 15
Mining town sites classified by chrysotile and total dust concentrations

6 DISCUSSION

6.1 Methodological Aspects

This study is the first attempt to measure systematically, over a one-year period, ambient asbestos in the mining towns of Québec. In 1980, air samples from the mining towns were analysed under the analytical transmission electron microscope by Singh and Thouez (35). The authors were interested mainly in the phenomenon of pollutant transport and their study dealt only with a limited period. In 1980, Gibbs et al. analysed 21 air samples from the mining region, but the results have not been published (17).

This study benefited greatly from recent improvement in ATEM asbestos analysis methods and the conclusions of the preliminary methodological report (26). The conclusions of Graham Gibb's pilot study recommending the use of the Connecticut Lo-Vol sampler were also taken into account. Although this sampler performed satisfactorily, its inlet collection efficiency for various aerodynamic diameters and wind speeds has never been determined. In light of the small dimension of the asbestos particles found on the filters, inlet efficiency would not appear to be a major problem - except perhaps if the fibres are trapped in coarser dust particles. These conclusions are consistent with those reached by Johnston et al. (36) concerning the effect of external aerodynamic factors on the measurement of the airborne concentration of asbestos fibres by the membrane filter method.

The preliminary methodological research was a determining factor in the success of the main study. It clarified several questions regarding the effectiveness of the two ATEM methods for asbestos analysis. Two aspects of the method used deserve to be mentioned: the indirect preparation of the membrane and the selective counting of particles longer than 5 microns. This selective counting considerably enhances the speed and reliability of ATEM analysis. It is also encouraging to note that the method used for the study (sampling of air passing through a membrane filter, indirect preparation, selective ATEM analysis of fibres longer than 5 microns) might become a reference method for measuring asbestos fibre concentrations in ambient air (37).

6.2 Characteristics of Pollution in Regions Studied

The asbestos pollution levels measured in Thetford-Mines and Asbestos are, on average, about 70 times greater than those measured in the control regions (Montreal and St.Etienne). The pollution levels measured in Black-Lake are, on average, about 200 times higher than those measured in the control region. During peak pollution periods, the levels may be as much as 1,000 times higher. In the control regions, the levels are on average lower in St. Etienne than in Montreal, but the difference is not significant.

In the mining region, 99 % of asbestos particles are of the chrysotile type, but tremolite fibres are also present, especially in Thetford-Mines. Chrysotile particles occur mainly in the form of fibres (86.5 %) but also as bundles and aggregates. The lengths of these measured particles are almost always in the 5 - 20 micron range. Only chrysotile fibres (not bundles or aggregates) were found in the control regions of Montreal and St. Etienne. The discovery of ambient tremolite is of particular importance. It was known that tremolite was found in asbestos deposits in Québec; it was also known that the pulmonary retention of tremolite is higher than that of chrysotile. But nothing was known about the proportion of tremolite in asbestos dust. The data obtained here will help interpreting asbestos levels in the lungs of miners, where the tremolite concentration almost always exceeds the chrysotile concentration (38, 39).

In the mining region, about 14 % of chrysotile particles longer than 5 μm have a length/diameter ratio greater than 3 and a diameter greater than 0.25 μm. They should therefore be visible under the phase-contrast optical microscope. Since they meet existing dimensional specifications of the standard method of measuring fibres in the workplace (fibre/cm^3), this makes it possible to calculate optic fibre concentrations as they might have been measured by this standard method (optical microscope) using short-term samplings (2 - 8 hrs.) on membrane filters and counting of fibres longer than 5 microns under the phase-contrast optical microscope.

These calculations yield the following average concentrations in the ambient air: Asbestos 0.007 fibre/cm^3, Thetford-Mines 0.010 fibre/cm^3, Black-Lake 0.026 fibre/cm^3. It should be emphasized that these concentrations are derived from theoretical calculations and that the standard method developed for measuring asbestos levels in the workplace appears to be of questionable value for measuring asbestos pollution levels in the general environment. However, Chatfield (20) showed recently, at least on experimental membranes, that the counting of "optic" fibres by the standard method and by an indirect ATEM method similar to the one used here led to similar concentration data. No equivalent data are available for actual membranes used in the field.

6.3 Other Studies on the Subject

The main reason for the preceding calculations is to compare environmental concentrations with occupational concentrations which, in Québec, are set at 2 fibres/cm^3 and are measured by the standard optical microscope method. Epidemiologists now consider that the risk of asbestos-induced cancer increases linearly with accumulated exposure to asbestos (10). It has also been calculated that an asbestos worker exposed 8 hrs./day for 30 years to 2 fibres/cm^3 would accumulate 30 x 2 = 60 fibres/cm^3/year. Using the same approach, a person living, for example, for 75 years in Black-Lake and exposed 24 hrs./day to 0.026 fibre/cm^3 would accumulate 0.026 x 75 x 3 = 5.8 fibre-years, i.e., about 10 times less. However, we will not develop this hypothesis further in view of the uncertainty regarding the dose-effect relationship with regard to asbestos exposure. It should be noted, however, that the levels measured in the mining towns would indicate exposure levels that are only 10 times lower than occupational exposure levels. For some contaminants greater differences are observed between standards in the workplace and the environment (40). It will also be recalled that these levels were measured in the very centre of the mining towns and most often on the roof of schools.

In the United States, most studies were based on the ATEM indirect method and gravimetric concentrations were expressed in ng/m^3. The background chrysotile pollution levels in large urban centres are between 1 and 10 ng/m^3 (41). The background pollution level was highest in New York City and near highway toll booths and in tunnels where drivers had to apply their brakes (32, 42). Levels up to 8,200 ng/m^3 were measured near asbestos plants (43). The use of serpentine rocks on country roads was also found to cause considerable pollution (44). Two major studies were conducted in buildings insulated with blown asbestos (45, 46). In some rooms, the levels reached 800 ng/m^3.

The ATEM indirect method (expressed in ng/m^3) was also widely used in France, confirming american data on background and indoor levels (47).

In Canada, measurements were taken by Chatfield in five Ontario communities, in the Toronto subway and in certain buildings, using ATEM direct method on Nuclepore® filters (48). These studies failed to reveal any abnormal pollution levels - even in buildings. Other studies are in progress, this time using an indirect method. A sampling was also conducted at Baie Verte in Newfoundland (49), using a direct method. In general, the levels measured were very similar, albeit lower than reported here, with an average of 24 fibres/litre (> 5 µm); 23.5 % of the levels were greater than 40 fibres/litre. The authors concluded that there was no correlation between the measured levels and the wind direction, or the mining operation. They suggested that there might be fugitive emissions and a resuspension of settled dust.

In the Netherlands, Lanting and den Doeft (50) used a method similar to ours (monthly sampling on Millipore® membrane filter, indirect preparation, counting of fibres longer than 5 microns) to measure chrysotile concentrations near asbestos-cement plants.

(4 fibres/l) and in a highway tunnel (3.6 fibres/l) which they compared to the general pollution in Amsterdam and Rotterdam (0.7 fibre/l) and that in the rural areas (0.1 fibre/l). It will be noted that the background pollution level in Holland's urban cities was nearly equivalent to that in Montreal. The levels measured near asbestos plants were six times higher.

In Germany, using the scanning electron microscope, Teichert reported concentrations of between 0.1 and 18 fibres/l near asbestos, cement and friction product plants (51).

In Great Britain, the Health and Safety Executive Agency has been conducting an environmental monitoring program for several years, using various electron microscopy methods (52, 53). The urban background pollution level was always lower than 4 ng/m^3. Higher pollution levels were identified near asbestos plants (35 - 1,300 ng/m^3) and near asbestos-emission sources (up to 200 ng/m^3) but not in buildings.

It is difficult to compare the results of these studies which used different methods. However, on reviewing the literature two points stand out:

- The existence of a low, homogenous background chrysotile pollution level;
- The possibility of reaching levels 1,000 times greater under special circumstances.

Our findings are fully consistent with these two observations. As well, it should be recalled that no survey of ambient asbestos pollution had previously been conducted for a period as long as one year.

6.4 Health Implications of Environmental Exposure to Asbestos

The health hazards of ambient asbestos are poorly understood and will probably remain so for some time in view of the methodological difficulties involved in evaluating them (10). To our knowledge, only three environmental pollution circumstances have been associated with excessive risks of respiratory cancer (pulmonary or pleural): proximity to crocidolite mines in South Africa (6), proximity to a factory in West Germany using the same crocidolite (11) and domestic exposure of families of asbestos workers (7). The other attempts at direct observation of risks of asbestos-induced cancer in the environment were negative (10).

The same is true for mortality studies carried out in Québec among the residents of mining towns of Thetford-Mines, Black-Lake and Asbestos (12-15). Several observations of morbidity were made but will not be reported here because of the difficulty in interpreting their results.

In other studies, the risk of asbestos-induced diseases in the general environment has been calculated, either by extrapolating the dose-effect relationship curves obtained from epidemiological study of occupational groups or by using the incidence of mesothelioma, as an index of asbestos-induced disease (16). In view of the model used (linear, dose-effect relationship without threshold), these reports all concur in the existence of a risk, but their margin of error is so high that their usefulness in the area of public health is not evident. These ideas deserve to be reviewed in the light of a new threshold preceding the risk of asbestos-induced cancer or the stability of the incidence of mesothelioma in women (10).

7 CONCLUSIONS

The following points should be underlined:

a) *Scope of the study* - 100 membrane filters (5,000 m^3 of air/filter), 9 sampling sites, almost a full year of sampling divided into 12 four-week periods, 5,494 asbestos particles identified, counted and measured (length and diameter) under the analytical transmission electron miscroscope. This is the first study of this scope ever conducted in the area of ambient asbestos pollution.

b) *Reliability of analytical methodology* - The study made good use of what has been learnt over the past 10 years in analysing asbestos through transmission electron microscopy. The conclusions reached in the methodological study were also helpful. The method used here might become a reference method for measuring the levels of asbestos in the general environment.

c) *Contrast of pollution levels* - The study showed clearly that chrysolite pollution levels in the mining region were higher than the general urban background level. Furthermore, there is tremolite pollution in the mining regions. Although there are no ambient asbestos standards, some agencies have made recommendations on air quality (Table 14).

d) *Epidemiological interpretation* - Little is known about the health effects of chrysotile dusts at levels below those experienced by workers in mining and milling. In view of measured levels and the uncertainties about the exposure-effect relationship, we recommend that the results of this study be examined closely. The existence of these data on atmospheric pollution levels offers unique opportunities to broaden our knowledge of the dose-effect relationship at low exposure levels. However, such research would require considerable epidemiological sophistications.

TABLE 14 RECOMMENDED AIR QUALITY STANDARDS FOR ASBESTOS

CANADA	
Ontario	40 f/l > 5 µm) 24 hr. average Electron microscopy
British Columbia	0,04 f/cm^3 Light microscopy
Montreal	0,05 f/cm^3 (24 hr. average) Light microscopy
USA	
Connecticut	30 ng/m^3 or 30 f/l (30 day average) Electron microscopy
New York City	100 ng/m^3 Electron microscopy
FRANCE	
Conseil supérieur d'hygiène publique de France (interior of buildings)	50 ng/m^3 (5 day average) Electron microscopy
FEDERAL REPUBLIC OF GERMANY	1 f/l Electron microscopy

Note: f/l = fibres per liter.
Source: ED. CHATFIELD. "Short Mineral Fibres in Airborne Dust". In *Short and Thin Mineral Fibres. Identification, Exposure and Health Effects. Proceedings from a symposium.* National Board of Occupational Safety and Health Research Department. Solna, Sweden, 1983.

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