ORIGINAL ARTICLES AAEM
Ann Agric Environ Med 2009, 16, 121-128

ENVIRONMENTAL EXPOSURE TO AIRBORNE ASBESTOS FIBRES IN A HIGHLY URBANIZED CITY

Ewa Krakowiak[1], Rafał L. Górny[1], Jolanta Cembrzyńska[1], Gabriela Sąkol[1], Marjorie Boissier-Draghi[2], Edmund Anczyk[3]

[1]Department of Biohazards, Institute of Occupational Medicine and Environmental Health, Sosnowiec, Poland
[2]Department of Sustainable Development – Energy, Health and the Environment, Scientific and Technical Centre for Building, Marne-la-Vallée, France
[3]Department of Health Policy, Institute of Occupational Medicine and Environmental Health, Sosnowiec, Poland

Krakowiak E, Górny RL, Cembrzyńska J, Sąkol G, Boissier-Draghi M, Anczyk E: Environmental exposure to airborne asbestos fibres in a highly urbanized city. *Ann Agric Environ Med* 2009, **16**, 121–128.

Abstract: Asbestos fibres, when released into the air, can pose serious health hazards to exposed people. The aim of this study was to determine the concentration of respirable asbestos fibres in a highly urbanized and densely populated town, where asbestos-containing materials have been widely used in building constructions. Their presence and degree of corrosion were the main criterion for location of sampling stations. All air samples were collected applying the recently elaborated sampling strategy. The origin of sampled fibres was additionally proved by SEM analysis. Concentrations of respirable fibres, derived from 2 groups of asbestos minerals (crocidolite and chrysotile) varied from 0.0010–0.0090 f/cm^3. The highest concentrations were observed in the immediate vicinity of the buildings where a large accumulation of damaged asbestos-containing materials was found, compared to sites located from 100–500 m from such buildings, or treated as a "free" from asbestos sources. It was revealed that even a relatively gentle air movement (1 m/s) plays an important role in the spreading of fibres near the asbestos source. The data of spatial distribution of respirable asbestos fibres in the form of a map can be a useful tool for the official bodies to plan necessary asbestos remediation actions.

Address for correspondence: Ewa Krakowiak, M.Sc., Department of Biohazards, Institute of Occupational Medicine and Environmental Health, ul. Kościelna 13, 41-200 Sosnowiec, Poland. E-mail: e.krakowiak@imp.sosnowiec.pl

Key words: asbestos fibres, asbestos-containing materials, air contamination, environmental exposure, monitoring.

INTRODUCTION

The term "asbestos" is a collective name for a category of naturally occurring fibrous minerals from the groups of serpentine (chrysotile) or amphibole (i.e. amosite, crocidolite, tremolite, actinolite, and anthophyllite). All of them belong to silicate minerals and are characterized by a crystalline and stringy structure (i.e. curly regarding chrysotile or needlelike in the case of amphibole fibres). Whereas the comminution of chrysotile fibres may produce separated unit fibrils, the breakage of amphiboles (by both parting and cleavage) occurs along defined crystallographic planes [40, 44, 56]. Macroscopically, asbestos structure resembles organic fibres such as cellulose. Since all asbestos fibres are silicates, they are strong yet flexible. They exhibit several other common properties, such as: incombustibility, thermal stability, resistance to biodegradation, chemical inertia towards the most chemicals, and low electrical conductivity [23]. For these reasons, asbestos has been commercially exploited because only a few other available substances combine the same features. During the last 100 years, asbestos (mainly chrysotile) has been widely used as a component of heavy industrial products such as sealants, cement pipes, cement sheets, and building insulating

Received: 23 December 2008
Accepted: 9 May 2009

materials (in Poland – usually as roofing and front elevation panels of buildings). The amount of asbestos in specific products (e.g., in building materials, older plastics, paper products, brake linings, floor tiles, and textile products) varied from 1 to almost 100%.

Respirable asbestos fibres (i.e., fibres with: a length greater than 5 µm, diameter smaller than 3 µm, and length to diameter ratio equal to or greater than 3:1) can easily penetrate the human air passages. Once inhaled, they may be deposited and retained in the airways and lung tissues. Hence, each individual exposure increases the likelihood of development of asbestos-related disease. The adverse effects of asbestos on human health, resulting from the inhalation of fibres released into the air, are well documented. Asbestos exposure can cause serious health problems leading to numerous diseases such as asbestosis (lung scarring – a chronic, restrictive, non-cancerous respiratory disease), plural plaques, lung cancer, mesothelioma (a cancer of the lung cavity lining) or, if asbestos is ingested, other cancers of the esophagus, larynx, oral cavity, stomach, colon and kidney [8, 56, 57]. The health outcomes depend on the size and concentration of fibres, penetration of the lower parts of the respiratory tract, and duration of exposure [17, 29, 39]. The longer a person is exposed to asbestos and the greater the intensity of exposure, the greater the probability of the appearance of health problem. It is well known that a long latency period for asbestos-related diseases causes numerous difficulties in clinical diagnosis. Because of a rapid increase of the risk in time, the lifetime effect of exposure in childhood is likely to be much greater than if it begins in adulthood. The symptoms may not appear until 20–40 years after first exposure [28, 54]. Asbestos-related disease, such as lung cancer, may not occur for decades after breathing asbestos fibres [15] and, as it is anticipated today in Europe, the peak of mortality will be reached around 2020. However, the differences between the countries are expected according to their distinct asbestos consumption curves [51].

The world has 200 million tons of identified asbestos resources [47]. In 2007, the production of asbestos was estimated to be 2.20 Mt (a slight increase from 2.18 Mt in 2006 is still visible). Russia, followed by China, Kazakhstan, Brazil, Canada, and Zimbabwe have been the major producers of asbestos for many years. These countries have accounted for 96% of world production. Nevertheless, the import, manufacturing, marketing, and use of asbestos products have already been banned (with minor exceptions) in 30 countries [50]. Since 1 January 2005, the use of asbestos has been forbidden throughout the European Union [51]. Despite the fact that in Poland there are no natural resources of asbestos, its products were widely used from the 1930s. Two-thirds of the asbestos, mostly chrysotile, was used to produce asbestos-containing construction materials such as corrugated roofing and cladding panels for residential and industrial buildings (i.e. asbestos-cement (AC) panels commonly known as "eternit"). The maximum demand for asbestos products occurred in Poland between 1970–1980, when about 2% of world production (about 100,000 tons of asbestos a year) was imported. Approximately 80% of this quantity has been utilized by the building industry [6]. By the mid-1980s, the production of asbestos materials had decreased to 60,000 tons. In 1991, it decreased to 30,000 tons, still making Poland the 16th biggest consumer in the world. Nowadays, the total amount of asbestos products in Poland is estimated at about 15 million tons, of which approximately 96% (about 1,351 million m^2) occurs in the form of AC sheets which, due to the corrosion process caused by both the construction mechanical damages and weather conditions, release asbestos fibres into the air [11].

In May 2002, the Polish Council of Ministers accepted the governmental "Programme for removing asbestos and asbestos-containing materials used on the territory of Poland", a task which will be fully accomplished by the end of 2032 [11]. According to the Order of the Minister of Economy, Labour and Social Policy of 21 April 2004 on "the ways and conditions for the safe use and disposal of asbestos-containing products", there is a necessity to monitor the levels of asbestos fibre air pollution [34]. The conditions imposed by the Order demand an air monitoring, which allows the ascertaining of correctness of the work involved in the asbestos removal processes, and to control the degree of contamination of the environment. Despite the enforced requirements, there is still no standardized method for determining asbestos fibres in the environment and the allowable concentration of respirable fibres in the air.

The fibre concentrations in urban areas are generally not known and knowledge about duration and frequency of exposure as well as the type of fibres are seldom available with an adequate precision. For this reason, the assessment of environmental exposure to asbestos fibres is rather difficult. Hence, the aim of this study was to determine the concentration of respirable asbestos fibres in the air of Sosnowiec, Poland, as an example of an highly urbanized city where asbestos materials in the form of AC sheets have been widely present in building constructions. The recently elaborated sampling strategy for respirable asbestos fibres in the air [20] were applied to the control of the environmental level of these pollutants.

MATERIALS AND METHODS

Sampling area and location of sampling sites. The concentration of respirable asbestos fibres was measured in Sosnowiec, a highly urbanized and densely populated town (city land area estimated at 91.26 km^2; population: 222,829) in the Upper Silesia conurbation in Poland [7]. This city was chosen because of the high housing density and ubiquity of AC panels on residential building elevations. It has been estimated that about 1,313,683 m^2 of asbestos-containing materials were located on the territory of

Sosnowiec. According to data provided by the City Hall, about 98% of building materials (roof and elevation covers) from single-family homes, residential blocks, public and manufacturing sector buildings contain asbestos [31]. Hence, the main criterion for location of sampling sites was the presence of asbestos-containing materials and degree of their corrosion (as the main phenomenon responsible for the release of asbestos fibres into the air). According to the Polish Standard PN-Z-04008-02 [35], the 62 sites scattered across the whole city were chosen for sampling. All the selected places were divided into 3 groups: in the immediate vicinity of the buildings with asbestos-containing materials, at a distance of 100–500 m from such buildings, and in the immediate vicinity of buildings without asbestos-containing materials. The total number of analyzed samples was 100. The filters from each sampling site were subsequently analyzed by both phase contrast microscopy and scanning electron microscopy. These techniques enable determination of quantity (and based on that the concentration) of fibres as well as the type of asbestos in the bulk material, respectively.

Phase contrast microscopy (PCM). The strategy used in this study is described in detail in [20], relies on the PCM technique which enables determination of both the percent and type of asbestos in the bulk material. In brief, the asbestos fibres were sampled using Casella aspirators (Casella Ltd., London, UK) with Harvard pumps (Air Diagnostic and Engineering Inc., Naples, ME, USA) at a high flow rate (8÷9 l/min) for 4–5 hours to obtain large volume samples (2–3 m^3). The samples were collected onto 25-mm nitrocellulose membrane filters with a pore size of 0.8 μm (Sartorius AG, Göttingen, Germany). The filters were transported in both directions, i.e. to the sampling points and back to the laboratory, in a hard container with special holders in order to avoid displacement of the collected fibres. After sampling, the filters were transferred onto a glass slide and subsequently treated to render them transparent using Acetone Vaporizer VAP 200 (BGI Inc., Woltham, MA, USA). Briefly, the whole process was as follows: each filter was transferred from the holder onto a microscopic slide and exposed for a few seconds to a stream of acetone vapour (approximately 0.1 ml of liquid acetone was injected into a hot block of vapourizer), then the excess acetone that condenses on the filter was allowed to parry on a hot block to render the filter transparent (as acetone dissolves cellulose esters based material). After that, a drop of triacetin (glycerol triacetate) was placed on the filter, purifying the granularity left from the acetone vapour clearing, and the whole sample was capped with a coverslip [22, 32]. All the filters were thus prepared and then viewed in a phase contrast microscope at 500× magnification. The fibres defined as respirable were counted according to the Polish Standard PN-Z-04202-02 [36]. To determine the dimensions of fibres, the Walton-Beckett G-22 graticule (Graticules Ltd., Tonbridge, Kent, UK) was used. The presence of fibres was checked in a much longer than usual number of microscopic fields of the Walton-Beckett graticule (i.e. 500) to increase the precision of asbestos quantitative identification.

The fibre concentrations were noted as the proportion of their number on the filter to a volume of the aspirated air given in cubic centimeters (f/cm^3). Although this method is relatively fast and inexpensive, it does not allow distinguishing between asbestos and non-asbestos fibres. In this study, however, all the samples were taken at specific locations in which the contribution of fibres other than asbestos was statistically insignificant, and the origin of sampled fibres was additionally proved by a scanning electron microscope (SEM) analysis.

SEM analysis. For this purpose, using Harvard pumps, the samples were taken onto a 25-mm nitrocellulose membrane filters with a pore size of 0.8 μm at high flow rate (see above) about 10 hours. The final volume of the examined samples was 10 m^3. After sampling, the membrane filters were coated with a thin layer of gold (metallization step) and randomly selected fragments of each filter were analyzed using a scanning electron microscope LEO, type 1430 (Carl Zeiss SMT AG, formerly LEO Electron Microscopy Ltd., Oberkochen, Germany) at 15,000× to 20,000× magnification. Finally, all fibres that showed up in the scanned fields underwent an elemental analysis by energy-dispersing X-ray spectroscopy (EDS) Link ISIS 300 (Oxford Instruments, High Wycombe, UK) to identify their chemical composition. The images obtained from an electron detector during the SEM analysis were digitized and subsequently compared with the elemental patterns characteristic for the known types of asbestos.

Environmental parameters. All asbestos measurements were carried out in spring (April–May) and autumn (September–October), when no rainfalls were observed. During sampling, the air temperature, relative humidity, and velocity were measured using the Omniport 20 portable handheld meter equipped with suitable sensing probes (E+E Elektronik Ges.m.b.H., Engerwitzdorf, Austria).

Data analysis. The obtained data were evaluated using analysis of variance (ANOVA) supplemented by *post-hoc* estimation (Scheffe's test), *t*-test, and Pearson ("r") correlation analysis using Statistica (data analysis software system) version 7.1 – 2006 (StatSoft, Inc., Tulsa, OK, USA).

RESULTS

The presence of asbestos fibres in the air was confirmed by collecting filter samples and investigating them under the SEM. Figures 1 and 2 show examples of SEM images and corresponding EDS spectra of identified respirable asbestos fibres. The performed identification revealed that the fibres sampled in the area of Sosnowiec originated from 2

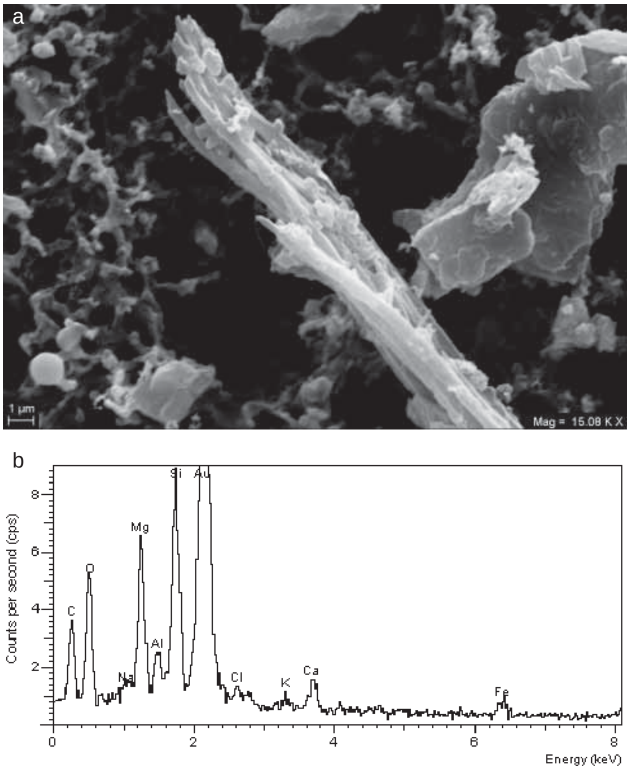

Figure 1. SEM image (a) and corresponding EDS spectrum (b) of crocidolite fibres. Legend of pattern (b): C = carbon, O = oxygen, Na = sodium, Mg = magnesium, Al = aluminum, Si = silicon, Au = gold, Cl = chlorine, K = potassium, Ca = calcium, Fe = iron.

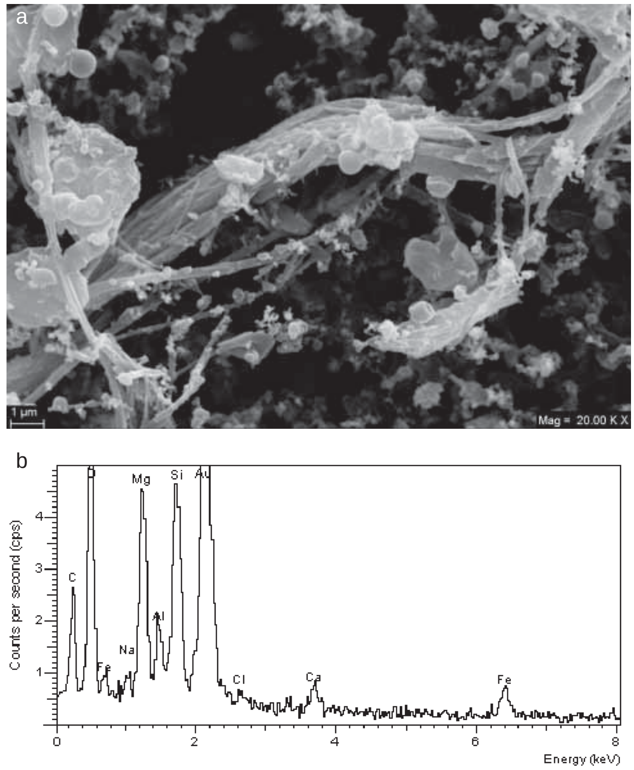

Figure 2. SEM image (a) and corresponding EDS spectrum (b) of chrysotile fibres. Legend of pattern (b): C = carbon, O = oxygen, Fe = iron, Na = sodium, Mg = magnesium, Al = aluminum, Si = silicon, Au = gold, Cl = chlorine, Ca = calcium.

groups of asbestos minerals: crocidolite (Fig. 1a and 1b) and chrysotile (Fig. 2a and 2b).

A total of 100 air samples from 62 sampling sites were collected for this study, including: 41 samples from 27 sites taken in the immediate vicinity of the buildings with asbestos-containing materials, 42 samples from 24 sites received at the distance of 100–500 m from such buildings, and 17 samples gathered from 11 sites in the immediate vicinity of buildings without asbestos-containing materials (Tab. 1). In 51 samples, the asbestos fibre concentrations obtained were below the limit of detection, i.e. <0.0010 f/cm^3. For the rest of the samples, the concentrations varied from 0.0010–0.0090 f/cm^3. The asbestos fibre concentrations were substantially different between 3 studied locations (ANOVA: $p<0.0001$). Significantly higher concentrations were observed in the immediate vicinity of the buildings with asbestos-containing materials, compared to sampling sites located at the distance of 100–500 m from such buildings (Scheffe test: $p<0.01$) or the sites "free" of asbestos-containing materials (Scheffe test: $p<0.001$).

Table 1. Concentration of respirable asbestos fibres [f/cm^3] at selected sampling sites in Sosnowiec.

Sampling site	Number of sampling sites	Number of samples	Average	Range
in the immediate vicinity of buildings with asbestos-containing materials	27	41	0.0018	<0.0010–0.0090
at a distance of 100–500 m from buildings with asbestos-containing materials	24	42	<0.0010	<0.0010–0.0020
in the immediate vicinity of buildings without asbestos-containing materials	11	17	<0.0010	<0.0010–0.0010

Table 2. Air temperature, relative humidity, and velocity values (mean ± SD) measured during asbestos fibre sampling at selected sites in Sosnowiec.

Sampling site	Temperature [ºC]	Relative humidity [%]	Velocity [m/s]
in the immediate vicinity of buildings with asbestos-containing materials	18.2 ± 3.3	56.5 ± 9.0	0.9 ± 0.3
at a distance of 100–500 m from buildings with asbestos-containing materials	21.6 ± 6.0	57.8 ± 19.3	1.0 ± 0.6
in the immediate vicinity of buildings without asbestos-containing materials	24.2 ± 4.5	52.0 ± 11.7	0.6 ± 0.4

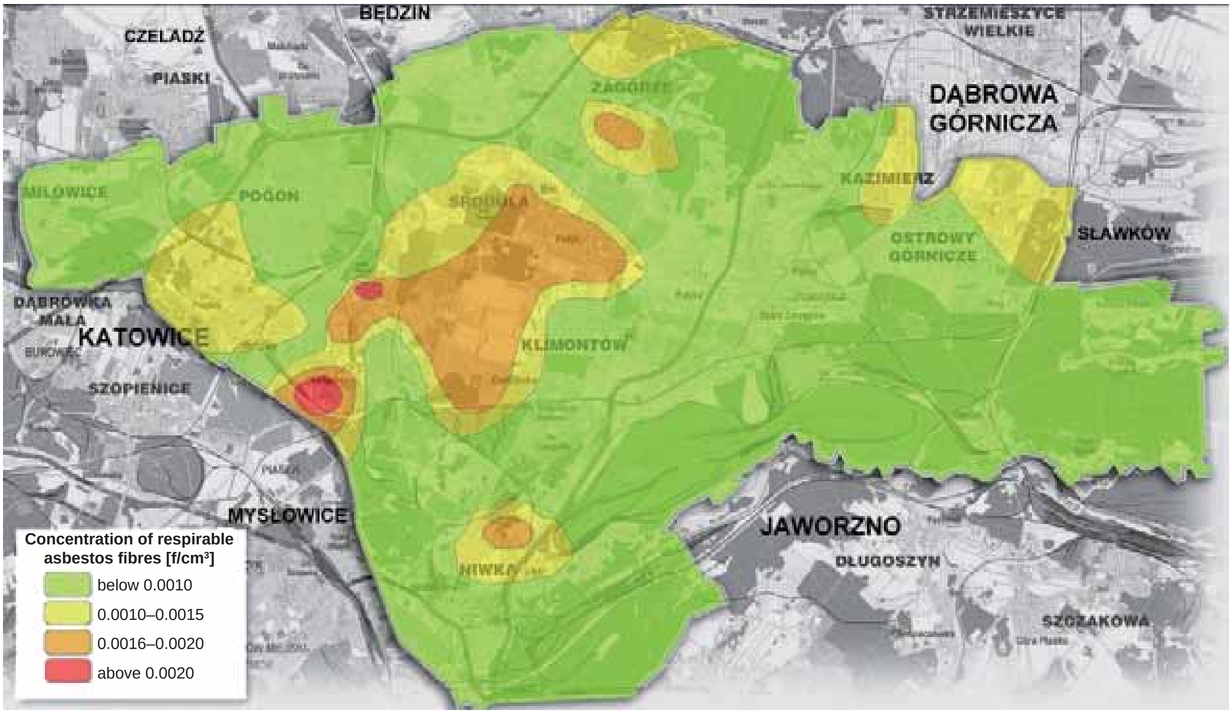

Figure 3. Map of spatial distribution of respirable asbestos fibre concentrations.

Table 3. Airborne asbestos fibre concentrations [f/cm³] in urban, rural and industrial environments.

Country [data source]	Mean concentration or range		
	Urban	Rural	Industrial
Japan [26, 42]	0.0198	0.0218	0.014
Korea [26]	0.00062	0.0003	0.00078
Greece [2]	NA	NA	0.07–0.19
India [3]	NA	NA	1.24–17.2
Poland [25, 45, 52]	0.0–0.0003	NA	<0.0006–0.43
Italy [5]	NA	NA	0.0061–0.1
Israel [14]	NA	NA	0.02–0.14
Canada [41]	NA	NA	0.05–5.0
Sweden [41]	NA	NA	1.0–2.0
England [41]	NA	NA	0.5–20
Philippines [49]	NA	NA	0.01–0.31
Republic of South Africa [38]	NA	NA	0.008–0.04
USA [4, 10, 18, 27, 37, 41, 53]	0.0–0.011	NA	0.000035–91.4
Other sources [1, 16, 17, 55]	0.000003–0.0198	0.0003–0.0218	0.00078–0.15

NA – not available

The proposed scattering of the sampling points allowed the identification, within the studied city area of the places with high, moderate and low concentrations of airborne asbestos fibres (Fig. 3). The performed monitoring therefore enabled the drawing a map of the environmental concentration of the studied fibres, which can be used to identify existing active sources of asbestos and, based on that, to plan the remediation actions in places where contamination of the surrounding environment is the most severe (i.e. where the degree of corrosion of the building materials posing a health hazard is substantial).

The environmental conditions in which all experiments were carried out are presented in Table 2. As can be seen, all measurements were carried out at air temperature, humidity and velocity typical for outdoor air in a Central-European city (temperate climatic zone) during the spring and autumn seasons. However, when these values between the studied locations were compared, the significant differences were visible for the noted temperatures only (ANOVA: $p<0.001$). As seen in Table 2, the highest values were observed near the buildings without asbestos-containing materials and were significantly distinct from those observed in the vicinity of buildings with such materials (Scheffe test: $p<0.001$). Hence, the convective mechanism of fibre transport could be a major factor responsible for the contamination of the environment in the immediate vicinity of this type of source.

Correlation analysis between the observed fibre concentrations and the values of measured air parameters revealed that only at sampling sites located at the distance of 100–500 m from the buildings with asbestos-containing

Table 4. Asbestos fibre concentrations [f/cm³] in indoor and outdoor air.

Country [data source]	Mean concentration or range				
	Buildings with asbestos-containing materials				Outdoor
	Public and commercial	School and university	Residential	Under renovation	
Korea [26]	0.00059	NA	0.00052	NA	0.00027
Japan [26, 48, 58]	NA	0.00065	0.0198	0.03–0.20	0.005
Russia [19]	0.006–0.058	NA	<0.001–0.049	0.002–0.57	<0.001–0.009
England [30]	NA	NA	NA	NA	<0.00065
Australia [12]	NA	NA	NA	NA	0.0012
Germany [12]	NA	NA	NA	NA	0.0002-0.0012
Poland [45]	<0.0006–0.0200	NA	0.0007–0.1210	0.002–0.014	<0.0006
USA [9, 10, 21, 24, 46]	0.00006–0.00009	0.00003–0.00024	0–0.00005	0.0–0.998	0.0–0.0017
Other sources [13, 14, 16, 43]	0.0002–0.022	0.00011–0.00051	0.00019	0.013	0.0001

NA – not available

materials, the air velocity significantly increased the levels of airborne asbestos fibres ($r=0.38$ at $p<0.05$). This suggests that even a very gentle air movement can play an important role in the spreading of fibres over a relatively wide area near the asbestos source.

DISCUSSION

Asbestos fibres have been found in different environments derived from both natural and anthropogenic sources. They are a proven human carcinogen (IARC Group 1). Already in 1980, the National Institute of Occupational Safety and Health (NIOSH) as well as the Occupational Safety and Health Administration (OSHA) working group concluded that there are no levels of exposure to asbestos below which clinical effects did not occur. Therefore, the exposure should be kept as low as possible. Considering the numerous health hazards resulting from the inhalation of asbestos dust, there is no safe environmental level for this harmful factor [33, 55, 57]. Although, in many countries the production and utilization of asbestos-containing materials has been banned, the numerous active environmental sources still exist. It is especially visible in housing, where the processes of corrosion, mechanical destruction or removal of deteriorated building cover panels can cause severe contamination of the surrounding environment thereby, posing a health hazard to inhabitants. Although the "bad name" of asbestos is widely known, its environmental control is still not prevalent and data regarding the environmental levels are scarce. Tables 3 and 4 summarize the data available in the scientific literature, covering different environments, types of buildings and human activities. The hitherto obtained results of environmental concentrations of respirable asbestos fibres show a wide range of values. The observed discrepancy in the concentrations are dependent on the different environments, specific sampling locations and/or presence of additional emission sources. As can be seen, the range of measured values is very wide, reaching maximally 91.4 f/cm³ at selected workplaces. The concentrations noted in the urban areas also varied (0–0.0198 f/cm³). Against a background of these results, the concentrations of airborne respirable asbestos fibres obtained in Sosnowiec are within this range.

When outdoor asbestos fibre concentrations are compared with those obtained indoors, the process of fibre migration is clearly visible. For example, Kovalevskiy and Tossavainen, taking measurements near a building with asbestos-containing materials in Moscow, showed that when outdoor concentrations reach the level of 0.009 f/cm³, at the same time, indoor concentrations approach 0.049 f/cm³ in residential premises, or even 0.57 f/cm³ if the building was undergoing renovation [19]. Based on the fact that environmental levels of asbestos fibre concentrations in Sosnowiec reached exactly the same level (i.e. 0.009 f/cm³), their indoor concentrations can be as high as in those in the Russian studies. Hence, the anticipated level of indoor exposure in Sosnowiec could be equally high (i.e. approximately 5-6 times higher than outdoors).

The presence of asbestos-containing materials should constantly be treated with special care, particularly in buildings. Many buildings in Central Europe are still covered with asbestos-containing thermal insulation panels. In many countries, asbestos-containing products used as insulating and fireproofing materials, drywalls, ceiling or floor tiles, are quite frequently placed in immediate contact with air-conditioning systems. Even if some of these asbestos products are no longer in use, they can be still found in many public and residential buildings. Many well known factors, such as renovation, repairs, maintenance, human activities, including routine housekeeping, external vibrations or vandalism, can considerably increase the emission of asbestos dust from existing indoor and outdoor sources [24]. When the above described deterioration of asbestos-containing materials occurs, respirable asbestos fibres can be released into the air and subsequently transported into the environment, even by a relatively gentle air movement

[9]. As was shown in the present study, the air velocity of about 1 m/s was strong enough to transport the majority of asbestos fibres from their source up to a few hundred meters away, expanding the area of exposure beyond the place of origin.

As visualized by the map of spatial distribution of respirable asbestos fibre concentrations, such an airborne transfer of this type of pollutant, however, occurred within a relatively narrow space around the active source. In the case of Sosnowiec area, 2 sites of the highest environmental concentrations of asbestos fibres were identified (in both cases, they were housing estates with a high compact settlement) and their dimensions did not exceed 1.5 and 7.0 km^2, respectively. This type of information can be useful for both the City Hall officials regarding the localization of planned remediation actions, and for the companies providing or responsible for asbestos removal and abatement services. Despite the size of the threatened area, the control of passive exposure caused by public buildings where asbestos may be decaying and, when airborne, spreading in outdoor air as well as slowly drifting into indoor air, should constantly be a major concern for all official bodies responsible for environmental protection.

CONCLUSIONS

The deterioration of asbestos-containing construction materials (such as asbestos-cement sheets used in residential and industrial buildings) causes contamination of the urban environment. The study performed in Sosnowiec, a highly urbanized and densely populated town of the Upper Silesia conurbation in Poland, revealed that asbestos fibres identified in the air samples near buildings covered with AC panels derived from 2 groups of asbestos minerals, i.e. crocidolite and chrysotile. The observed concentrations of respirable asbestos fibres varied from 0.0010–0.0090 f/cm^3. Significantly higher values were noted in the immediate vicinity of the buildings with asbestos-containing materials, compared to sampling sites located at a distance of 100–500 m from such buildings or the sites treated as a "free" from asbestos sources. Correlation analysis between observed fibre concentrations and the values of air temperature, relative humidity, and velocity revealed that only the latter parameter (even at a very low level, i.e. 1 m/s) plays an important role in the spreading of fibres near the asbestos source.

The ranging with sampling points over the city area enabled (as was shown in this study using the city of Sosnowiec as an example) the reckoning of the spatial distribution of respirable asbestos fibre concentrations and, subsequently, the drawing of a map with precisely described places where an environmental exposure to this pollutant is the highest. Such a map with clearly indicated so-called "hot spots" could be a useful tool for the official bodies in planing necessary asbestos remediation actions.

REFERENCES

1. Agency for Toxic Substances and Disease Registry (ATSDR): *Toxicological Profile for Asbestos*. US Department of Health and Human Services, Public Health Service, Atlanta 2001.
2. Anastasiadou K, Gidarakos E: Toxicity evaluation for the broad area of the asbestos mine of northern Greece. *J Hazard Mater* 2007, **139**, 9-18.
3. Ansari FA, Ahmad I, Ashquin M, Yunus M, Rahman Q: Monitoring and identification of airborne asbestos in unorganized sectors, India. *Chemosphere* 2007, **68**, 716-723.
4. Blake CL, Dotson GS, Harbison RD: Evaluation of asbestos exposure within the automotive repair industry: A study involving removal of asbestos-containing body sealants and drive clutch replacement. *Regul Toxicol Pharmacol* 2008, **52**, 324-331.
5. Bologna L, Ferri A, Lauria E, Wojtowicz M: The necessity of SEM analysis in outdoor environment monitoring of airborne asbestos fibres. **In:** *Proceedings of the International Conference on Asbestos Monitoring and Analytical Methods, 5-7 December 2005*, 22-23. Venice 2005.
6. Brzozowski A, Obmiński A: Where is it necessary to secure or remove asbestos in Poland? (1). *Bezpieczeństwo pracy – nauka i praktyka* 2004, **4**, 11-15 (in Polish).
7. City Hall of Sosnowiec (http://www.um.sosnowiec.pl).
8. Commins BT: *The Significance of Asbestos and Other Mineral Fibres in Environmental Ambient Air. Scientific and Technical Report 2*. Commins Association, Maidenhead 1985.
9. Corn M, Crump K, Farrar DB, Lee RJ, McFee DR: Airborne concentrations of asbestos in 71 school buildings. *Regul Toxicol Pharmacol* 1991, **13**, 99-114.
10. Corn M: Airborne concentrations of asbestos in non-occupational environments. *Ann Occup Hyg* 1994, **38**, 495-502.
11. Council of Ministers: *Programme for Removing Asbestos and Asbestos-Containing Materials Used on the Territory of Poland accepted on 14 May 2002.* The Chancellery of the Prime Minister, Warsaw 2002 (in Polish) (in Polish).
12. enHEALTH Council, Department of Health and Ageing: *Management of asbestos in the non-occupational environment*. Australian Government, Canberra 2005.
13. Esmen NA, Erdal S: Human occupational and nonoccupational exposure to fibers. *Environ Health Perspect* 1990, **88**, 277-286.
14. Ganor E, Fischbein A, Brenner S, Froom P: Extreme airborne asbestos concentrations in a public building. *Br J Ind Med* 1992, **49**, 486-488.
15. Greenberg M: The defence of chrysotile, 1912-2007. *Int J Occup Environ Health* 2008, **14**, 57-66.
16. Health Effects Institute (HEI): *Asbestos in public and commercial buildings: a literature review and synthesis of current knowledge. Report of the asbestos literature review panel*. HEI, Cambridge 1991.
17. International Agency for Research on Cancer (IARC): *IARC Monographs, Supplement 7: Asbestos*. IARC, Lyon 1987.
18. Jiang GCT, Madl AK, Ingmundson KJ, Murbach DM, Fehling KA, Paustenbach DJ, Finley BL: A study of airborne chrystotile concentrations associated with handling, unpacking, and repacking boxes of automobile clutch discs. *Regul Toxicol Pharmacol* 2008, **51**, 87-97.
19. Kovalevskiy E, Tossavainen A: Asbestos fibers in the urban environment in Moscow. **In:** *Proceedings of the IOHA 6th International Scientific Conference 19-23 September 2005*, Paper J5. Pilanesberg 2005.
20. Krakowiak E, Cembrzyńska J, Sąkol G, Górny RL: Sampling strategy of atmospheric air samples for determination of concentration of respirable asbestos fibers. *Environ Med* 2008, **11**, 23-30 (in Polish).
21. Lange JH, Lange PR, Reinhard TK, Thomulka KW: A study of personal and area airborne asbestos concentrations during asbestos abatement: A statistical evaluation of fibre concentration data. *Ann Occup Hyg* 1996, **40**, 449-466.
22. Le Guen JMM, Galvin S: Clearing and mounting techniques for the evaluation of asbestos fibres by the membrane filter method. *Ann Occup Hyg* 1981, **24**, 273-280.
23. Lee RJ, Strohmeier BR, Bunker KL, Van Orden DR: Naturally occurring asbestos – A recurring public policy challenge. *J Hazard Mater* 2008, **153**, 1-21.

24. Lee RJ, Van Orden DR: Airborne asbestos in buildings. *Regul Toxicol Pharmacol* 2008, **50**, 218-225.

25. Lesz M: Asbestos in the air. **In:** *Proceedings of the International Conference on Asbestos Risk Reduction and Measurement of Asbestos Fibre Concentration, 28-29 September 2006*. University of Science and Technology, Cracow 2006.

26. Lim HS, Kim JY, Sakai K, Hisanaga N: Airborne asbestos and non-asbestos fiber concentrations in non-occupational environments in Korea. *Ind Health* 2004, **42**, 171-178.

27. Liukonen LR, Weir FW: Asbestos exposure from gaskets during disassembly of a medium duty diesel engine. *Regul Toxicol Pharmacol* 2005, **41**, 113-121.

28. London Hazards Centre: *Asbestos Hazards Handbook: A Guide to Safety Work in the Community and at Home (London Hazards Centre handbook)*. London Hazards Centre Trust, London 1995.

29. Marek K (Ed): *Occupational diseases*. Wydawnictwo Lekarskie PZWL, Warsaw 2003 (in Polish).

30. Massey SW, Llewellyn JW, Brown RC: Environmental exposure to fibrous materials. **In:** *Fibrous Materials in the Environment*, 47-70. Institute for Environment and Health, Leicester 1997.

31. Mayor of Sosnowiec, *Programme of removing asbestos and asbestos-containing materials for the city of Sosnowiec*. City Hall of Sosnowiec 2006 (in Polish).

32. National Occupational Health And Safety Commission: *Guidance Note on the Membrane Filter Method for Estimating Airborne Asbestos Fibres*, 2nd Ed. NOHSC, Canberra 2005.

33. NIOSH/OSHA Asbestos Work Group: *Workplace Exposure to Asbestos. Review and Recommendations*. DHHS (NIOSH), Washington 1980.

34. Order of the Minister of Economy, Labour and Social Policy of 21 April 2004 on the Ways and Conditions for the Safe Use and Disposal of Asbestos-Containing Products (Dz.U. Nr 71, poz. 649) (in Polish).

35. Polish Standard PN-Z-04008-02: *Air Purity Protection - Sampling - General Guidelines for Sampling of Ambient Air (immission)*, Polish Committee for Standardization (PKN), Warsaw 1984.

36. Polish Standard PN-Z-04202-02: *Air Purity Protection - Tests for Asbestos - Determination of Numerical Concentration of Respirable Asbestos Fibers in Work Places by Optical Microscopy*, Polish Committee for Standardization (PKN), Warsaw 1988.

37. Ribak J, Ribak G: Human health effects associated with the commercial use of grunerite asbestos (amosite): Paterson, NJ; Tyler, TX; Uxbridge, UK. *Regul Toxicol Pharmacol* 2008, **52**, 82–90.

38. Rödelsperger K, Woitowitz HJ: Airborne fibre concentrations and lung burden compared to the tumour response in rats and humans exposed to asbestos. *Ann Occup Hyg* 1995, **39**, 715-725.

39. Roggli VL, Vollmer RT: Twenty-five years of fiber analysis: what have we learned? *Human Pathology* 2008, **39**, 307-315.

40. Ross M, Kuntze RA, Clifton RA: A definition for asbestos. **In:** Levadie B (Ed): *Definitions for Asbestos and Other Health-Related Silicates*, 139-147. ASTM International, Philadelphia 1984.

41. Ross M: The schoolroom asbestos abatement program: a public policy debacle. *Environ Geology* 1995, **26**, 182-188.

42. Sakai K, Hisanaga N, Kohyama N, Shibata E, Takeuchai Y: Airborne fiber concentration and size distribution of mineral fibers in area with serpentinite outcrops in Aichi Prefecture, Japan. *Ind Health* 2001, **39**, 132-140.

43. Schneider T, Burdett G, Martinon L, Brochard P, Guillemin M, Teichert U, Draeger U: Ubiquitous fiber exposure in selected sampling sites in Europe. *Scand J Work Environ Health* 1996, **22**, 274-284.

44. Skinner HC, Ross M, Frondel C: *Asbestos and Other Fibrous Materials*. Oxford University Press, New York 1988.

45. Stroszejn-Mrowca G, Szadkowska-Stańczyk I: Monitoring of environment and evaluation of occupational exposure to asbestos dust during removal of "asbestos products" from environment. **In:** Dyczek J (Ed): *Asbestos Risk Reduction and Measurement of Asbestos Fibre Concentaration, Proceedings of the International Seminar held in AGH, University of Science and Technology, Appendix, 28–29 September 2006*, 21-24, Cracow 2006.

46. US Environmental Protection Agency (US EPA): *US EPA Asbestos Assessment for El Dorado Hills*. US EPA Region 9, San Francisco 2005.

47. US Geological Survey: *Mineral Commodity Summaries 2008*. US Geological Survey, Washington 2008.

48. Uchiyama I: Risk communication – a case study: Accidental Exposure to Asbestos at a Nursery School. **In:** Kazan-Allen L (Ed): *Report of the Global Asbestos Congress (GAC 2004), 19-21 November 2004*, Tokyo 2004.

49. Villanueva MBG, Granadillos NG, Cucesco MTS, Estrella-Gust DP: *Asbestos in the Philippines: Country Report*. Occupational Safety and Health Center (OSHC), Quezon City 2004.

50. Virta RL: Asbestos. **In:** *2007 Minerals Yearbook*. US Geological Survey. Denver 2008.

51. Vogel L (Ed): *Special report. Asbestos in the world*. Hesa Newsletter, Brussels 2005.

52. Więcek E: Asbestos – exposition and health effects. *Bezpieczeństwo Pracy* 2004, **2**, 2-6 (in Polish).

53. Wilson R, McConnell EE, Ross M, Axten CW, Nolan RP: Risk assessment due to environmental exposures to fibrous particulates associated with taconite ore. *Regul Toxicol Pharmacol* 2008, **52**, S232-S245.

54. Woitowitz HJ: *Asbestos-related diseases-the current situation*. Report given to the European Asbestos Conference, Dresden 2003.

55. World Health Organization (WHO): *Air Quality Guidelines for Europe*, 2nd ed., WHO Regional Office for Europe, Copenhagen 2000.

56. World Health Organization (WHO): *Environmental Health Criteria 53. Asbestos and Other Natural Mineral Fibres*. WHO, Geneva 1986.

57. Woźniak H, Więcek E: Asbestos and asbestos-related diseases. *Ann Agric Environ Med* 1996, **3**, 1-6.

58. Yu IJ, Yoo CY, Chung YH, Han JH, Yhang SY, Yu GM, Song KS: Asbestos exposure among Seoul metropolitan subway works during renovation of subway air-conditioning systems. *Environ Int* 2003, **29**, 931-934.