Journal of Hazardous Materials A139 (2007) 9–18

Journal of Hazardous Materials

www.elsevier.com/locate/jhazmat

Toxicity evaluation for the broad area of the asbestos mine of northern Greece

Kalliopi Anastasiadou, Evangelos Gidarakos *

Laboratory of Toxic and Hazardous Waste Management, Department of Environmental Engineering, Technical University of Crete, Politechnioupolis, Chania, P.C. 73100, Greece

Received 20 March 2006; received in revised form 1 June 2006; accepted 6 June 2006
Available online 16 June 2006

Abstract

The existing data regarding the quality of the environment in the asbestos mine of northern Greece (MABE) region related to the presence of asbestos are insufficient to determine the current pollution problem. In the present work, a first approach to this problem has been taken through a toxicity risk assessment. The environmental quality of an open air asbestos mine was evaluated over a long period of time by measuring and monitoring the concentration of asbestos fibres in air, soil and water. Air measurements were made to determine the concentration of asbestos fibres in the atmospheric air of the mine, the depositions and the nearby villages. The asbestos fibre concentration was also specified inside the building facilities of MABE. Analyses of soil, dust and water samples were carried out showing the presence of enormous quantities of chrysotile asbestos. The concentration of asbestos fibres in the atmospheric air was compared to older measurements that were taken at the same sampling points during the operation of the mine. The results of this work, in conjunction with individual researches that have been carried out in the past and with the evaluation of international standards of scientific and experience-based findings, provide a reliable framework with which to estimate the threat of MABE to its surrounding environment, and help to determine a basic criterion for the remediation and rehabilitation of the region. In addition, mathematical models based on human and animal studies were used to estimate the probability of a person developing cancer from breathing air containing asbestos fibres in the wider vicinity of the mine in order to define appropriate procedures for evaluating asbestos-related risk.

Keywords: Asbestos; Mine; Toxicity; Fibres; Risk assessment

1. Introduction

Asbestos is a silicate mineral of fibrous form and has been used for many years as a raw material for the production of a large variety of materials and objects by virtue of its exceptional attributes. Unfortunately asbestos is considered responsible for serious lung diseases such as asbestosis, mesothelioma and lung cancer that are caused by the inhalation of asbestos fibres and appear usually after a long period of exposure.

Legislative regulations have been published by the EU and the USA regarding asbestos, its use, its restriction from the market, the protection of workers as well as the prevention and reduction of environmental pollution.

The permissible exposure limit (PEL) for asbestos in Europe is determined at 0.10 fibres/cm^3 (f/cm^3) of air as a time-weighted average (TWA) concentration over an 8-h workshift according to the modification of Directive 83/477/EC, with 2003/18/EU [1]. The current Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for asbestos is 0.2 f/cm^3 of air as a time-weighted average (TWA) concentration over an 8-h workshift with an action level of 0.1 f/cm^3 as an hour TWA [2,3]. The National Institute for Occupational Safety and Health (NIOSH) recommends that asbestos be controlled and handled as a potential human carcinogen in the workplace and that exposure be minimized to the lowest feasible limit. The NIOSH recommended exposure limit (REL) is 0.1 f/cm^3 as a TWA concentration for up to an 8-h workshift [4].

EPA has also determined limits for the presence of asbestos in internal spaces and in the atmosphere, depending on the quantitative evaluation of danger for human health. Air with asbestos concentrations of 0.01–0.02 f/cm^3 is acceptable fol-

* Corresponding author. Tel.: +30 2821037789; fax: +30 2821037850.
E-mail address: gidarako@mred.tuc.gr (E. Gidarakos).

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doi:10.1016/j.jhazmat.2006.06.031

Table 1
Asbestos exposure limits

Exposure limits	Air (f/cm^3)	Water (f/l)	Soil
TWA (time-weighted average)	0.1 (EU), 0.1 PEL (OSHA-EPA action level), 0.1 REL (NIOSH)	7,000,000 (EPA)	No limits
TLV (threshold limit value)	0.6 Chrystile asbestos (EU), 0.3 other types of asbestos (EU), 0.1 (ACGIH) [5]		

lowing abatement of asbestos containing materials according to EPA regulations.

Table 1 presents the exposure limits for asbestos fibres in the environmental means according to several federal agencies.

As indicated by the EPA, in the atmosphere there are other cancer-causing elements, thus increasing the total risk. Consequently, the aim of the strict limits for individual substances is to reduce the total risk to less than 10^{-6}, in other words for the probability of a case of cancer to develop, which is connected with these substances, to be one in 1,000,000 persons. According to the EPA the probability of cancer developing in an individual due to the inhalation of asbestos fibres is calculated by the following empirical formula-equation [6]:

$$\text{Danger level} = 2.3 \times \frac{C}{10}$$

where C is the concentration of asbestos fibres in the air (f/cm^3). The analytical procedures used for risk analysis use a minimum fibre dimension of 5 μm in length, 0.2 μm in width, with a minimum aspect ratio of 3:1. It has to be pointed out that the risk model assumes a lifetime exposure at a known airborne concentration.

2. Description of MABE, the asbestos mine and depositions

The presence of asbestos at Zidani in the prefecture of Kozani was found for the first time in 1936 while at the beginning of the 1950s, it was determined as the most exploitable asbestos layer in Greece. The asbestos mine of northern Greece (MABE) is situated 1 km south of the river Aliakmona near the artificial lake.

Polyfytou and at a distance from the city of Kozani of about 40 km. The water supply of Thessalonica, the second largest city of Greece, comes from the river Aliakmonas. The average quality of excavated asbestos is of category 4 according to the Canadian Scale of classification (QAMA) [7]. The reserves were calculated to be around 30 million tonnes but there could be as much as 100 million tonnes. During the period 1982–2000, there were roughly 70 million tonnes of the mineral serpentine excavated from the MABE mine, of which 1 million tonnes of chrysotile asbestos were produced [8]. The region of MABE covers an area of 4,135,115 m^2, at an altitude of 672–100 m. It is separated schematically in four units that consist of the mine, the depositions, the building facilities and the open air area. Today and for the next 30 years the MABE facilities will belong to the municipality of Kozani, with the intended purpose of remediation, improvement and exploitation of the entire area.

In Fig. 1 the map of west Macedonia (Greece) is present and the location of the MABE asbestos mine is pointed out.

Fig. 2 illustrates the entire MABE region. The mine and the depositions, as well as the building facilities are clearly showed. The measuring points of soil and air sampling are placed also on the map.

2.1. The mine

The production process of minerals was carried out in the mine for a period of 18 years and can be distinguished into three phases. The excavation took place in the open mine using the benching method. It included the revelation of upper barren (excavation, loading, transfer and direct rejection in the deposition of the mine), and the excavation of minerals and subsequent transportation by mechanical means to the factory. Explosives were used for the excavation of minerals and the rocky barren. The transportation of the minerals to the factory and to the depositions was conducted through internal corridors that were created in order to connect the benches. The result of this process was the creation of funnel-shaped excavation, with a depth of 180 m, with benches 10 m high and 5 m wide. The total expanse of the mine covers 335 acres. The continuous excavation created a small lake at the bottom of mine (altitude + 480 m), the level of which is not stable, as the surrounding serpentinite is not waterproof and is greatly influenced by rainfall.

In Fig. 3 a view of the open mine excavation of MABE is present. In the background a part of the building facilities

Fig. 1. Map of Greece and Kozani.

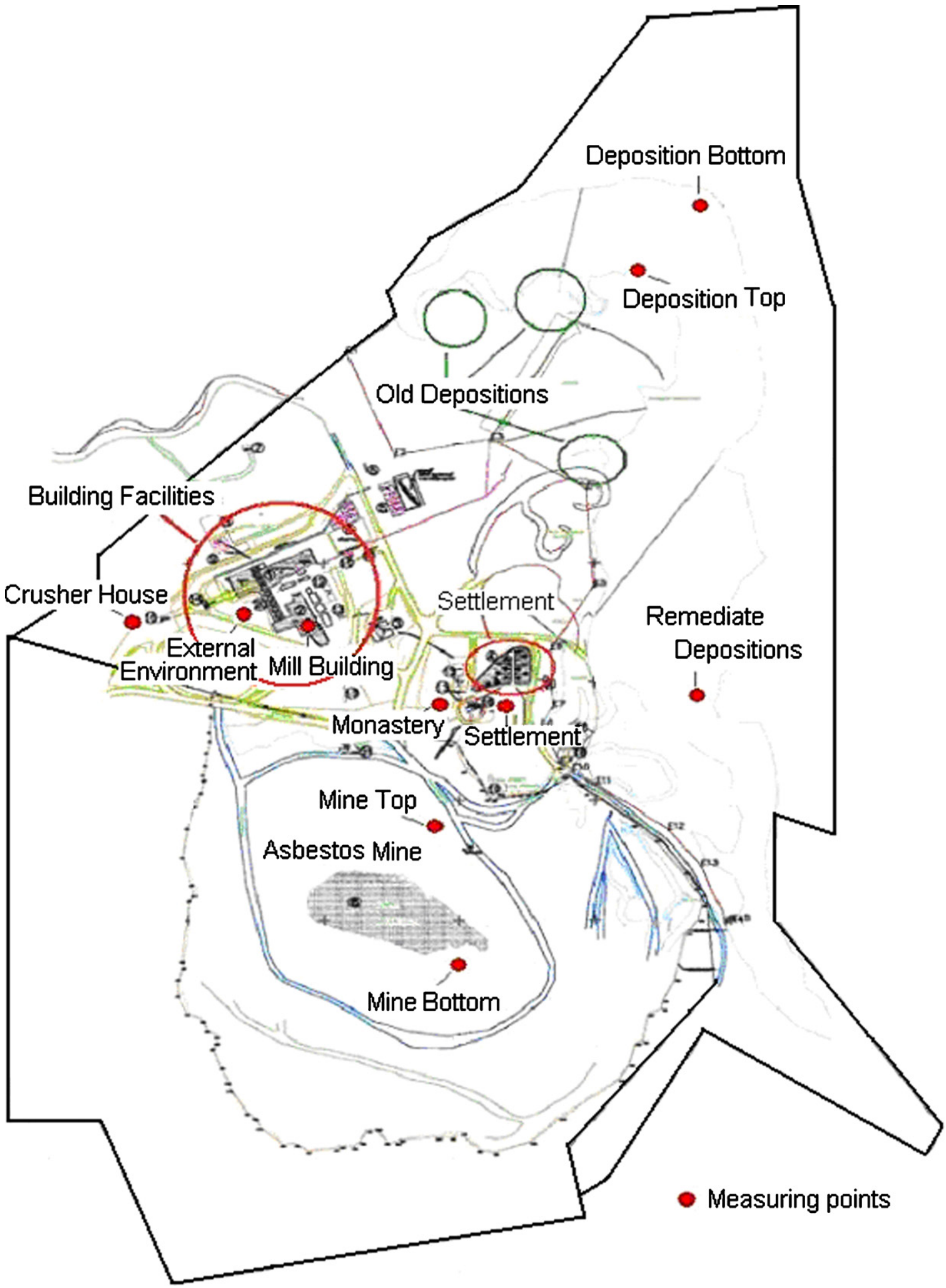

Fig. 2. Map of the MABE region.

Fig. 3. Closed benching excavation.

(Crusher house) is located, were the mineral was transferred to from the open mine. The lake inside of the open mine excavation is also described in Fig. 3.

2.2. Deposition of barren material

All these years the barren materials from the mine as well as the fine grain materials coming from the mineral treatment were being deposited into the ravine, which is found at the eastern and southeastern part of the facilities, very close to the river Aliakmonas. It was calculated that the barren material contained around 0.2% asbestos [9]. Considering that the total quantity of barren materials in the depositions is 69,000,000 tonnes, one can conclude that the depositions contain the equivalent of about 138,000 tonnes of pure asbestos.

Fig. 4 presents the views from the deposition of the barren material. As it is shown in this figure they are placed very close to the river Aliakmonas.

The extended area of the depositions is 532 acres and because of the ground morphology, a single slope of 170 m without intermediary benches was progressively shaped from the superior to the inferior sections. The height of the depositions decreases from north to south, over a distance of 3 km, from 180 m down to 10 m. The steepest inclination (80%) is observed at the northern and northeastern side, covering 65% of the surface. The area of the barren waste depositions is found in the southeastern department of the MABE region. The transfer of these materials to the factory was accomplished with mechanical equipment (dumper, shovel, chargers) while bulldozers were used for the configuration, creating a progressively horizontal square at an altitude of +590 m with a single bench to the ravine. Because of the method of deposition and the nature of the material as far as the size is concerned, the larger deposits eventually reach the base of the slope while the smaller deposits remain on the slope, creating piles. The lowest section of the deposition has an altitude of +512 m and has suffered repeatedly from landslides and subsidences due to the great difference in altitude (78 m).

Fig. 4. Site of depositions from the bridge of the river Aliakmonas.

The deposition area of the waste material, which remained after the treatment of the minerals in the factory, was concentrated in the eastern section of the region—a distance of roughly 800 m from the factory. The process of progressively depositing fine grain waste materials created a square at the altitude of +567 m with a small bend on the slopes brow and a single slope with a steep inclination (about 90%) and a hypsometric difference of 190 m between the brow and the base of the slope. Landslides and subsidence have occurred because of the enormous volume of deposits that is combined with exceptionally abrupt bends.

2.3. Description of the building facilities

The building installations are found in the western site of the MABE region and occupy a total expanse of roughly 10,000 m^2.

The main installations of the mineral processing facilities are the following [8]:

(1) crusher house,
(2) dryer building,
(3) transfer house,
(4) three wet silos and six dry silos,

(5) mill building,
(6) storage building,
(7) tailing conveyors.

Other than these main installations the MABE facilities include various auxiliary installations (administrative buildings and other services, garages, deposits, settlements, etc.).

3. Materials and methods

3.1. Air sampling

Air sampling was performed according to the standard method for asbestos sampling—the NIOSH Method 7400 written by the National Institute of Occupational Safety and Health [10] for phase contrast microscopy (PCM)—and according to the air sampling process described by the EU Directive 83/477/EC [11]. Static samples were taken at fixed locations, 1.5 m above floor level. By using this specific method, a measured volume of air was drawn through a membrane filter, which was subsequently mounted on a microscope slide and rendered transparent. Fibres on a measured area of filter were counted using phase contrast microscopy (PCM), and the concentration of fibres in the air was calculated.

The membrane filters were made of mixed esters of cellulose nitrate, with a pore size of 0.8 m and 25 mm in diameter with a printed grid. The selected flow rate was 2 l/min and the total sample duration was 4 h per sample, in accordance with the requirements of the analytical method. The practical lower detection limit was approximately 0.01 f/cm^3 [12,13].

During the measurement of free asbestos fibres using PCM, countable fibres are defined as particles with length >5 μm, width <3 μm and aspect ratio (length:width ratio) >3:1 [10].

3.2. Soil samples

The sampling of asbestos dust, crude asbestos as well as rock serpentine was conducted. Scope of the sampling program was to determinate the diffusion of the free asbestos fibres into the external environment due to the operation of the mine. Samples of asbestos dust were taken from the building facilities and the monastery (external walls).

Soil samples were also taken from the depositions to determinate the concentration of asbestos in the fine grain size barren material (coming from the mineral treatment and not the mine). After the mineral treatment the serpentine rock coming from the mine is crushed and the enclosed asbestos fibres are no more bounded to the main rock. In this way, free asbestos fibres are diffused easily into the environment. In order to determinate the highest concentration of free asbestos fibres in soil (worst case scenario), only the fine grain size of the soil samples were analyzed. For the collection of each sample, five representative samples were taken randomly with a total sampling depth of 30 cm and were homogenized. The soil samples were taken from the deposition square (deposition top) and only the part of soil with a grain size less than 2 mm was used for the analyses.

The samples were stored in special plastic bags (PE) and were preserved at a temperature of 4 °C [14]. The samples were first observed optically and were analyzed afterwards with X-ray powder diffraction (XRD) according to the NIOSH Method 9000 asbestos by XRD [9]. A scanning electronic microscope (SEM) [14] was also used and the suspect fibres were examined with an energy dispersive X-ray for their composition.

For routine analysis, scanning electronic microscope (SEM) allows for good visualization of fibre morphology down to widths of about 0.05 μm, depending on the method used [15]. In addition, an energy dispersive X-ray analyser determines the elemental composition of fibres with widths greater than about 0.2 μm. In XRD analysis, a bulk sample of material is subjected to X-ray bombardment and the angle of the diffracted radiation is measured. This technique allows the crystal structure of mineral compounds to be determined [16].

3.3. Water measurements

Water samples were examined by transmission electronic microscope (TEM) according to EPA/600R-94/134 [17]. This test method is recommended when aiming to determine the presence and quantification of asbestos structures in drinking water samples. The method allows for the quantification of structures greater than 10 μm in length.

Water is collected in a polyethylene or glass container and shipped to the laboratory. Known aliquots of the sample are filtered through a 0.1–0.22 μm pore mixed cellulose ester (MCE). A carbon extraction replica is prepared from a portion of the filter and is examined in the TEM at a magnification of 10,000–20,000 times. Asbestos structures are identified by morphology, selected area electron diffraction (SAED) and energy dispersive X-ray analysis (EDXA) [15]. Structures are then classified.

4. Results

The determination of pollution from free asbestos (fibres) in the wider area of the MABE asbestos mine was judged advisable, so that the necessity of a direct remediation of the place can be evaluated. Depending on the seriousness of the situation, appropriate measures must be taken before and during the remediation. The goal was to record the existing pollution of the entire region (mine, depositions, building facilities, settlement, Zidani's monastery, external environment, nearby villages), In the current work, some indicative concentration values of asbestos in the various environmental elements are given, potential hot spots are determined concerning the building installations, so that at a next stage a systematic sampling program can be developed and finally the determination of an appropriate remediation action for the MABE region could follow.

Table 2 presents the average values of the new measurements (2004–2005) of asbestos fibre concentrations in the atmospheric air that were taken, by the Technical University of Crete, in the region of the mine and the depositions, older measurements that where taken at the same sampling points [9], with maximum and minimum values of fibre concentration that have been recorded,

Table 2
Concentration of asbestos fibres (f/cm^3) in the air and evaluation of cancer risk

Area	2005	2004	1999	1998	1997	1996	1995	Maximum	Minimum	EU	EPA	Cancer risk (%)
Mine top (altitude + 660 m)	0.12	0.13	0.15	0.13	0.14	0.15	0.27	0.27	0.13			2.76
Mine bottom (altitude + 480 m)	0.15	0.15	0.16	0.14	0.16	0.17	0.30	0.30	0.13			3.45
Deposition square (altitude + 590 m)	0.16	0.14	NA	NA	NA	NA	NA	NA	NA	0.1	0.1	3.68
Deposition top of slope (altitude + 592 m)	0.17	0.15	NA	NA	NA	NA	NA	NA	NA			3.91
Deposition foot of slope (altitude + 512 m)	0.19	0.17	NA	NA	NA	NA	NA	NA	NA			4.37
Remediate depositions (soil layer and trees planted)	0.02	0.03	NA	NA	NA	NA	NA	NA	NA			0.46

NA, not available. Measurements of asbestos fibres in the atmospheric air were taken for the first time in 2004 in the region of the depositions. It is expected that the concentration of asbestos fibres during the operation of the mine were much higher than the one determined in 2004, due to the activities taking place at the deposition (over the permissible limit of Directive 83/477).

as well as the probability of cancer developing, according to the EPAs empiric formula. Limits of the Directive 2003/18/EU, as well EPA limits are also entered.

New measurements have shown decreased values of asbestos fibre concentrations in the atmospheric air, above the permissible limit of Directive 2003/18/EU, and the calculated cancer risk is exceptionally high. Sampling conditions were not ideal, considering the absence of wind and the rainfall 1 week before the measurements, therefore the real asbestos fibre concentrations in the atmosphere are expected to be higher.

New analyses of soil samples from the depositions showed that the presence of chrysotile asbestos in the part of fine grain size reached the value over 40% [18]. This of course is the worst case scenario because only in this grain size the amount of asbestos fibres is expected to be the highest one. This does not mean that the overall concentration has been increased, but a hot spot of chrysotile fibres was found. A proper sampling program must be applied at the depositions to examinate the concentration of asbestos fibres in all the grain size distribution of the barren material.

In addition, mixed serpentine rock samples taken from the mine contain also enormous quantities of free fibres that can enter into human lungs.

In Fig. 5 pictures from scanning electron microscopy are present which show the chrysotile fibres enlarged 500 and 1000 times, respectively.

4.1. Mine

Airborne asbestos was released by explosions during the operation of the mine and the circulation of vehicles transferring the asbestos in the wider region. Unfortunately even today the whole mine constitutes a hot spot because no remedial action has been taken and therefore the transfer of asbestos fibres by air remains a problem. The diffusion of the asbestos fibres in the environment, especially during the dry period and when intense wind prevails, is very dangerous. If slippage of the bench material occurs, this problem intensifies. In periods of heavy rainfall, the rain waters provide a vehicle for the asbestos from the area of the mine to the broader area through the existing hydrographical network. The result is the pollution of adjacent aquatic volumes.

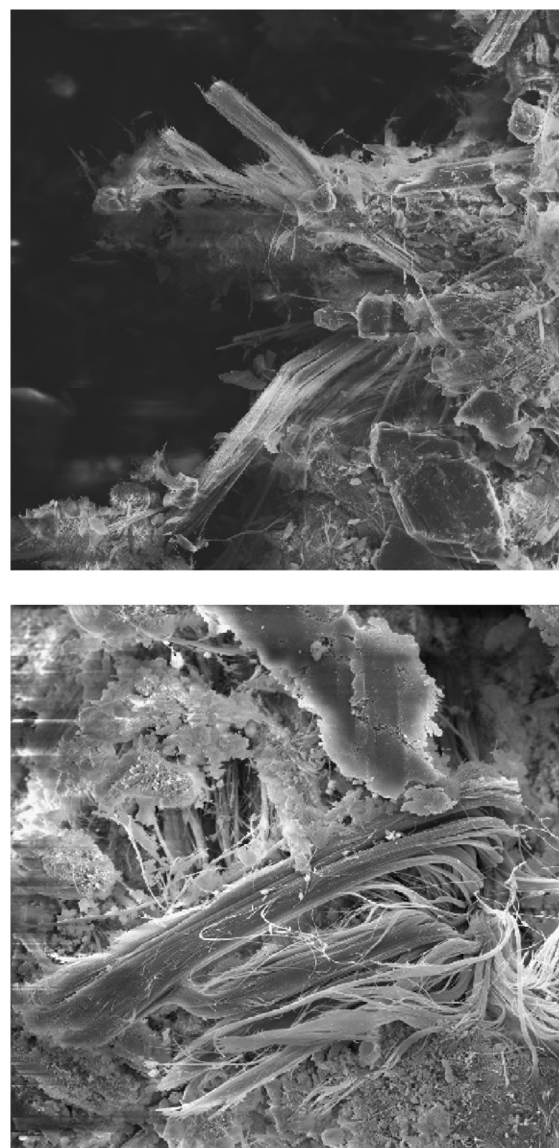

Fig. 5. Pictures from a scanning electronic microscope which show chrysotile fibres examined enlarged 500 and 1000 times, respectively.

Table 3
Concentration of asbestos fibres (Millions of Fibres per Liter = MFL by TEM) in the water of river Aliakmonas and the artificial lake of Polyfytou

Date	Sampling position	Concentration of asbestos fibres (MFL)	Measure error (MFL)
August 1993 (by AUT)	Saint Barbara	5.5	1.3
	Dam Sfikia (6 km)	7.8	1.3
	Bridge Serbia (18 km)	24.6	2.5
December 1993 (by AUT)	Saint Barbara	1.3	0.7
	Bridge Serbia (18 km)	3.9	1.3
	Bridge Rymnio (4 km)	37.4	3.4
January 1994 (by AUT)	Bridge Neapoli	4.8	3.4
June 2005 (by TUC)	Saint Barbara (35 km)	8.5	1.3
	Bridge Serbia (18 km)	14.3	2.2

TUC, Technical University of Crete; AUT, Aristotle University of Thessaloniki [16].

4.2. Depositions

The depositions constitute the most serious source of pollution for the broader area. New analyses of soil material from the depositions showed that the barren material contains between 60 and 70% of clean asbestos and not only 0.2% as it is reported in previous studies [9] mentioned before in this text. The asbestos fibres are being diffused via air and water, since the deposition volumes contain 138,000 tonnes of clean asbestos supposing that the asbestos concentration of the depositions is 0.2%, thus if the concentration is 70% (new results) the total volume of clean asbestos reaches 48,300,000 tonnes. Another point which must be taken into account is the danger posed by the slopes instability, which results in the local or regional slipping phenomena. Such an incident can cause the release of considerable quantities of asbestos into the atmosphere and into the nearby aquatic volumes of the region, as was also reported in the case of the mine benches.

In addition, a stream exists around the base of the depositions. The initial watercourse of the river has been changed by the barren material not only in the higher section (southern) and but also in the lower section (north). Thus standing water is created and the flow takes place through the corrosion of the depositions. After taking away unknown quantities of asbestos from the depositions the water is led to the river Aliakmonas.

In the past, water samples were taken from the river Aliakmonas. They showed particularly high concentrations of free asbestos fibres, which at some points exceeded the permissible limit of asbestos fibre concentration in water (7,000,000 f/l) [17]. Water samples taken from locations a few kilometres from the depositions of waste materials had concentrations that varied from 8,000,000 to 35,910,000 f/l [19]. New water samples taken by the Technical University of Crete, in June 2005 at Saint Barbara and the Serbia Bridge also contained high concentrations of asbestos fibres [20] It must be pointed out, as mentioned before, that the river Aliakmonas is a key source of water for the city of Thessalonica, that is why the EPA action level in drinking water is used for river water. Until now no further action (filtering) is used to collect the asbestos fibres in the water of the Aliakmonas river before consumption.

Table 3 presents the results of several sampling programs which were contacted over a period of almost 10 years at the river Aliakmonas and the artificial lake of Polyfytou.

The deposition of the factory had been partially restored during the operation of the factory. A soil layer was placed on the deposition with a thickness of roughly 0.50 m and trees were planted (acacias and pines), aiming to fix the asbestos fibres in the ground [8]. This remedial measure, even though not completed, contributed significantly to a reduction in the asbestos fibre concentration of the atmospheric air and of the underground water. The concentrations in the atmospheric air (cf. also Table 1) are remarkably reduced (almost by a factor of 10) compared to the asbestos fibre concentrations measured at the untreated depositions. This fact emphasises the importance of the development and completion of a full remedial program for all deposition volumes and indeed for the entire area of the mine.

Fig. 6 shows views of the part of the deposition which has already been remediate. The trees which were planted above the barren material reach a height of 2–3 m.

4.3. Mineral processing facilities

The mineral processing facilities constitute also hot spots of pollution. It must be clarified that during the mines operation, leakage from the buildings to the external environment was not hugely significant, since the distribution and treatment of the excavated material was conducted using a suction process. Unfortunately the current picture is different.

A particularly intense presence of free asbestos fibres in the factory is most obvious after even primary optical inspection. Piles of clean asbestos lie everywhere, but also resides inside the mechanical equipment and in the filters of the vacuum system. A strict prohibition of human presence in the factory is required as a result of the extreme contamination.

It was observed that certain parts of the factory are exposed to the open air and to rain (broken panes, deterioration, etc.), and therefore asbestos fibres are diffused into the environment and transferred to the wider region. Even minimal quantities of asbestos constitute a most serious pollution factor and a great threat to public health due to the highly toxic nature of this material.

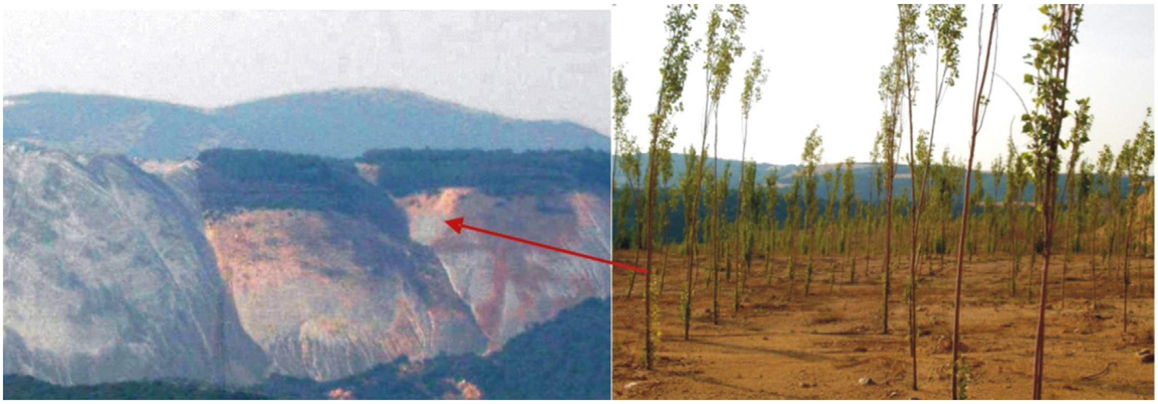

Fig. 6. Restored depositions, soil layer and trees planted.

Table 4
Concentration of asbestos fibres (f/cm^3) in the air and evaluation of cancer risk

Region	2005	2004	1999	1998	1997	1996	1995	Maximum	Minimum	EU	EPA	Cancer risk (%)
Crusher house	0.07	0.05	0.14	0.11	0.11	0.14	0.15	0.20	0.10	0.1	0.1	1.61
Mill building	0.17	0.16	0.57	0.46	0.44	0.47	0.54	0.65	0.40			3.91
Mill building upper floors	0.19	0.17	1.08	0.78	0.69	NA	NA	NA	NA			4.37
External environment	0.10	0.09	0.15	0.10	0.12	0.10	0.12	0.18	0.08			2.30

Fig. 7 presents the pictures from the mechanical equipment inside the factory which is covered with piles of asbestos dust.

Table 4 presents the average values of new measurements (2004–2005) of asbestos fibre concentrations in the air inside the mineral processing facilities and in the atmospheric air from the external environment of the Crusher house. Again, older measurements taken at the same sampling points [9] are given, as well as the evaluated cancer risk and limits of the Directive 2003/18/EU and the EPA.

One observes that the old measurements of asbestos fibre concentrations in the mineral treatment building are above the permissible limit of Directive 83/477. Again new measurements showed decreased values of asbestos fibre concentrations in the atmospheric air, which is due to the fact that the mine has been out of operation since 2000. It must be pointed out that the applied sampling method was static. The asbestos fibres covering the surfaces in the building facilities (the piles of asbestos) have not been taken into account in the sampling procedure. As a result, the measurements may not reflect the actual levels of asbestos present.

4.4. External environment, settlement and Zidani's monastery

Large quantities of asbestos fibre deposits as well as free asbestos fibres can be clearly observed in the wider region of the mineral processing facilities. All the open air spaces, including the existing streets, are polluted. It is quite alarming how asbestos fibres have been scattered over a distance of hundreds of metres, reaching trees (dust on their leaves), which have been naturally and freely transported to the wider region with the least of wind. In general, during the operation of the mine, no deci-

Fig. 7. Extended pollution of the mineral processing facilities.

Table 5
Concentration of asbestos fibres (f/cm^3) in the air and evaluation of cancer risk

Village-Town	2005	Last measurement	Maximum	Minimum	EU	EPA	Cancer risk (%)
MABE settlement (inside MABE)	0.03	0.09 (24/02/88)	0.09	0.03			0.69
Zidani's monastery (inside MABE)	0.02	NA	0.02	0.02			0.46
Mikrovalto (2 km)	0.02	0.03 (14/07/87)	0.29	0.03	0.1	0.1	0.23
Rymnio (4 km)	0.01	0.02 (16/07/87)	0.07	0.01			0.23
Kozani (40 km)	0.02	0.03 (16/02/88)	0.03	0.02			0.46

sive measures for environmental protection from asbestos fibres were taken, except for dowsing with water, and subsequently the quantity of free fibres estimated in the wider region is enormous.

Air measurements have shown (cf. also Table 4) that the values of asbestos fibre concentration in the atmospheric air outside the building facilities generally oscillate under the permissible exposure limit.

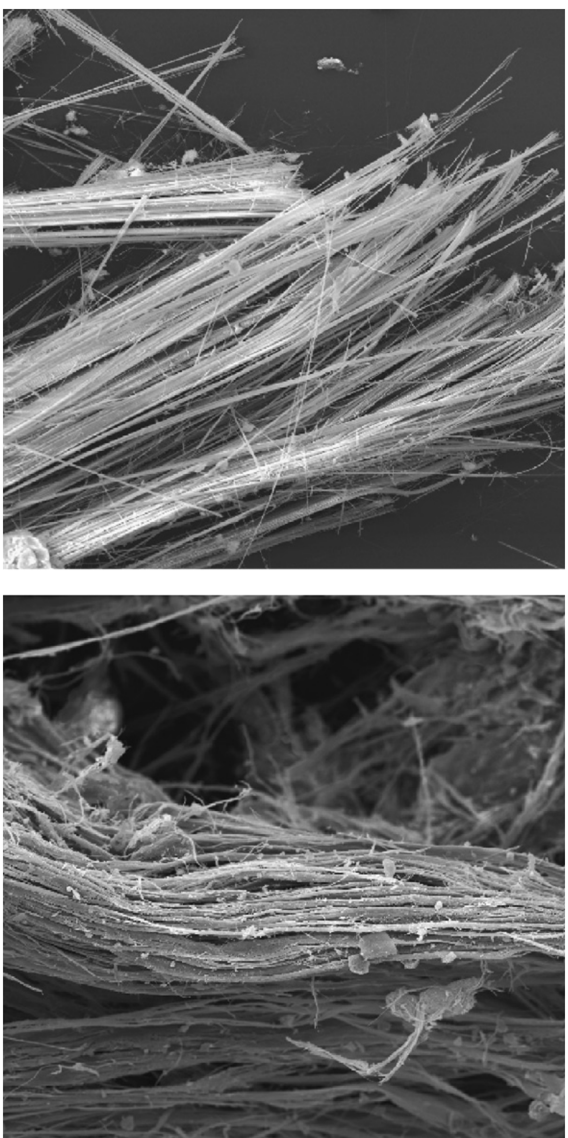

Fig. 8. Pictures from scanning electronic microscope which show amphibole (left) and chrysotile (right) fibres enlarged 500 and 1000 times, respectively.

Soil sampling from two different places of the MABEs external environment proved the presence of chrysotile asbestos in the form of free fibres. The first sample consists of mixed dust taken from a metal machinery of the transport building. The sample contains chrysotile asbestos in the form of free fibres. The second sample consists of drilling mud, taken near to MABEs settlement, southeast from the mineral processing facilities. Analyses have shown that this sample also contained free chrysotile fibres.

Another soil sample was taken from the monastery of Zidani, located between the mineral processing facilities and the mine, a distance of 500 m from the mine. It contains mixed asbestos dust.

In Fig. 8, the amphibole and chrysotile fibres enlarged 500 and 1000 times, respectively appear clearly.

A secondary pollution of the external environment, the building facilities, even the settlement and Zidani's monastery, is evident from the sample analyses of soil materials in the MABE region.

Table 5 shows the air analyses which were conducted at the nearby villages and the town of Kozani, both during the operation of the mine and in 2005. All values of asbestos fibre concentration were under the permissible limit of Directive 2003/18/EU. The only access to the village Mikrovalto and the well known monastery of Kozani is through the MABE area. Vehicular traffic causes the transfer and diffusion of asbestos fibres into the entire area of MABE (MABE settlement, Zidani's monastery) and to the village of Mikrovalto located within a few kilometres of MABE.

5. Conclusions

Low concentrations of asbestos are found in the atmosphere due to natural erosion. Nevertheless, the majority of incidents show that asbestos exposure is attributed to human activities, such as excavations, the treatment of asbestos, the use of asbestos and the disposal of asbestos products into landfills. Measurements showed high concentrations of asbestos fibres in the environment at the MABE region, which were caused by the operation of the mine. The quantities of asbestos that were released during the mines operation due to continual explosions in the open mine, treatment procedures, dissolution, loading and unloading of asbestos and barren material, are inestimable. High concentrations of asbestos fibres existed in the air inside the mineral processing facilities, during the operation of the mine. These concentrations were kept under control through a vacuum system in order to avoid dangerous leakages to the environment.

Today, the building facilities constitute a hot spot of pollution, which is apparent simply from a visual inspection. The results of the new sampling program, contacted in 2004–2005, were also compared to older measurements that were taken at the same sampling points during the operation of the mine. Samplings confirm the enormous presence of chrysotile asbestos in the form of free fibres, dissipating into the various environmental elements. The asbestos fibres detected are able to enter the lungs. Even today the mine and the depositions constitute major sources of pollution for the broader area and the risk of an occurrence of a local or regional landslide is high in the area of the mine and the depositions.

Considering the high toxicity of asbestos in even minimal quantities, it becomes clear why they constitute a most serious pollution hazard and a grave threat to public health. Therefore an application of a remedial program needs to be applied as soon as possible to minimise the current transportation of asbestos fibres from the mineral processing facilities into the environment.

References

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