Airborne Crocidolite Asbestos Fibers in Indoor and Outdoor Air in a Rural Area, China

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ABSTRACT

Forty-eight air samples were collected in a rural area of China. The concentrations of asbestos fibers in the samples were determined by phase contrast microscopy and scanning electron microscopy in combination with energy-dispersion X-ray analysis. The mean concentrations of asbestos fibers in indoor and outdoor air samples were 0.0038 and 0.0037 fibers/mL, respectively. The fiber concentration was higher in areas in which outcrop crocidolite asbestos is present in the soil than in areas lacking this feature. Airborne asbestos fibers in the study area might be attributable to the weathering of natural outcrop crocidolite asbestos and the impact of human activities on crocidolite asbestos-containing soils. About 50% of the total asbestos fibers in both indoor and outdoor air samples were 5 to 10 µm long. Scanning electron microscopy showed that the crocidolite asbestos fibers were mostly thinner than 0.25 µm. At present, asbestos-containing soils are rarely used to produce asbestos stoves, pave roads, construct houses, or paint walls. However, asbestos fibers are continuously released into the air from these soils, due to natural weathering and human activities, and local residents are thus exposed to asbestos fibers throughout their lifetimes, and thus their health might be adversely affected by long-term inhalation of the fibers.

Keywords: Crocidolite asbestos fiber; Indoor air; Outdoor air; Rural area; Naturally occurring asbestos.

INTRODUCTION

Asbestos is a generic term for a group of naturally occurring magnesium-mineral silicates in a variety of forms that are easily separated into long and thin, flexible fibers when crushed or processed (Kakooei et al., 2007, 2009). The regulated asbestiform mineral silicates include amphibole, anthophyllite, chrysotile, crocidolite, amosite and tremolite (Addison and McConnell, 2008). Since 4000 B.C., asbestos has been utilized by humans for many purposes (Abratt et al., 2004). It is a remarkable material for commercial, building and industrial applications such as insulation, automobile clutches and brakes, and in asbestos cement products such as well panels, roofing plates, ventilation ducts, water tubes, and sewage pipes (Kakooei et al., 2009).

Many studies have been conducted worldwide to investigate the adverse effects of exposure to asbestos dust on human health since the early twentieth century (e.g., Levine, 1985; Corn, 1991; Dement, 1991; Dopp and Schiffmann, 1998; Ni et al., 2000; Lohani et al., 2003; Berry and Gibbs, 2008; Lee and Van Orden, 2008; Richardson, 2009; Pesch et al., 2010). The results indicated that asbestos poses a serious potential health risk resulting from occupational exposure to asbestos dust during mining, milling, manufacturing, installation, and post-use abatement activities (Lee et al., 2008). Based on evidence from epidemiological studies and animal experiments, asbestos is regarded as a complete carcinogen, an initiator and a tumor promoter of mesothelioma, lung cancer and bronchogenic carcinomas (Dopp and Schiffmann, 1998). Therefore, asbestos has been listed as a primary carcinogen by the World Health Organization (WHO, 1986; IARC, 1987).

Therefore, environmental asbestos contamination has been a major concern for many years. Many studies have been conducted to investigate concentrations and morphology of airborne asbestos fibers in asbestos-containing work places (e.g., Anastasiadou and Gidarakos, 2007; Ansari et al., 2007; Pastuszka, 2009; Kakooei and Marioryad, 2010; Panahi et al., 2011). The results indicated that, generally, the concentrations of asbestos were considerably higher in work places than the permissible asbestos exposure limit in Europe (0.1 fibers/mL) and USA (0.1 fibers/mL) (Directive 83/477/EC, 1983; OSHA,
Naturally occurring asbestos also induces asbestos-related diseases in rural areas from natural outcrop crocidolite asbestos in soils (Senyiğit et al., 2000; Metintas et al., 2002; Luo et al., 2005; Hendrickx, 2009). Many studies have been conducted to investigate airborne particulate matter and metals in workplaces, urban and rural area (Begum et al., 2010; Shen et al., 2010; Choosong et al., 2010; Huboyo et al., 2011; Ny and Lee, 2011; Tsai et al., 2011). However, investigations into airborne asbestos concentrations in rural areas containing natural asbestos outcrops are rare. In China, several epidemiologic studies have reported that the incidences and mortality rates of cancer, mesothelioma and lung cancer were higher in Dayao, a rural area in Yunnan province with outcrops of natural crocidolite asbestos mineral in soils (Kong et al., 2002; Luo et al., 2005; Zou et al., 2005). Nevertheless, the concentration of asbestos fibers in ambient air at Dayao has not been investigated. Therefore, in this study we investigated the concentration and morphology of airborne asbestos fibers in outdoor and indoor air at Dayao. Another aim of this study was to discuss the anthropogenic factors that disturb the outcrop asbestos.

**MATERIALS AND METHODS**

**Studied Area Description**

Dayao is situated in the northwest of Yunnan province, China, from 100°53' E and 25°33' N to 101°42' E and 26°24' N (Fig. 1). It is a county with a surface area of 4,146 km² and a population of 280,846 at the end of 2007. Dayao has a moderate subtropical monsoon climate, a mean annual temperature of 15.6 °C, and a mean annual rainfall of 796 mm. The rainfall is concentrated in summer and autumn.

In recent years, the ecological environment of Dayao has degenerated rapidly owing to intensive anthropogenic activities. The anthropogenic activities mainly include agricultural activities, road and house construction, and urban development. An area of up to 2,114 km² has experienced soil erosion. Low forest coverage in the asbestos-outcrop distribution area, combined with serious disturbance of the rocks and natural asbestos-containing soils, might lead to increased asbestos dust emission into the environment. As a result, the residents might be exposed to high doses of asbestos fibers in the environment.

**Sampling**

Airborne particulate samples were collected at 24 sites in Dayao county (Fig. 1). One indoor air sample and one outdoor air sample was collected at each site. A total of 48 air samples were collected according to standard procedures in February, 2011 (EPA, 1990; OSHA, 1996). The airborne asbestos was collected on mixed cellulose ester filter...
membranes (0.45 µm pore size; 37 mm diameter) using an open-face filter holder in a three-piece cassette. The flow rate was 10 L/min using a battery-powered pump. The duration of a sample was about 8 h. All of the samples were collected at a height of approximately 1.5 m above ground or floor level.

Analysis Method
The samples were prepared and analyzed according to National Institute for Occupational Safety and Health (NIOSH) method 7400 (NIOSH, 1989). First, a portion of the filter membranes were made transparent on glass slide using acetone vapor. The filter wedge was mounted by using triacetin. Then, the filter was covered by cover slide. Finally, asbestos fibers were examined using phase contrast microscopy (PCM). The microscopy (type: Axio imager A1) was produced by Zeiss corporation, Germany. The fibers were defined as visible particles with a length greater than 5 µm, and aspect ratio higher or equal to 3:1 (NIOSH, 1989). In this study, the concentrations of asbestos fibers in air were determined by PCM. However, the method can not distinguish between asbestos fibers and non-asbestos fibers. Using PCM, the smallest fibers that were visible have diameters of about 0.2 to 0.25 µm, while the finest asbestos fibers may have diameters as small as 0.02 µm (OSHA, 1997; Perry, 2004).

Therefore, to have an accurate estimate of the asbestos fiber concentration, scanning electron microscopy (SEM) was used in combination with energy-dispersive X-ray analysis (EDXA) to identify asbestos fiber and its chemical composition in this study, according to ISO 14966 (ISO, 2002). The analysis was conducted in the National Research Center for Environmental Analysis and Measurement using scanning electron microscopy(S-2700) produced by Japanese Hitachi Ltd..

RESULTS AND DISCUSSION

Distribution of Crocidolite Asbestos Mineral in Dayao
Approximately 5% of the surface area of Dayao contains a thin layer of outcrop bluish clay-like crocidolite ore, which is called ‘blue asbestos’ by local residents because of its color. The distribution of outcrop crocidolite ore is shown in Fig. 1. The outcrop blue asbestos is mainly distributed in ShiYang, Xinjie and Jindi, covering about 200 km².

Based on energy-dispersive X-ray analysis, the main composition of the blue clay was shown in Fig. 2. It can be seen that the blue clay can be seen as crocidolite asbestos. Moreover, the blue clay was also digested by mixture acids (HNO₃ + HF + HClO₄). Then the concentrations of Na₂O and Fe₂O₃ were measured by ICP-OES. The concentration of SiO₂ was analyzed by loss on ignition. The results shown the blue clay was characterized by 40.63% SiO₂, 14.71% Fe₂O₃, 8.53% Na₂O, 8.14% Al₄O₉, 1.59% CaO, 1.01% K₂O, and 7.07% MgO.

Disturbance of Outcrop Asbestos in Dayao
The blue clay is friable and easily broken up by natural factors. Therefore, the asbestos is easily disturbed by natural factors such as weathering, and a large number of asbestos fibers may be released into ambient air.

In addition to natural factors, human activities might have a major impact on the outcrop asbestos in Dayao. According to a survey in 1984, the asbestos mineral was usually used to produce stoves, construct houses, pave roads, and paint walls (Luo et al., 2003). As shown in Table 1, 30% of local families produced asbestos stoves using the blue clay. Furthermore, every local family had used asbestos stoves. About 60% of families had used the blue clay to paint the walls of their houses. These activities had seriously disturbed the crocidolite mineral in the soil. Thus asbestos fibers might be released into the air during these activities.

The use of crocidolite asbestos-containing soils was also surveyed in 2011 (Table 1). The results indicated that less than 1% of families still produced and used asbestos stoves. The blue clay was also hardly used to pave roads and paint walls. Although the asbestos-containing soils were hardly used in recent years, the outcrop asbestos is still significantly disturbed by human activities, including

![Fig. 2. EDXA spectrum and SEM image of the crocidolite mineral in Dayao.](image)

<table>
<thead>
<tr>
<th>Year</th>
<th>Families producing asbestos stoves (%)</th>
<th>Families using asbestos stoves (%)</th>
<th>Road paving</th>
<th>House construction</th>
<th>Walls painted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>32%</td>
<td>100%</td>
<td>Usually found</td>
<td>Usually found</td>
<td>60%</td>
</tr>
<tr>
<td>2011</td>
<td>&lt; 1%</td>
<td>&lt; 1%</td>
<td>Hardly found</td>
<td>Hardly found</td>
<td>&lt; 1%</td>
</tr>
</tbody>
</table>
agricultural activities, road construction, house construction, and urban development by local residents (Fig. 3). These activities might cause disintegration of the outcrop asbestos in soils into fine dust particles, which might contain abundant asbestos fibers. Consequently, the local residents might be exposed to elevated concentrations of asbestos fibers in the air both outdoors and indoors.

**Concentration of Airborne Asbestos Fibers**

The concentrations of asbestos fibers (based on PCM) in indoor and outdoor air samples at Dayao were listed in Table 2. The mean concentrations of asbestos fibers in outdoor and indoor air were 0.0037 f/mL (range 0.0010–0.0291 f/mL) and 0.0038 f/mL (range 0.0003–0.0101 f/mL), respectively. ANOVA of the data showed that there was no significant difference between asbestos fiber concentrations in indoor and outdoor air. The mean concentrations of fibers in indoor and outdoor air samples were hardly varied, while the lowest and highest concentrations of fibers vary widely among indoor air and outdoor air. The concentrations of fibers in all air samples are lower than the permissible exposure limits for asbestos in Europe (0.1 f/mL) and by NIOSH (0.1 f/mL). However, this does not mean that there is no health risk for local residents caused by exposure to airborne asbestos fibers at Dayao. Many epidemiologic investigations into asbestos-related diseases have shown that exposure to a low concentration of asbestos in the environment can also elevate the incidences and mortality rates of mesothelioma, asbestosis, and lung cancer (Metintas et al., 2005). These features reflect that the atmospheric environment in Dayao is still significantly contaminated by naturally occurring asbestos.

The concentrations of total particles and asbestos fibers in air samples collected near an asbestos crusher house were investigated in 1984 (Luo et al., 2003). The mean and maximum concentrations of airborne asbestos fibers < 2 m from the asbestos crusher house estimated with PCM were 6.6 and 25.4 f/mL, respectively. These values are much higher than the values reported in the environment in the present study and the permissible exposure limits. The concentrations of total particles were decreased at distances further from the crusher house. A photomicrograph of blue asbestos fibers collected in the air and blue asbestos mineral in soils from Dayao are shown in Figs. 3(e) and (f). Based on scanning microscopy analysis, the fibers in air samples mainly contained Na, Mg, Si and Fe (Fig. 4). The results indicated that the fibers were crocidolite asbestos fibers.

**Length Distribution of Airborne Asbestos Fibers**

The morphological characteristics of asbestos fibers in the samples are summarized in Table 3. Based on length, asbestos fibers were grouped into > 5 to ≤ 10 µm, 11–20 µm, 21–30 µm, and > 30 µm. The proportions of fibers in the > 5 to ≤ 10 µm subgroup were 55.1% and 57.1% in indoor and outdoor air samples, respectively. More than 80% of all asbestos fibers were shorter than 20 µm. Moreover, crocidolite asbestos fibers were mostly thinner than 0.25 µm under scanning electron microscopy analysis as seen in Fig. 4.

Many investigations have reported that the risk of asbestos-related diseases (e.g., lung cancer and mesothelioma) among people exposed to asbestos increases with exposure to longer asbestos fibers. Thus, the toxicity of long asbestos fibers is higher than that of short asbestos fibers (Dodson et al., 2003; Roggli, 2006; Loomis et al., 2010). This is because long asbestos fibers are less easily discharged from the human

**Table 2. Descriptive statistics of asbestos fibers in air samples collected from Dayao in this study.**

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Outdoor air (f/mL)</th>
<th>Indoor air (f/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample number</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.0010</td>
<td>0.0003</td>
</tr>
<tr>
<td>Mean</td>
<td>0.0037</td>
<td>0.0038</td>
</tr>
<tr>
<td>Median</td>
<td>0.0021</td>
<td>0.0030</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.0297</td>
<td>0.0101</td>
</tr>
<tr>
<td>Std. deviation</td>
<td>0.0057</td>
<td>0.0025</td>
</tr>
</tbody>
</table>

The levels of asbestos fibers in ambient air from rural and urban areas of North America and Europe are estimated with PCM to be $2 \times 10^{-7}$ f/mL and $2 \times 10^{-6}$ f/mL, respectively (HEI, 1991). In this study, the mean concentration of asbestos fibers in ambient air was considerably higher than the above-mentioned estimated values. Moreover, the asbestos concentration in ambient air samples at Dayao was much higher than the levels of asbestos in outdoor air recorded in the USA and urban environments of Europe ($5 \times 10^{-5}$ f/mL) (Marconi et al., 1989; WHO, 1998). However, the mean asbestos concentrations in air samples in the present study are similar to those reported in Tehran (0.0034 f/mL) (Kakooei et al., 2009). These features reflect that the atmospheric environment in Dayao is still significantly contaminated by naturally occurring asbestos.

**Fig. 3. Use of blue asbestos-containing materials and asbestos fiber in air. a = Blue asbestos ore in agricultural soil; b = producing an asbestos stove; c = asbestos stove; d = walls painted using asbestos-containing soil; e = asbestos fiber under phase contrast microscopy; f = asbestos mineral.**
body. Thus, such fibers can be persistent in the body for a long time. However, some studies report that the toxicity of short and thin asbestos fibers is higher. Suzuki et al. (2005) reported that short and thin asbestos fibers are important causal contributors to human malignant mesothelioma. Short and thin asbestos fibers easily penetrate deep into the respiratory system. Therefore, it is important to determine the dimensions of asbestos fibers in air samples.

### Characteristics of Airborne Asbestos Fibers in Different Areas of Dayao

Indoor air samples were collected from new houses (in which the walls were cement brick and decorated with tiles or lime) and old houses (in which the walls used soils from the local area). The mean concentration of asbestos fibers in indoor air in old houses (0.0043 f/mL) was higher than that in new houses (0.0031 f/mL), while the maximum values were found in indoor air (Table 4). According to ANOVA, significant differences among the asbestos fiber concentrations in different areas in Table 4 were found. This could not reveal that weathering of the walls might release asbestos fibers into the indoor air. In recent years, the blue clay has been hardly used to pain walls. Moreover, the previous used of blue clay on the walls of old houses have been eliminated. Meanwhile, the walls have been painted by limewash to cover the residual blue clay. Therefore, the airborne asbestos fibers were mainly derived from natural weathering and anthropogenic interference of the outcrop asbestos in the local area.

The air sampling sites can be divided into two groups. As shown in Fig. 1, one group was located in the area in which outcrop crocidolite asbestos is present in the soil (group 1), while the other group was from areas lacking outcrop asbestos in the soil (group 2). The mean concentration of asbestos fibers in both group 1 sites and group 2 sites varied little among indoor and outdoor air samples (Table 4). This might indicate that airborne fibers were mainly derived from weathering of natural blue clay. The asbestos fibers in indoor air were seldom influenced by emission of the walls.

The mean and maximum values from group 1 sites were 0.0045 and 0.0297 f/mL in outdoor air, and 0.004 and 0.0101 f/mL in indoor air, respectively. The values were all higher than that from group 2 sites. The lowest concentration was found in indoor air from group 2 sites. These features indicate that outcrop crocidolite asbestos in the soil significantly influences the concentration of airborne asbestos fibers in the group 1 sites. Moreover, the concentration in the air in areas lacking outcrop crocidolite asbestos in the soil might be influenced by asbestos fibers blown from neighboring areas in which outcrop crocidolite asbestos is present in the soil.

### CONCLUSIONS

In the present study, abundant asbestos fibers were found in both indoor and outdoor air samples in a rural area, Dayao, in China. Airborne asbestos fibers were also detected in areas lacking outcrop crocidolite asbestos in the soil neighboring areas with outcrop crocidolite asbestos present in the soil. Natural weathering of crocidolite asbestos in soils might be a main source of airborne asbestos fibers. Nevertheless, human activities, such as excavations, asbestos stove production, road construction, house construction, and

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### Table 3. Comparative length of asbestos fibers in air samples collected from Dayao.

<table>
<thead>
<tr>
<th>Length</th>
<th>Indoor %</th>
<th>Outdoor %</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 5 to ≤ 10 µm</td>
<td>55.1</td>
<td>57.1</td>
</tr>
<tr>
<td>11–20 µm</td>
<td>31.3</td>
<td>25</td>
</tr>
<tr>
<td>21–30 µm</td>
<td>7.1</td>
<td>9.1</td>
</tr>
<tr>
<td>&gt; 30 µm</td>
<td>6.5</td>
<td>8.8</td>
</tr>
</tbody>
</table>

### Table 4. Descriptive statistics of asbestos fibers in air samples collected from different areas in Dayao.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Asbestos fibers in indoor air (PCM, f/mL)</th>
<th>Areas with outcrop asbestos in the soil (PCM, f/mL)</th>
<th>Areas without outcrop asbestos in the soil (PCM, f/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Old houses</td>
<td>New houses</td>
<td>Outdoor air</td>
</tr>
<tr>
<td>Sample number</td>
<td>10</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.0011</td>
<td>0.0003</td>
<td>0.001</td>
</tr>
<tr>
<td>Mean</td>
<td>0.0043</td>
<td>0.0031</td>
<td>0.0045</td>
</tr>
<tr>
<td>Median</td>
<td>0.0044</td>
<td>0.0021</td>
<td>0.0023</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.0079</td>
<td>0.0101</td>
<td>0.0297</td>
</tr>
</tbody>
</table>
urban development might be the main source of asbestos fiber contamination in the air. Higher concentrations of asbestos fibers in both indoor and outdoor air samples occurred in areas with outcrop crocidolite asbestos present in the soil. This indicates that airborne asbestos fibers in Dayao are mainly derived from natural crocidolite asbestos in soils.

The crocidolite asbestos were often excavated and used to produce asbestos stoves, pave roads, construct houses, and paint walls during the twentieth century, but these applications of crocidolite asbestos-containing soils are rare in the last decade. However, the natural outcrop asbestos is still strongly affected by human activities, such as agricultural activities, and house and road construction. Asbestos fibers are released into ambient air during these processes. As a result, abundant asbestos fibers are released into ambient air.

The local residents in Dayao are exposed to asbestos fibers throughout their life. Their health might be strongly affected by airborne asbestos fibers. Therefore, epidemiologic investigation of asbestos-related diseases should be conducted in this area.

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