Available online at www.sciencedirect.com
SCIENCE DIRECT®

Environment International 29 (2003) 931–934

ENVIRONMENT INTERNATIONAL

www.elsevier.com/locate/envint

Asbestos exposure among Seoul metropolitan subway workers during renovation of subway air-conditioning systems

Il Je Yu*, Chan Young Yoo, Yong Hyun Chung, Jeong Hee Han, Sook Young Yhang, Gye Mook Yu, Kyung Seuk Song

Center for Occupational Toxicology, Occupational Safety and Health Research Institute, Korea Occupational Safety and Health Agency, 104-8 Munji-dong, Yuseong-gu, Daejeon 305-380, South Korea

Received 20 December 2002; accepted 25 February 2003

Abstract

Air quality in underground spaces has seldom been evaluated in Korea. Accordingly, the current study recently evaluated asbestos exposure among Seoul metropolitan subway workers during the renovation of the subway's air-conditioning system. To identify possible routes of asbestos exposure, suspected sources, including gaskets, ceiling boards, ceiling materials, and dust settled inside ducts, were all sampled. Personal air samples were also taken to evaluate any asbestos exposure during the renovation. The asbestos fibers found in the samples were analyzed using a transmission electron microscope (TEM) equipped with an energy dispersive X-ray analyzer (EDX). Twelve out of eighteen bulk samples contained asbestos, the majority of which was chrysotile fibers. Asbestos was detected in 9 out of 72 personal air samples and the level ranged from 0.003 to 0.02 fibers/cm^3. While asbestos levels were below Korean occupational limit of 2 fibers/cm^3, they were still detectable and therefore further monitoring would be appropriate.

Keywords: Asbestos exposure; Subway workers; Air-conditioning system

1. Introduction

Seoul has two subway systems, as such, subway lines 1–4 are operated by the Seoul Metropolitan Subway Corporation (SMSC), while subway lines 5–8 are operated by the Seoul Metropolitan Rapid Transit Corporation (SMRTC). Millions of daily commuters use the Seoul metropolitan subways. However, there have already been a number of controversies regarding the health effects on the public and subway workers as a result of over-exposure to underground hazardous factors, particularly, noise, radon, fine particles, and asbestos. An annual audit report submitted by Seoul City to the National Assembly indicated that the noise levels in subway lines were above 80 dB (Park, 2001). Another report submitted by Seoul City to the Construction and Transportation Committee of National Assembly (CSC) indicated that the radon levels for several subway stations were at a level of concern (Chun, 2001). A report submitted by the SMSC to the CSC indicated that the concentrations of fine particles in the SMSC subway lines were higher compared with the previous year (Kim, 2001). The SMSC and SMRTC both take regular measurements of hazardous materials to comply with the Act Related to Air Quality in Underground Spaces (ARQUS) (MOE, 1996). Recently, such measurements have been conducted more frequently to monitor the air quality in the Seoul subway system in preparation for the 2002 FIFA World Cup Korea–Japan, which will be hosted in 10 Korean cities and 10 Japanese cities from May 31 to June 30, 2002. Recently, four non-governmental organizations (NGOs) announced that the Seoul subway system may represent a risk for commuters and subway workers in terms of asbestos exposure (Sim, 2001). In addition, they reported that asbestos had been detected in the air during the renovation of the subway station air-conditioning system (Lee, 2001a). The SMSC operates 95 subway stations, which were built 15–26 years ago. Thirty-five stations have already had their air-conditioning systems renovated, while 60 more stations are scheduled to have their systems renovated within the next 6–8 years.

* Corresponding author. Tel.: +82-42-863-8182; fax: +82-42-863-8361.
E-mail address: u1670916@chollian.net (I.J. Yu).

0160-4120/$ - see front matter
doi:10.1016/S0160-4120(03)00058-8

Accordingly, the current paper describes an investigation of potential asbestos sources and exposure among subway workers during the renovation of the subway air-conditioning system. The study was conducted under the supervision of the Labor Office of Seoul in the presence of representatives from the SMSC Labor Union.

2. Materials and methods

2.1. Sampling sites

The SMSC subway lines that had been built more than 15 years ago were selected for sampling, as it was suspected that asbestos-containing materials (ACM) may have been used when constructing these lines, plus many of the subway stations on these lines were being renovated at the time. Eight subway stations undergoing renovation were selected for sampling; six subway stations on SMSC subway lines, one SMRTC subway station currently under construction, and one station serving as a connecting point for SMSC and SMRTC lines.

2.2. Description of renovation

The renovations were originally planned in 2000 and started in late December 2000. The renovation was scheduled to finish by the end of July 2001 so as to provide air-conditioning during the summer period. At the beginning of the renovation, the old ceiling panels and ventilation ducts were dismantled and removed, as such, the workers were potentially exposed to dust that had settled in the ducts or panels over a long period of time. Next, the new ventilation systems were installed, including new air-conditioners, fans, and ducts. Finally, equipment related to the station automation and communication systems was installed (Fig. 1). Operations that involved welding, cutting, drilling, painting, and assembling were performed irregularly and intermittently during the day and at night at the work sites. The day work lasted from 08:00 to 16:00 and focused on the ventilation room, electricity room, and station business room and bedroom, i.e. areas with no public access. Whereas, the night work lasted from 00:00 to 05:00 while the subway was not running. Since the various tasks, including dismantling, assembling, cutting, and welding, were performed under quite strenuous conditions, there was a relatively high risk of physical injury, fire, and electrocution.

2.3. Sampling methods

Bulk samples were obtained in the presence of labor union representatives and sampled from sites suspected for the presence of asbestos. Bulks included gaskets for connecting ducts, welding curtains, sprayed ceiling materials, ceiling boards, and settled dust in the ventilation exhaust and supply ducts.

The air samples were taken by drawing air through mixed cellulose ester filters in sampling cassettes (25 mm diameter, 0.8 μm nominal pore-size, 2-in. cowl) obtained from Environmetrics, Inc (cat No. 20-31-0-1401, Charleston USA). Samples were collected in the breathing zone using SKC-battery operated sampling pumps at a flow rate of 1.2 l/min. The sampling holders were changed during the sampling period to avoid overload. The samplings were performed during the normal work periods 08:00–15:00 and 00:00–17:00. The typical durations used in air sampling were 180–240 min for night shift and 300–360 min for day shift.

2.4. Asbestos analysis

The air samples were analyzed according to the NIOSH analytical method 7402 (1994). The filter was coated with carbon and mounted onto carbon-coated nickel grids (Veco, Eerbeek, Holland) using chloroform vapor. The asbestos fibers were morphologically identified using a transmission electron microscope (TEM, Hitachi 7100, Tokyo), while the asbestos types were determined by comparing the elemental composition of the asbestos fibers using an energy dispersive X-ray analyzer (EDX, KEVEX 7000Q, Foster City, CA). All fibers with diameter greater than 0.25 μm that meets the definition of a fiber (aspect ratio $\geq$ 3:l, longer than 5 μm) were counted in more than 50 grid openings at random.

The bulk samples were broken into small pieces and then powdered using a pestle. The powdered samples were

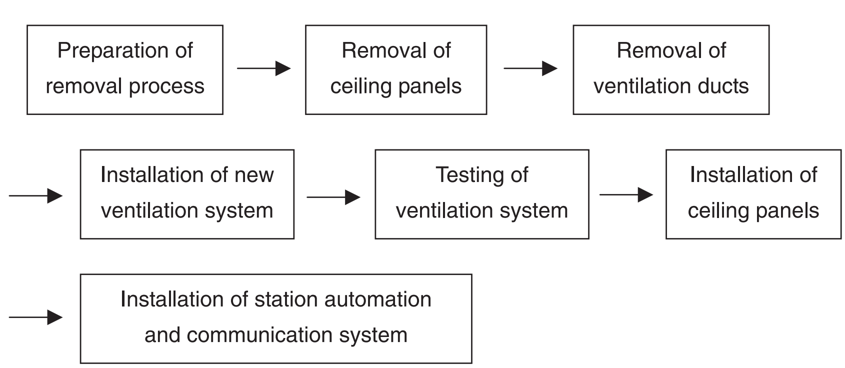

Fig. 1. The renovation process of air-conditioning system.

suspended in 50 ml of distilled water and then ultrasonicated for a period of 5 min to separate the bundles into single fibers. The liquid containing the sample was filtered through a 0.2 μm nucleopore filter (Nucleopore, Pleasanton, CA), and subsequent preparation and identification of the fibers was similar that used for the air samples.

3. Results

3.1. Bulk samples

To identify the presence of asbestos sources in the subway system, bulk samples from the gaskets of the existing ventilation ducts, welding curtains, dust settled in the ducts, ceiling materials, and ceiling-coating materials were sampled from eight subway stations. Newly installed gaskets, canvas connecting the fans with the ducts, materials described as asbestos containing tapes, and the brake linings of the subway electrical locomotive trains were not sampled because they had been previously identified as not containing asbestos.

Table 1
Results of bulk sample analysis

Station	Sampling sites	Presence of asbestos, %
Euljiro (No. 2)	(1) Dust from inside exhaust duct in rest room	< 0.1
	(2) Gasket for exhaust duct connection in rest room	>90 (chr)
	(3) Dust from inside exhaust duct in dining room	0.1 (chr)
	(4) Dust from inside supply duct in control room	0.1 (chr)
Yaksu (No. 3)	(5) Gasket for exhaust duct connection in front of rest room	>90 (chr)
	(6) Dust from supply duct in front of transform room	< 0.1
	(7) Dust from speaker located at exit	< 0.1
	(8) Dust from exhaust duct in storage room for communication equipment	< 0.19
	(9) Gasket for supply duct for outdoor air	>90 (chr)
	(10) Welding curtain	>90 (chr)
City Hall (No. 2)	(11) Ceiling-coating material on first floor of station	>90 (tre)
	(12) Ceiling-coating material in front of ticket office on second floor	>90 (tre)
Chungmuro (No. 4)	(13) Wall-coating material in connection passage between 3rd and 4th floors of station	0.1 (chr)
Suyu (No. 4)	(14) Ceiling material in utility room	>90 (chr)
Abgujeong (No. 3)	(15) Ceiling material in station office	>90 (chr)
	(16) Ceiling material in bed room (talc board)	< 0.1
World Cup Stadium	(17) Ceiling material in construction office	< 0.1
Sindang (Nos. 2 and 6)	(18) Gasket for duct connection in connection passage between No. 2 and No. 6 subway lines	>90 (chr)

Chr, chrysotile; tre, tremolite.
Detection limit was 0.1% for the bulk samples.
Expressed as < 90%, if the bulk sample was mainly composed of asbestos.

Table 2
Air sampling results from subway station

Subway station	Operation	Level of asbestos (TWA), fiber/cm^3
Euljiro	Installing light fittings in waiting room (N)	0.003 (chr)
City Hall	Duct insulation in 1st floor waiting room (N)	0.003 (act)
	Electrical wiring in 1st floor waiting room (N)	0.004 (tre)
	Brick laying (D)	0.016 (tre)
Suyu	Ceiling panel installation (N)	0.003 (chr)
		0.006 (chr)
	Painting of pipes in vent. Room B (D)	0.020 (chr)
Abgujeong	Painting in station office (D)	0.012 (chr)
Chungmuro	Patrolling station office and platform (D)	0.003 (chr)

The detection limits were ranged from 0.002 to 0.003 fibers/cm^3.
Chr, chrysotile; act, actinolite; tre, tremolite; N, night time; D, day time.

Twelve of the eighteen bulk samples were found to contain asbestos (Table 1), although four samples were less than 0.1% that is usual detection limit for most labs. Ten samples contained chrysotile fibers and two samples contained tremolite fibers (Table 1). The original four gaskets used in the duct connections at the Euljiro, Yaksu, and Sindang stations were found to contain asbestos. These gaskets were removed during the initial renovation work and may have generated asbestos-containing dust. Thus it would explain the presence of asbestos fibers in the dust samples, which were actually collected during the latter part of the renovation work (80%). The ceiling-coating materials used in the City hall station were found to include tremolite asbestos fibers (Table 1), while the wall-coating materials in connection passage between 3rd and 4th floors of station ceiling-coating materials used in the Chungmuro station contained chrysotile fibers (Table 1). The ceiling boards used in the Suyu and Abgujeong stations contained chrysotile fibers (Table 1).

3.2. Personal air sampling results

Asbestos was detected in 9 out of 72 samples (Table 2). As seen in the bulk sample analysis, the majority of the asbestos was chrysotile fibers, which were detected at six sites (Tables 2). Tremolite was found at two sites II, while actinolite was only detected at one site (Table 2). Both tremolite and actinolite were detected at the City Hall station, which corresponded with the results of the bulk sample analysis. The concentrations of asbestos identified ranged from 0.003 to 0.02 fibers/cm^3 and were much lower than 2 fibers/cm^3, which is the current Korean occupational exposure limit. Asbestos fibers were detected at five out of seven stations, and all stations where asbestos fibers were detected were on SMSC subway lines, including subway line No. 2 (Euljiro, City Hall, and Sindang), No. 3 (Yaksu and Abgujeong), and No. 4 (Suyu) (Table 2). No asbestos was detected in the SMRTC subway line World Cup Stadium. Asbestos was detected during both day and night work hours in City Hall, Suyu, and Abgujeong stations (Table 2).

4. Discussion

Since there have only been a few previous reports on monitoring hazardous materials in subways (Fromme et al., 1998; Kim and Kim, 1993), in contrast to the several monitoring studies related to outdoor railroads (Mancuso, 1988; Kaptsov et al., 2000; Camilucci et al., 2000), it is difficult to discuss the current results in the context of other observations. Although it is not directly comparable, the environmental monitoring studies by Italian Railway Technical Departments on 619 rolling stock vehicles indicated that in over 99% of the samples the fiber concentrations were below 0.002 fibers/cm^3, indicating that the levels were slightly lower than those of the underground air-conditioning system renovation. The Seoul subway still contains many asbestos-containing materials, including gaskets connecting ducts, ceiling boards, ceiling-coating materials, and dust settled inside ventilation ducts. As such, subway workers will inevitably be at risk of asbestos exposure during renovation work. The current results for the bulk sampling and personal exposure monitoring also clearly indicated a risk of exposure to asbestos during the renovation process. The renovation of the subway ventilation system was conducted over a short period, within 7–8 months, and many of the operations involved were intermittent, irregular, and carried out during day and night work hours. Concurrently conducted investigation on other hazardous materials in the Seoul Metropolitan Subway indicated that welding fume and lead concentrations were detected over the Korean occupational exposure limits (5 mg/m^3 for fume and 0.05 mg/m^3 for lead) in 3 out of 15 personal air samples (5.75–20.405 mg/m^3) for fume and in three out of 20 six personal air samples (0.059–0.083 mg/m^3) for lead (KOSHA, 2001). The workplaces were also basically confined spaces and varied widely from subway lines to station floors. Accordingly, the subway workers were at a higher risk of being exposed to many hazardous materials, such as asbestos, dust, and heavy metals.

Since the asbestos monitoring was only started after the renovation had been 80% completed, the monitoring results do not represent the entire renovation process. Furthermore, no exposure-monitoring data was collected during the duct removal process, when the maximum generation of asbestos was suspected. However, the current results still clearly demonstrate a risk of asbestos exposure during the renovation process.

The authors also investigated other subway systems in Korea, including 5–8 subway lines in the SMRTC, Daegu and Busan subway systems. No asbestos fibers were detected in these subway systems, mainly because these lines were all recently built and no asbestos-containing materials were involved in their construction.

Accordingly, the Korean Ministry of Labor has determined that it will impose stricter regulations from 2003 regarding the use of asbestos, along with the requirement for special training when handling asbestos-containing materials. As a result, the removal or renovation of ACM requires a special permit. In addition, the occupational exposure limit of asbestos will be lowered from the current 2 fibers/cm^3 to 0.1 fibers/cm^3 in 2003 (Lee, 2001b).

References

Camilucci L, Catasta PF, Chiappino G, Governa M, Munafo B, Verduchi P, et al. Measurement of airborne asbestos fibers on railroad rolling stock. Med Lav 2000;91:46–52.

Chun SH. Carcinogenic materials were detected in the subway stations. Yeonhap News (Korean newspaper), September 6, 2001.

Fromme H, Oddoy A, Piloty M, Krause M, Lahrz T. Polycyclic aromatic hydrocarbons (PAH) and diesel engine emission inside a car and subway train. Sci Total Environ 1998;217:165–73.

Kaptsov VA, Tikhova TS, Suvorov SV, Khvastunov RM, Trofimova EV, Zinina SA, et al. Health status of workers contacting chrysotile asbestos waste on rail way objects. Med Tr Prom Ekol 2000;11:23–6.

Kim, YS. Fine particle pollutions in the Seoul Metropolitan Subways are getting worse. Yeonhap News (Korean newspaper), August 29, 2001, Seoul.

Kim DS, Kim YS. Distribution of airborne radon concentrations in Seoul metropolitan subway stations. Health Phys 1993;65(1):12–6.

Korea Occupational Safety and Health Agency (KOSHA). Investigation report on asbestos and other hazardous materials in the Seoul Metropolitan Subway. Incheon: KOSHA; 2001.

Mancuso TF. Relative risk of mesothelioma among railroad mechanists exposed to chrysotile. Am J Ind Med 1988;13:639–57.

Lee JE. Asbestos exposure to Seoul subway passengers. Hankyoreh News (Korean newspaper), April 25, 2001a.

Lee SH. Twenty fold increase of asbestos occupational exposure level. Yeonhap News (Korean newspaper), October 10, 2001b.

Ministry of Environment (MOE). Act relating air qualities in underground space. Korean Ministry of Environment, Seoul; 1996.

NIOSH. Manual of analytical methods, method 7402. Cincinnati: National Institute for Occupational Safety and Health; 1994.

Park SJ. Serious noise problem in Seoul Metropolitan Subway. Yeonhap News (Korean newspaper), September 17, 2001.

Sim IS. Asbestos fibers were detected in the subway stations. Yeonhap News (Korean newspaper), April 24, 2001.