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Asbestos Exposures to Truck Drivers During World Trade Center Cleanup Operations

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This article presents results of asbestos air sampling conducted to assess the exposure to truck drivers working at the World Trade Center site. Sampling consisted of a combination of area and personal monitoring of 49 truck drivers and included optical and electron microscopic analyses. Three sampling periods were conducted: October 1–7, 2001, October 17–26, 2001, and April 13–23, 2002. Area sample locations were selected to estimate airborne concentrations around the perimeter of the site, on top of the pile, and in the pit. Air samples were collected using a 50-mm conductive cowl and a 25-mm mixed cellulose ester filter at flow rates ranging from 0.5–2 L/min. Samples were analyzed using a combination of phase contrast microscopy (PCM) NIOSH method 7400, transmission electron microscopy (TEM) NIOSH method 7402, and the direct method specified under the Asbestos Hazardous Emergency Response Act. Sample times and flow rates were adjusted to prevent overloading while maximizing sample volume. Personal sampling results suggest that asbestos fiber exposures to truck drivers at the site were low. Exposures based on TEM results generally ranged from less than detectable to 0.1 structures per cubic centimeter (s/cm^3). TEM-based results further indicate that the majority of asbestos fibers were chrysotile and less than 5 μm in length. PCM-based estimates were generally higher than the TEM results. This is likely due to the counting of nonasbestos fibers. This conclusion is supported by the NIOSH 7402 TEM results, which did not detect asbestos fibers longer than 5 μm. Area sample results were generally less than the personal results (except for the sample collected on top of the rubble pile) and decreased over the course of the cleanup. Our results show low airborne asbestos concentrations and a predominance of short fibers. Given these low concentrations, evidence of short fibers, and the short duration of the exposure (less than 10 months to complete the cleanup), it is likely that truck drivers working at the site are not at an increased risk for asbestos-related disease.

Keywords World Trade Center, asbestos, truck drivers, exposure assessment

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The September 11, 2001, terrorist attack on the World Trade Center (WTC) resulted in the airborne release of a complex and highly variable mixture of dusts, metals, combustion products, gases, and vapors.[1−3] The large influx of rescue and cleanup personnel to the WTC site generated concern about possible occupational exposures to these hazardous substances. Specific air pollutants of concern include concrete dust, asbestos, lead, mercury, polychlorinated biphenyls (PCBs), combustion products (dioxins, dibenzofurans), and benzene. Exposure to these contaminants can result in acute and chronic toxicity with some of them being known or probable human carcinogens.

In response to this concern, the National Institute for Environmental Health Sciences (NIEHS) sponsored a coordinated effort to assist in an environmental health response to the WTC attack. As a part of this response, an evaluation of occupational exposures to one group of cleanup workers—truck drivers—was undertaken. The International Brotherhood of Teamsters provided logistical support for recruitment.

Truck drivers were chosen because they represented a large and important group of workers at the site. Between September 22 and October 5, 2001, it was estimated that 1350 construction workers were on site each day.[4] During the first week of October 2001, the minimum daily average number of truck drivers was 135. This estimate was based on sign-in records for the local labor union that represented drivers who participated in this study and does not include drivers on site represented by other local labor unions. However, this number suggests that truck drivers accounted for a significant portion of the construction work force at the site.[5]

Truck drivers worked 12-hour shifts at the site (6 a.m. to 6 p.m. and/or 6 p.m. to 6 a.m.) 7 days a week. Trucks lined up just off site waiting to collect a load. While waiting to advance in line, truck drivers spent varying amounts of time sitting in their trucks, walking along the street, and walking onto the site in proximity to the pile. Once they reached the front of the line, the trucks were directed onto the site alongside of or directly into the debris. Later in the cleanup effort, trucks were driven into the excavation pit where they waited for a load. If the wait was more than a few minutes, the drivers routinely got out of the trucks and walked around the edges of the pile or pit. Since each load was carefully inspected for evidence and human remains prior to leaving the site, truck drivers typically spent extended periods of time on site waiting to receive a load. Early in the cleanup effort, loaded trucks were driven directly to a landfill where they were emptied of their contents. They were then driven back to the site to be reloaded. In early October, the process was changed. Loaded trucks were driven to a nearby pier where their loads were emptied onto a platform. The debris was then transferred onto a barge for transport to the landfill and the trucks were returned to the site for another load. This change resulted in truck drivers spending a greater amount of time at or near the site, as opposed to driving to and from the landfill. During October, wash systems were put in place that vigorously sprayed all trucks with water before they left the site. Spraying was conducted to both cool the debris, which often was hot enough to ignite, and to limit the resuspension of debris as the trucks were driven through residential neighborhoods.

It is known that large amounts of asbestos-containing insulation were used in the construction of the WTC complex, although the exact amount of asbestos contained within the WTC buildings is not known.[6] The massive dust cloud generated by the collapse of the buildings potentially released asbestos into the ambient environment. In addition, the ongoing excavation work associated with rescue, recovery, and cleanup activities was a possible continuing source of asbestos contamination. The long-term consequences of exposure to asbestos generated a great deal of concern among workers and the surrounding community.

This article presents results of asbestos air sampling during the WTC cleanup effort. Results of dust and vapor sampling and health assessment are presented elsewhere.[5,7] Asbestos samples were collected during three sampling periods: October 1–7, 2001, October 17–26, 2001, and April 13–23, 2002. Personal air samples were collected on truck drivers. Area air samples were collected at the perimeter of the site and directly in the rubble pile or pit.

METHODS

Sampling consisted of a combination of area and personal air monitoring. Sample analysis included both optical and electron microscopic methods. Truck drivers were selected for personal air monitoring based on willingness to volunteer. All participants granted informed consent. Drivers were monitored during their work shift with personal air samples collected from their breathing zone. Area air samples were collected during matched sampling periods at locations shown in Figure 1. Sample locations were selected to estimate airborne concentrations around the perimeter of the site and in the debris pile or pit. Area air samples were collected approximately 2 meters above ground.

Air samples were collected using a 50-mm conductive cowl and a 25-mm mixed cellulose ester filter connected to a battery operated sampling pump.[8] Samples were analyzed using a combination of phase contrast microscopy (PCM) according to NIOSH Method 7400, transmission electron microscopy (TEM) using NIOSH Method 7402, and the direct method specified under the Asbestos Hazardous Emergency Response Act (AHERA).[8−10] Samples collected during the first sampling period in October, with quantifiable asbestos according to AHERA method, were also analyzed by TEM according to NIOSH Method 7402. Since the NIOSH Method 7402 results from the first sampling period were all below the limit of detection, samples collected from the remaining sampling periods were not analyzed according this method.

All air sample pumps were calibrated before and after sampling using a DryCal DC-calibrator (BIOS International Corp., Pompton Plains, N.J.). The sampling period was designed to coincide with the work shift. Sample flow rates ranged from 0.5–2.0 L/min. Flow rates were adjusted to prevent dust overloading while maximizing sample volume. Maximizing sample volume while minimizing the opportunity for overloading was difficult given the highly variable nature of the exposure environment. Airborne particulate concentrations varied tremendously depending on the extent of combustion and the intensity and degree of debris clearing activities.[5] Approximately 10% of samples were submitted as blanks. All samples were analyzed by a laboratory accredited by the AIHA Laboratory Accreditation program.

PCM microscopy has been used for decades to quantify asbestos exposures in the workplace, and health-based standards and guidelines for acceptable asbestos exposure have been set based on PCM methods. The United States Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL)[11] standard and the American Conference of Governmental Industrial Hygienists (ACGIH®) threshold limit value (TLV®)[12] guideline for asbestos are both set at 0.1 fiber per cubic centimeter (f/cm^3) using PCM. The utility of PCM methods for quantifying asbestos exposure outside asbestos workplaces is limited for two main reasons. First, PCM lacks analytical capability and assumes that any piece of observed particulate matter meeting the definition of a fiber (>5 μm

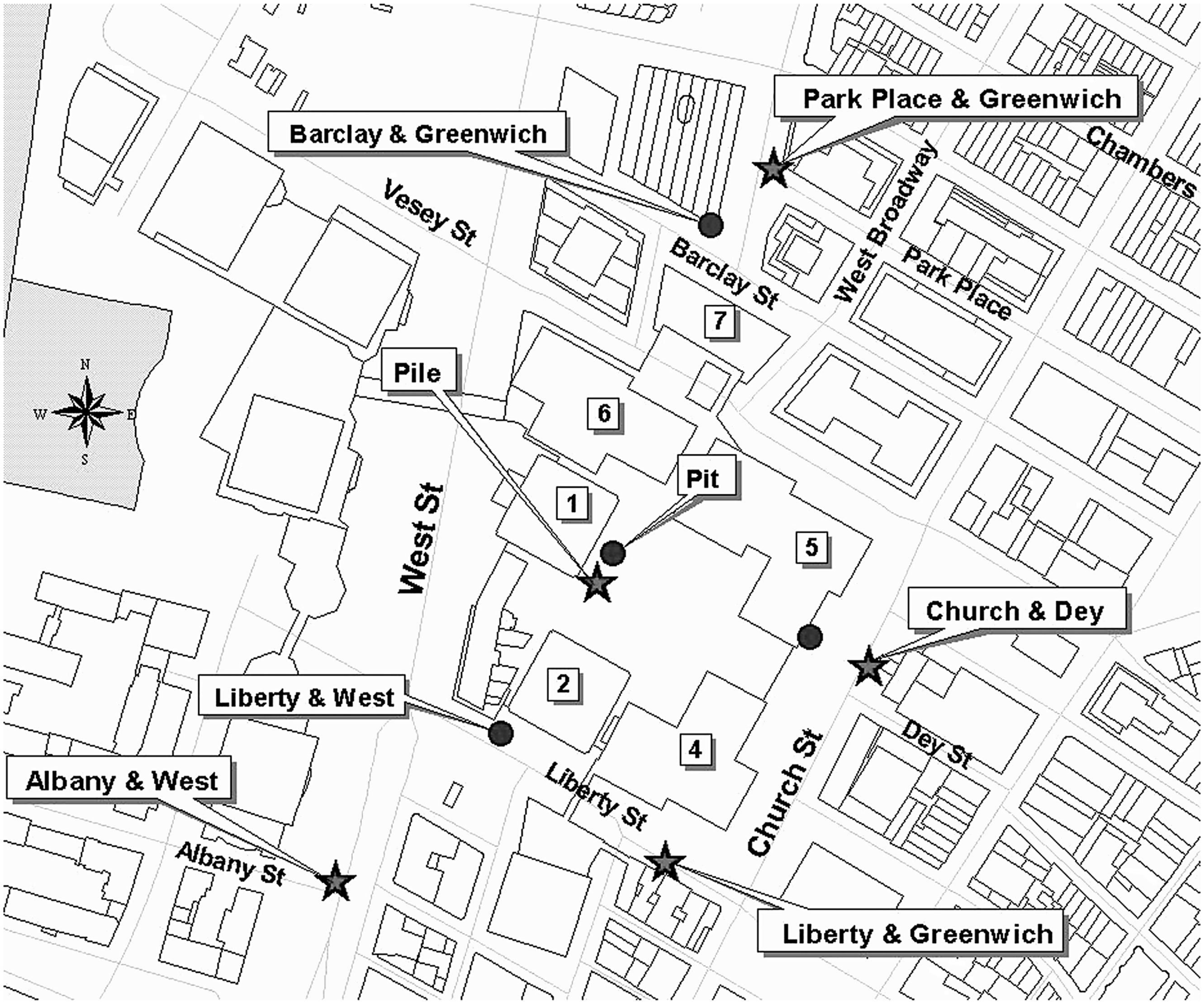

FIGURE 1. Area monitoring locations. October sampling locations are indicated by the stars and April sampling locations are indicated by the dots. Numbers indicate the WTC buildings.

long with an aspect ratio of 3:1 in the case of NIOSH Method 7400) is asbestos. Second, the limit of resolution of PCM (approximately 0.2–0.4 μm) is not sufficient to view asbestos fibers as small as 0.01 μm in diameter.[13] TEM methods of fiber counting were developed to address these limitations and are often used in combination with PCM in occupational environments where the majority of fiber-shaped particles are not asbestos. The limit of detection for NIOSH Method 7400 is based on counting at least seven fibers in 100 counting fields giving a minimum fiber density of 9 f/mm^2.

The AHERA TEM direct transfer method was developed to quantify airborne levels of asbestos in non-occupational environments (schools and buildings with asbestos-containing materials). This method quantifies the number of asbestos structures per cubic centimeter (s/cm^3) and has a limit of detection based on counting one structure. AHERA TEM samples can also be analyzed using an indirect sample preparation method. The indirect method can be used when samples are too overloaded with particulate matter to count any asbestos structures that may be present. The indirect method of preparation was not used in this investigation because it has been shown that the additional steps associated with resuspending, sonicating, and filtering the samples result in artificially high structure counts.[13]

The AHERA TEM method, however, is of limited utility for health-based decision making because there are no health-based exposure guidelines in terms of s/cm^2 and because all current risk assessments are based on the more traditional definitions of a fiber (i.e., based on fibers > 5 μm in length). Currently, the U.S. EPA has adopted a clearance level of 70 s/mm^2 for a 1.2 m^3 sample volume for a 25-mm filter for post-remediation occupancy.[10] This number is not considered a health-based exposure guideline and is used as a measure of acceptable contamination for occupancy purposes. To make TEM asbestos counts more closely comparable to existing standards and guidelines and risk assessments, concentrations are often reported both in terms of total structures and structures greater than 5 μm in length. Structure counts limited to asbestos fibers, clumps, bundles, or structures that are greater than 5 μm in length are considered more relevant for health-based decisions.

By taking advantage of the analytical capabilities of the TEM, NIOSH Method 7402 is designed to provide electron microscopic asbestos fiber counts that are equivalent to PCM methods (i.e., NIOSH Method 7400). Analytical results are expressed in terms of the traditional exposure metric of asbestos f/cm^3. The relationship between TEM exposure estimates expressed in terms of f/cm^3 and s/cm^3 is not known. NIOSH Method 7402 results are directly comparable to current health-based exposure guidelines.

For the purpose of statistical calculations, all results less than the limit of detection were replaced with the limit of detection divided by the square root of 2.[14]

RESULTS

Results of personal air sampling are presented in Tables I and II. Thirty-four drivers were monitored during October. All 15 drivers remaining at the site were monitored during April. Of the 49 truck drivers monitored during the three sampling periods, 15 drivers were monitored more than once. Sampling was conducted during both a.m. and p.m. work shifts. Sample times ranged from 85–742 min. Eighty-four percent of the samples successfully captured exposure across the entire work shift. Seventeen samples could not be analyzed due to overloading with particulate matter.

A total of 45 samples were analyzed using the AHERA TEM method (Table I). Median AHERA airborne asbestos personal air sampling results for each of the three sampling periods were similar, ranging from 0.012 to 0.017 s/cm^3. The highest individual sample was 0.10 s/cm^3 collected during the week of 10/01/01. However, the collection period for this sample was only 3.33 hours due to pump failure. Of the asbestos structures detected, all but one were chrysotile, and very few (4%) were >5 μm in length. The number of samples below the limit of detection for each sampling period ranged from 10% to 47%. The distributions of airborne personal exposure concentrations during the three sample periods are similar and generally range from below the limit of detection to 0.1 s/cm^3.

TABLE II. Summary of PCM Personal Monitoring Results

Dates	N	Median (Range)	No. < LOD
10/1–10/7/01	8^A	0.01 (0.007–0.015)	2
10/17–10/26/01	25^B	0.04 (0.01–0.11)	1

Note: Results in f/cm^3.
^{A}One sample was overloaded and was not analyzed.
^{B}Five samples were overloaded and were not analyzed.

Personal airborne fiber exposures assessed using PCM were measured during the two October sampling periods (Table II). A total of 33 samples were analyzed using PCM. Median airborne fiber concentrations ranged from 0.01 to 0.04 f/cm^3. Only one sample exceeded the OSHA asbestos PEL of 0.1 f/cm^3. The sample concentration equaled 0.11 f/cm^3 and was collected over 580 min. It is difficult to interpret PCM results due to the wide variety of other nonasbestos fibrous materials that may be present. Other studies have documented large amounts of synthetic vitreous fibers released during the collapse of the WTC.[15] PCM fiber concentrations were slightly higher than the asbestos fiber concentrations based on AHERA TEM. This is likely due to the PCM counting of nonasbestos particulate matter that meets the size definitions of asbestos fibers.

A summary of AHERA TEM area air samples results is presented in Table III. A total of 50 samples were collected and 5 were too overloaded with particulate matter to be analyzed. The airborne concentrations were highest in the last sampling period of October 2001, (median area concentration of 0.03 s/cm^3), followed by the first week in October 2001, (median area concentration of 0.005 s/cm^3). The majority (79%) of area air samples collected in April were below the limit of detection. All structures observed during area air sampling were chrysotile. The highest area air samples were collected from the middle of the rubble pile. Five samples were collected from the middle of the debris field, one sample from the pile

TABLE I. Summary of TEM AHERA Personal Monitoring Results

Dates	N	Median (Range)	Total No. Structures	Total No. Structures >5 μm in Length	Number < LOD
10/1–10/7/01	12^A	0.012 (<0.004–0.101)	30^B	3	3
10/17–10/26/01	19^C	0.017 (0.017–0.083)	22^B	0	9
4/13–4/23/02	14	0.013 (0.006–0.04)	21^D	0	5

Note: Results in s/cm^3.
^{A}Six samples were overloaded and were not analyzed.
^{B}All structures chrysotile.
^{C}Eleven samples were overloaded and were not analyzed.
^{D}One structure amosite, 20 structures chrysotile.

TABLE III. Summary of TEM AHERA Area Monitoring Results

Dates	N	Median (Range)	Total No. Structures	Total No. Structures $>5\ \mu m$ in Length	Number $<$ LOD
10/1–10/7/01	5	0.005 (<0.005–0.037)	6^B	0	2
10/17–10/26/01	7^A	0.03 (0.015–0.123)	10^B	0	3
4/13–4/23/02	33	$(<0.006–0.089)^C$	25^B	0	26

Note: Results in s/cm^3.
[A]Five samples were overloaded and were not analyzed.
[B]All structures chrysotile.
[C]Median not presented due to large proportion of samples < LOD.

during the last sampling period of October, and four samples from the pit during April. The five samples ranged from below the limit of detection to 0.123 s/cm^3. The highest area air sample collected (0.123 s/cm^3) was based on counting six chrysotile structures in a 551-L sample from the middle of the pile. Overall, the area air samples indicate a great deal of spatial heterogeneity with no single sampling site having consistently higher airborne asbestos concentrations.

CONCLUSIONS

Personal air sampling results suggest that asbestos fiber exposures to truck drivers at the site were below occupational exposure limits. This conclusion can be drawn from both PCM and TEM sampling results. Median personal air asbestos exposure based on AHERA TEM results ranged from 0.012 to 0.017 s/cm^3. In addition, TEM-based sampling results indicate that the vast majority of asbestos fibers were chrysotile and less than 5 μm in length. It is interesting to note that the NIOSH 7402 analyses did not detect any OSHA countable fibers (i.e., optically visible asbestos fibers longer that 5 μm). Many reviews have concluded that fiber length is an important predictor of toxicity, with short fibers being less toxic.[16,17] The short fiber morphology seen in this study is consistent with expectations, given the tremendous pulverizing forces produced by the collapse of the towers. Given the low airborne concentrations, the predominance of short fibers, and the short duration of the exposure (less than 10 months to complete the cleanup), it is not expected that truck drivers working at the site will be at a significant increased risk for asbestos-related disease.

Area air sampling results indicate that asbestos concentrations were detectable around the site with the highest concentrations, as expected, occurring on top of the rubble pile. As with the personal air samples, the structures were chrysotile and less than 5 μm in length. Of the 40 nonpile area air samples collected around the perimeter of the site, 78% (31/40) were below the limit of detection, indicating that asbestos released from the site during cleanup was sporadic and at low levels. These results are likely due to the dust suppression activities undertaken during the cleanup.

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