Evaluation of Ambient Asbestos Concentrations in Buildings Following the Loma Prieta Earthquake

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On October 17, 1989, an earthquake struck central, coastal California including San Francisco and the Bay Area, damaging many buildings. Because of concern over the possible exposure to asbestos in the damaged buildings, building owners/managers hired several Bay Area industrial hygiene firms to collect air samples in suspect buildings. RJ Lee Group analyzed a total of 419 air samples from 55 buildings (25 school, 3 university, 20 commercial, 5 public, and 2 residential buildings) using transmission electron microscopy and has compiled the results. The data from each building were averaged and grouped accordingly into three classifications: indoor buildings, buildings with asbestos abatement in progress at the time of the earthquake, and buildings where sampling was performed to monitor clean-up of debris. Several buildings were sampled on more than 1 day. The results indicate that asbestos levels differed little from outdoor levels, even immediately after the earthquake. Exceptions to this were samples collected in the vicinity of debris clean-up and in buildings undergoing abatement which were higher than the indoor or outdoor samples. However, these samples generally had concentrations below the AHERA clearance levels and all were well below the OSHA action limit.

1.0. INTRODUCTION

Central, coastal California was struck by the Loma Prieta earthquake measuring 7.1 on the Richter scale ($M_c$) on Tuesday, October 17, 1989. Buildings were shaken and damaged in one of the most populated areas of the United States. The earthquake killed 62 people, injured 3757, destroyed 367 businesses, and left more than 12,000 homeless (Benuska, 1990). During the Loma Prieta earthquake, buildings in the San Francisco Bay Area experienced light to moderate shaking for less than 10 sec during the initial earthquake (Benuska, 1990). Though the 7.1-$M_c$ shaking was short lived, the motion detected by the California Strong Motion Instrumentation Plan indicated buildings experienced motion ranging from 0.1g to 1g acceleration, depending upon such factors as location relative to the epicenter, foundation materials, and structural design. These accelerations also varied within buildings; higher floors reported larger accelerations (Shakal et al., 1990).

Though the earthquake caused extensive damage, it has provided an opportunity to evaluate the effect of a brief, violent episode on the release of asbestos fibers from the in-place asbestos-containing materials (ACM). This study reports on the asbestos concentration of air samples collected within the first 5 days following the Loma Prieta earthquake. While the initial earthquake caused the extensive damage, 38 additional earthquakes of magnitude $M_c \geq 4$ occurred during this sampling period, while total earthquake activity exceeded 250 events per day through this study period (McNutt and Toppozada, 1990).

2.0. SOURCES OF SAMPLES

The air samples described in this report were collected by several industrial hygiene firms between October 18, 1989 and October 22, 1989 at the request of the building owner in order to assess the airborne concentration of asbestos in the building prior to reoccupation. The samples reported here were collected during the first 5 days following the earthquake. During this time period, schools and most businesses were closed; by the following Monday, conditions began to return to normal.

Most of the buildings which were sampled were partially occupied, but no systematic evaluation of occupancy was performed. Sampling was conducted in areas where the building owner or the consulting industrial hygiene firm felt there was the greatest potential source of airborne asbestos from the disruption of asbestos-containing materials.

Sampling was performed according to the requirements of National Institute of Occupational Safety and
Health (NIOSH) Method 7400 (NIOSH, 1989) or the Asbestos Hazard Emergency Response Act (AHERA) (USEPA, 1987). Sample volumes ranged from 83 to 2160 liters for indoor samples and from 83 to 1408 liters for personal samples. Specific information on sampling times and sample flow rates was usually not provided by the industrial hygiene firm.

The samples were collected throughout the San Francisco Bay area, but range in locale from Sacramento south to Monterey. Figures 1 and 2 show the location of the 55 buildings (25 school, 3 university, 20 commercial, 5 public, and 2 residential buildings) that were sampled as part of this study.

Three groups of buildings were identified: (a) those with currently active asbestos abatement projects—"abatement," (b) those where sampling was performed to monitor clean-up of earthquake debris—"clean-up," and (c) all other buildings—"indoor." Separation of the air samples from buildings under abatement or clean-up avoided skewing the data set on indoor air by potential fiber generation activities. Three buildings were identified as undergoing clean-up (including one public building, one school, and one residence) with an additional eight buildings classified as undergoing abatement (seven commercial buildings and one public building).

2.1. Sample Analytical Procedures

The measurement of asbestos concentration from samples by transmission electron microscopy (TEM) consists of sample preparation, asbestos fiber identification, reporting, and quality assurance. Techniques for each of these phases have been developed by a number of groups over a period of years (USEPA, 1987; Lee et al., 1977; Yamate et al., 1984; Berger et al., 1989).

2.2. Statistical Analysis

For each sample, the total asbestos structures per unit air volume (s/ml) were calculated, along with the fiber
concentration for structures ≥5 μm and the concentration for fibers ≥5 μm with a width of at least 0.25 μm. The latter category is referred to as "optically equivalent" structures and represents the fraction of asbestos structures that would be identified by phase-contrast microscopy. Optically equivalent concentrations are comparable to numbers used in performing risk estimations.

For data evaluation purposes, all samples with no asbestos structures counted were treated as 0 s/ml and not as a "less than" detection limit (Oehlert et al., 1994).

For each building, air concentrations calculated from indoor stationary samples are averaged. Summary averages are presented by building category (indoor, clean-up, and abatement). The indoor samples were further divided into groups reflecting building usage (commercial, public, residential, school, and university). Averages of outdoor samples and personal samples are based on individual samples rather than building averages.

3.0. RESULTS OF THIS STUDY

A total of 419 air samples and 34 blanks from 55 buildings are included in this analysis. This includes 90 samples from 25 schools, 9 samples from 3 university buildings, 238 samples from 20 commercial buildings, 35 samples from 5 public buildings, and 6 samples from 2 residential buildings. There were a total of 3 buildings (16 samples) where clean-up activities were underway. In the 8 buildings that were being abated prior to the earthquake, 174 samples were collected. The locations of these buildings are shown on the maps in Figs. 1 and 2.

The average concentrations for each group of samples and class of structures (all structures, fibers longer than 5 μm, and optical equivalent) are shown in Table 1. The standard deviations for these values ranged from equaling the mean to 2 to 3 times the value of the mean.

There are significant differences (P = 0.024) in the concentrations between the indoor group and the outdoor samples. The area samples in the indoor group averaged about 0.004 s/ml for all structures, while the outdoor samples averaged about 0.001 s/ml. There was no significant difference (P = 0.876) between the indoor group and the outdoor samples when considering all fibers longer than 5 μm or optically equivalent fibers; in the latter case, both the indoor and outdoor groups averaged about 0.0001 s/ml.

The clean-up and abatement samples had significantly higher concentrations than the outdoor samples (P = 0.0013 for optically equivalent fibers), averaging 10–20 times higher than the outdoor concentrations for the various categories.

Personal samples had average concentrations of optically equivalent fibers of about 0.04 s/ml. The personal

FIG. 2. Location of earthquake samples from within San Francisco.
TABLE 1
Summary of Buildings Sampled Following the Loma Prieta Earthquake and Mean Asbestos-in-Air Concentration for All Asbestos Structures, Asbestos Fibers >5 μm, and Optically Equivalent Fibers

<table>
<thead>
<tr>
<th>Building type</th>
<th># Buildings</th>
<th># Samples</th>
<th>Structures/ml</th>
<th>Fibers/ml &gt;5 μm</th>
<th>Optical equivalent (f/ml)°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor</td>
<td>44</td>
<td>188</td>
<td>0.00366</td>
<td>0.00043</td>
<td>0.00012</td>
</tr>
<tr>
<td>School</td>
<td>24</td>
<td>81</td>
<td>0.00390</td>
<td>0.00019</td>
<td>0.00010</td>
</tr>
<tr>
<td>University</td>
<td>3</td>
<td>9</td>
<td>0.00211</td>
<td>&lt;0.0012</td>
<td>&lt;0.0012</td>
</tr>
<tr>
<td>Commercial</td>
<td>13</td>
<td>68</td>
<td>0.00229</td>
<td>0.00083</td>
<td>0.00003</td>
</tr>
<tr>
<td>Public</td>
<td>3</td>
<td>28</td>
<td>0.00413</td>
<td>0.00044</td>
<td>0.00023</td>
</tr>
<tr>
<td>Residential</td>
<td>1</td>
<td>2</td>
<td>0.01882</td>
<td>0.00213</td>
<td>0.00213</td>
</tr>
<tr>
<td>Clean-up</td>
<td>3</td>
<td>16</td>
<td>0.01812</td>
<td>0.00240</td>
<td>0.00164</td>
</tr>
<tr>
<td>Abatement</td>
<td>8</td>
<td>174</td>
<td>0.09799</td>
<td>0.01122</td>
<td>0.00195</td>
</tr>
<tr>
<td>Outdoor</td>
<td>5</td>
<td>25</td>
<td>0.00091</td>
<td>0.00015</td>
<td>0.00015</td>
</tr>
<tr>
<td>Personal, indoor</td>
<td>2</td>
<td>3</td>
<td>0.00929</td>
<td>&lt;0.0015</td>
<td>&lt;0.0015</td>
</tr>
<tr>
<td>Personal, clean-up</td>
<td>2</td>
<td>2</td>
<td>8.89523</td>
<td>1.20199</td>
<td>0.12457</td>
</tr>
<tr>
<td>Personal, abatement</td>
<td>3</td>
<td>11</td>
<td>0.76092</td>
<td>0.05726</td>
<td>0.04098</td>
</tr>
</tbody>
</table>

° Fibers at least 5 μm long with a diameter of at least 0.25 μm (fibers projected to be counted by phase-contrast microscopy).

The two personal samples collected in buildings undergoing clean-up averaged 0.00981 f/ml TWA for fibers at least 5 μm long and 0.25 μm wide (optical equivalent). Eleven personal samples collected from buildings undergoing abatement averaged 0.03266 f/ml TWA (optical equivalent fibers). Of these 11, only 2 samples had concentrations greater than 0.1 f/ml; the TWA of both were below the OSHA PEL (0.2 f/ml) or the OSHA action limit (0.1 f/ml). There was no specific description of activities identified with these personal samples.

Because most buildings reported in this study were sampled only once, there are insufficient data to summarize the data on a daily basis to determine if any trends in the data are apparent. However, three buildings were sampled on consecutive days (Table 2), and the data showed no statistically significant variation in asbestos concentration over the sampling period.

As mentioned earlier, a goal of this analysis was to evaluate the effect of distance from the epicenter on the airborne concentrations. After review, it was decided that the buildings which were sampled were too highly clustered in San Francisco and Oakland (Fig. 1) to permit this comparison.

4.0. DISCUSSION

Potential risk to building occupants resulting from exposure to airborne asbestos in buildings with asbestos-containing materials has been the subject of intense debate for a number of years (Sawyer and Spooner, 1978; HEI-AR, 1991). The development of large data sets of airborne concentrations of asbestos in buildings has demonstrated that the presence of asbestos in building materials has little or no effect on airborne concentrations; i.e., the average building occupant is not at risk because of the mere presence of ACM in buildings (HEI-AR, 1991; Lee et al., 1992; Mossman et al., 1990). The potential risk resulting from episodic exposures, caused by direct disturbance of asbestos-containing materials or asbestos-containing material debris either during renovation/maintenance activities or potentially by a large-scale event such as an earthquake, has remained the subject of debate (HEI-AR, 1991; USEPA, 1990). Airborne asbestos concentrations in samples collected from San Francisco buildings after the 1989 Loma Prieta earthquake were evaluated and can be compared to both regulatory levels and other sets of air data. Insofar as these data provide information about the potential exposure (in buildings containing ACM) resulting from an earthquake and subsequent clean-up activities, they are of considerable scientific and practical interest today.

The largest published databases of ambient airborne...
asbestos concentrations is found in HEI-AR (1991) and Lee et al. (1992). Though these data sets contain no samples from within the earthquake study area, they can be used to provide a comparison of the data. The average value for all structures is comparable between this study and the Lee study and shows no statistical difference (P = 0.214). For fibers longer than 5 μm, the average value in the earthquake buildings was 0.00043 f/ml, a value about twice that reported by HEI-AR (0.00027 f/ml) and about three times that reported by Lee et al. (0.00013 f/ml). The earthquake concentrations for fibers longer than 5 μm are statistically different from the Lee data (P = 0.0005); however, there is no difference between the two data sets for optically equivalent fibers (P = 0.516). This indicates there may be an increase of the concentration of long, thin fibers compared with buildings nationwide, but there is also no difference in concentration between indoor and outdoor samples from this study (P = 0.876).

These comparisons were repeated using the logarithmic-transformed means for each building. (A half-fiber was used to calculate a concentration for those buildings in which no asbestos was observed (Oehlert et al., 1994).) These calculations showed minor changes in the P values from before, but no changes in the conclusions.

The data reported herein indicate that average ambient levels in buildings after the earthquake are far below (typically on the order of 1000-fold less) OSHA regulatory levels. It should also be kept in mind that the action levels themselves are considerably below any levels that have been shown to cause disease in humans.

Levels of all fibers were slightly elevated compared to outdoor levels, about fourfold. They were still below EPA clearance levels and were well within the range of airborne levels (both indoor and outdoor) measured around the country (HEI-AR, 1991; Lee et al., 1992). Some elevation of asbestos concentrations was observed in both area and personal samples collected during debris clean-up and near abatement areas, but they were well below OSHA regulatory levels (USDOL, 1989).

Taken together, these data provide strong support for the premise that the presence of asbestos in buildings has little or no effect on airborne concentrations, even if subjected to violent episodes such as an earthquake. In addition, they strengthen the growing body of data that show that routine maintenance activities (Corn et al., 1994), even those involving clean-up of debris, are most likely to result in exposures far below the OSHA PEL.

5.0. CONCLUSIONS

The 1989 Loma Prieta earthquake damaged many buildings in the San Francisco area. Because of concern over the possible exposure to asbestos in the damaged buildings, building owners/managers hired several Bay Area industrial hygiene firms to collect air samples in suspect buildings. RJ Lee Group analyzed a total of 419 air samples from 55 buildings using transmission electron microscopy.

The data from each building were averaged and grouped according into three classifications: indoor buildings, buildings with asbestos abatement in progress at the time of the earthquake, and buildings where sampling was performed to monitor clean-up of debris. There were significant differences for all buildings when comparing structure concentrations for those samples collected indoor with those collected outdoors. There were no differences between indoor and outdoor samples, however, when considering the concentration of fibers longer than 5 μm. Only for those buildings where clean-up activities were in progress during the sampling was there a significant difference in the concentration of fibers longer than 5 μm.

Several buildings were sampled on more than 1 day and showed no temporal change in concentration.

While the concentrations reported here averaged several times those values reported in the literature, these samples generally had concentrations below the AH-ERA clearance levels and all were well below the OSHA action limit.

REFERENCES


