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Facilitating occupational noise management: The use of a smartphone app as a noise exposure, risk management tool

Williams, Warwick1, Zhou, Dan1, Stewart, Greg1 and Knott, Peter2

Abstract:
With the arrival of the modern smartphone, a pocket-sized computer was introduced for every-day use and applications rapidly developed for uses other than straightforward telephone calls. The purpose of applications (apps) range from gaming to scientific. With the inclusion of an inbuilt microphone use as a sound level meter was inevitable. By including a time measurement, use is easily extended into personal noise dosimetry. But how practical and useful is a smartphone app as a dosimeter? The National Acoustic Laboratories addressed this in a practical way by developing a noise dosimeter app. This paper focusses on establishing the app utility by verifying noise level and dosimetry results for precision and accuracy, and for use in occupational noise management and as a hearing health education tool.

Introduction
Contemporary Workplace Health and Safety (WHS) is based on a risk management, consultative principle as opposed to the traditional prescriptive approach where definite courses of action were required (The Cabinet Office: 1997; WorkCover: 2001; Safe Work Australia: 2009). The intent is to encourage an appropriate degree of participation from all of those who have contact with the workplace. One of the goals for the National Acoustic Laboratories (NAL) is to decrease hearing loss in the workplace due to noise. One possible method of engaging individuals in hearing loss prevention programmes is through the use of personal noise dosimetry via the use of a simple smartphone noise exposure app.

Following an examination of the numerous sound level meter smartphone apps currently available, NAL personnel decided to develop their own app. This decision was made in lieu of undertaking a review and evaluation of existing apps, as many others have done previously (Keene et al: 2013; Kardous & Shaw: 2014; Nast et al: 2014; Staab: 2016). NAL was particularly interested in developing an app as a research and educational tool. It was considered practical to develop a combined sound level meter (SLM) and personal sound exposure meter (PSEM)/dosimeter app for which requirements and procedures are described in Australian Standards and various codes of practice (Standards Australia: 2005 ; NOHSC 2000).

Methodology
Platform selection
The first task was to choose an appropriate platform on which to develop the tool. An informal review of smartphones available (n = 13) revealed an almost equal mix of both Android and iPhone (Apple®) based devices.
A practical discrimination task was designed where the comparative performance of the respective microphones mounted within the devices could be undertaken. On each of the devices a white noise recording was made using the recording application ‘PCM Recorder Lite’. This application has identical Android and Apple® versions. The recorded output RMS voltage levels were then compared from their respective WAV files for precision and consistency. At this stage ‘trueness’ was not considered as this could be accounted for through a future calibration process.

The Apple® devices were found to match the criteria with much less variation than the Android devices (see Figure 1 below). The Apple® devices were consequently adopted for the development platform.

**Platform development**
The software for the SLM/dosimeter App was developed by proceeding through a number of iterative development stages of test and re-test before the formal verification.

**Laboratory verification**
For the initial tests the App was installed on an iPhone 5 (OS 7.1.1) in a laboratory setting with low background noise ($L_{Aeq} < 30$ dB) and positioned about one meter in front of a Tannoy V8 loud speaker. Testing consisted of the comparison of the indicated output level ($L_{Aeq}$) on the iPhone to an adjacent, calibrated, precision, integrating SLM, B&K model 2250 SLM, in accordance with IEC61672-1:2013 Class 1 requirements. The measured $L_{Aeq}$ on the App and the B&K 2250 SLM over a range of 40 to 120 dB for a 1 kHz pure tone sine wave signal and a ‘pink’ noise were assessed. In addition, because human speech is predominantly around 4 kHz and is therefore considered to be an important area, of the acoustic spectrum, the response of the App microphone in relation to a 4 kHz sine wave was assessed.

**Field verification**
Field testing aimed to directly compare measurements made in numerous workplaces and other noisy locations. Relatively short duration, task sampling measurements (up to about 30 min) were made using a SLM while long duration measurements (up to around eight hours) were carried out with a PSEM or dosimeter. The SLM measured loudness ($L_{Aeq}$) was used in conjunction with the exposure time to calculate noise exposure ($L_{Aeq,8h}$) while the PSEMs present both loudness and exposure. For WHS purposes both methods are equally valid.

Seventy-two (72) measurements were made at a wide variety of locations including: underground and open cut mining operations in New South Wales, Queensland and the Northern Territory; train stations, bus stops, busy intersections; shops, restaurants, cafes, libraries and offices. Specific noisy tasks such as use of machinery and power tools were also assessed.

All measurements were carried out with the iPhone microphone in as close proximity as possible and oriented similarly to the SLM or dosimeter microphone as required by the combined Australian/New Zealand Standard (Standards Australia: 2005).

**Results**

**Verification in the laboratory**
Figure 1 shows the distribution of the relative magnitude of the output signal WAV files recorded on the sampled smartphones. The seven Apple® iPhones tested, Model 4 (n = 2) and Model 5 (n = 5), provided greater consistency of results compared to the six Android counterparts tested (one each of: HTC Desire; Samsung S3; Google Nexus S; Samsung GT-19100T; Samsung Google Nexus; and Sony Xperia). Important features of good measurements are accuracy and trueness. The better grouping of the Apple® device microphones demonstrates they have a consistent performance and repeatability between microphones, implying better accuracy. The second feature, trueness, can be accounted for during a calibration process.
Figure 1: Comparative distribution of WAV file output L_{Aeq} for various smartphone platforms [iPhone 4 (2); iPhone (5); and one each of HTC Desire, Samsung S3, Google Nexus S, Samsung GT19100T, Samsung Google Nexus, and Sony Xperia].

Figure 2 compares the measured L_{Aeq} on the App and the B&K 2250 SLM over a range of 40 to 120 dB for a 1 kHz pure tone sine wave signal. The curve of ‘best fit’ shows there is a linear relationship between the B&K 2250 SLM and the App response (R^2 = 0.99).

The assessment of the response of the App microphone in relation to a 4 kHz sine wave found a satisfactory linear correlation over the main range of interest of 80 to 120 dB (R^2 = 0.98) as presented in Figure 3.
Figure 4 compares $L_{Aeq}$ results for the pink noise test signal. Again there is a satisfactory correlation of $R^2 = 1$ over the range 40 to 120 dB.

Verification in the field

The 72 field measurements of $L_{Aeq}$ taken from the App output are compared to the combined results from the B&K 2250 SLM used for short time sample measurements and two CEL, model 350 and 35X, dosimeters used for the longer term, dosimetry measurements. The resulting correlation is good at $R^2 = 0.97$.

Figure 5: Comparison of field $L_{Aeq}$ measurements from App and a combination of B&K 2250 and CEL model 350 and 35X dosimeters from 20 to 100 dB.
A detailed examination of the ‘outlying’ data points was undertaken to find reasons for their departure from the line of best fit. The low \( L_{Aeq} \) data point (21.3, 28.3) was taken in a low noise, anechoic room where the Apple® microphone would not normally be expected to operate because its primary function is to operate at or above conversation voice levels. Other measurements in the 60 to 70 dB range lying away from the line were taken in locations such as external balconies on buildings, walkways, in railway stations, and in the vicinity of road traffic where there was wind noise affecting the microphone performance. This is reflected in the direction of the outliers above the line of best fit (ie higher noise levels). The SLM/CEL microphones were protected by a microphone wind-shield as routine best practice while the smartphone microphone was unprotected. Overall the correlation is good notwithstanding the inclusion of the outliers.

Figure 6 presents results for \( L_{Cpeak} \) (C-weighted peak noise level) measurements between the combined results from the B&K 2250 SLM and two CEL model 350 and 35X dosimeters and the equivalent iPhone results. The Apple® microphone appears to exhibit a saturation effect at high peak levels, as demonstrated by a second degree curve of best fit \((R^2 = 0.91)\). The microphones used in smartphones are not designed to respond accurately to high level impulse noise.

A closer examination of peak measurement responses has not been conducted given that the aim is to produce an App suitable for assessment of exposure to continuous noise. Peak values must be considered unreliable and indicative only.

The App visual output is illustrated by the ‘screen shots’ presented in Figure 7. The output provides the measurement start time, in real (local) time, and sample duration. A graph provides a series of one minute \( L_{Aeq} \) values for the entire recording period. Values greater than or equal to 85 dB are red in colour and black if less than 85 dB. Included are the maximum peak value \( L_{Cpeak} \) measured over the whole sampling period and the calculated exposure \( L_{Aeq,8h} \) in \( \text{dB} \) and in Pascal squared hours \( (\text{Pa}^2\text{h}) \). Also included is what is referred to as a “Safe exposure time estimate” under the assumption that this was a measurement of the typical projected exposure. Geographical co-ordinates and a map for the location of the measurement site are included as a display option. If the measurement site is mobile or the measurement was taken over several locations, the location information is that of the last one minute measurement interval. Options are also available for measurement details and any appropriate comments.
Discussion

Under laboratory conditions with continuous noise there is excellent agreement between measurements taken with the App and those carried out in parallel with a Class 1 integrating SLM and dosimeters. For some field measurements the discrepancies occurred when wind noise caused disturbance to the microphone. Smartphone platforms are not normally required to operate precisely under these conditions without a wind-screen as is normal practice with an SLM or dosimeter.

A comparison of the consistency of the LAeq results was carried out using a Student t-test. The results can be summarised as: i) SLM results compared to app results, \( p = 0.102 \); ii) Dosimeter results compared to app results, \( p = 0.002 \); and iii) combined SLM/Dosimeter results compared to app results, \( p = 0.026 \). These are as would be expected in that the results taken with the SLM compared to the NAL app was better when compared to the Dosimeter results while the overall comparison of the combined was within a 95% confidence interval (\( p = 0.026 \)). Implying that the better the instrument used, the better the results.

For impulse noise measurement, the results show obvious limitations in the performance of the App. Smartphone microphones are not expected to be able to accommodate sudden transients during normal use. As a general comment, using dosimeters for measuring peak results can be uncertain because inadvertent bumping or deliberate interference with the microphone can occur with an unattended instrument. Occupational hygienists and others using dosimetry will regularly check peak noise levels with an SLM. However, the correlation (\( R^2 = 0.94 \)) with the measurement microphone appears reasonable until a saturation effect begins above around 110 dB. The App was intended to monitor continuous noise so this is not a significant limitation to its use.

As a noise exposure risk management tool, by supplying noise level (\( L_{Aeq} \)) in dB, exposure in both dB (\( L_{Aeq,8h} \)) and in a linear measure (\( E_{A,T} \)) of Pa\(^2\)h, the App provides sufficient information for the user to judge the relative level of risk. It is indeed fortunate that the accepted daily Exposure Standard of 85 dB \( L_{Aeq,8h} \) is 1.01 Pa\(^2\)h. Thus \( E_{A,T} \) is easily interpreted as a level of 1 Pa\(^2\)h being ‘acceptable’ for daily exposure to within 1% accuracy. An exposure greater than 1 Pa\(^2\)h can be interpreted as unacceptable and thus preventative action is required. The App provides an estimate of the recommended exposure time required to remain at less than the Standard on the assumption that the nature of future exposure does not significantly change.

Limitations

There are obvious limitations in the use of this App as a direct replacement for those instruments required by the regulations in various WHS jurisdictions. The use of a smartphone noise measurement app is not a direct replacement for a ‘detailed assessment’ as required by paragraph 6.1.3 of combined “Australian/New Zealand Standard (2005) AS/NZS 1269.1 Occupational noise management, Part 1: measurement and assessment of noise immission and exposure” (Standards Australia 2005). However, within a regime where WHS is structured toward
risk management, access to a self-assessment tool on a device that people have at their disposal is a reasonable approach. The concept is to actively engage individuals in the process of looking after their hearing health. The use of a smartphone monitoring App offers a tool of exceptional convenience for noise exposure risk management and assessment. It is a true ‘personal’ noise exposure meter and use can not only assist with the management of noise exposure but also function as an awareness raising tool.

Microphone positioning is often difficult in an active workplace and particularly so where personal dosimetry is undertaken. However, it should be kept in mind that the aim of this was not dosimetry per se but rather the comparison of dosimetry results from different measurement instruments. While the positioning of the microphone location met the Standard requirements as far as practicable, the microphones on the iPhone and the dosimeter and the SLM respectively were always co-located.

While accurate measurement is desirable more relevant, is that this SoundLog App provides non-technical persons access to a simple means of assessing noise exposure risk without having to resort to specialist assistance. In small businesses the effort and cost of accessing professional WHS services is a significant deterrent. For small businesses and the individual who may be aware that exposure to loud noise may poses a risk to future hearing health the App functions as an awareness raising and discrete assessment tool.

Conclusion
For general and preliminary assessments, as described by the Australian/New Zealand Standard (Standards Australia: 2005), the App does should be able to perform as a satisfactory assessment tool within the acceptable limits of accuracy of risk management practice as applicable for WHS. While it cannot replace a detailed assessment (Standards Australia: 2005) it can act as a personal exposure assessment tool and as an educational and awareness raising opportunity. The App is equally applicable in the workplace or during leisure activities.

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Asbestos fibre concentrations and health risks resulting from fire impacted properties with asbestos materials
Nathan Aust1

Abstract:
Airborne asbestos fibre concentrations generated from fire affected buildings having asbestos containing materials were assessed. Air samples were collected during the 2013 Blue Mountains bushfires during and after which numerous buildings containing asbestos products were impacted.

The results of 283 airborne asbestos sampling events were received. Air sampling was undertaken during a fire event; during Make Safe works; during Clean-up, Removal and Demolition works; and as background area concentrations. All airborne asbestos sampling events across these scenarios measured concentrations less than 0.01f/ml. Overall, airborne asbestos fibre concentrations resulting from fire-damaged buildings are shown to be minimal, presenting a very low risk to health when the property is appropriately managed in line with Work Health and Safety legislation, guidelines and best practice.

CITE THIS ARTICLE AS

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CORRESPONDENCE
Nathan Aust, Toxicology and Environmental Health Consultants, 37 Escolar Dr, Mountain Creek, QLD Australia 4557 nathan@tehc.com.au

Introduction
The purpose of this research was to examine measured airborne asbestos fibre concentrations and to assess the associated health risks resulting from fire-affected buildings containing asbestos materials in an Eastern Australian context. Asbestos fibre concentrations were measured during a series of bushfires at several locations in the Blue Mountains, New South Wales, Australia. Numerous buildings containing asbestos materials were impacted during the bushfires that were active from the 16 October to 13 November 2013. The suburbs of Winmalee and Yellowrock were the worst affected communities with approximately 193 homes destroyed and 100 damaged.

Fire and Asbestos Containing Materials
The most common Asbestos Containing Material (ACM) used within Australian domestic and commercial buildings is the non-friable Asbestos Cement (AC) sheeting for walls, eaves, roofs or fences. Occasionally friable asbestos products may be found within materials such as the backing for vinyl floor tiles, some fibre boards and as non-bonded insulation (enHealth, 2013; VIC DHS, 2006; enHealth, 2005).

When the AC is intact and well maintained, there is minimal chance of fibre release from the matrix. However, in the event of a fire, there is potential for fibre release. The release of asbestos fibres from ACM during a fire event depends on several factors including the type of structure containing ACM, the type and amount of ACM present and the location of the ACM in relation to the fire (enHealth, 2013, enHealth, 2005).

During a fire, building materials that contain asbestos can become damaged due to the direct exposure to fire which may result in charring, spalling, delamination and the loss of structural strength. Spalling occurs when fragments of the material are explosively released due to the build-up of steam pressure inside the material. Damage to ACM, in the form of thermal expansion, has also been observed even when no direct exposure to fire has taken place (Bennets et al, 2013; Smith & Saunders, 2007; VIC DHS, 2006).

Fires involving buildings that contain asbestos can produce a range of asbestos debris, including unburnt and partly burnt pieces. Some ACM can be further damaged if the building or part of the building collapses (enHealth, 2013; VIC DHS, 2006).
**Hazard Assessment**

Asbestos fibres pose a human health risk if inhaled. If deposited and retained in the lungs, the fibres can initiate diseases that take many years to present. These diseases include asbestosis, lung cancer and mesothelioma and tend to be the result of higher levels of long-term exposure, most often occupational. Asbestos is classified by the IARC and USEPA as a known human carcinogen (OEHHA, 2013; IARC, 2011; ATSDR, 2001; WHO, 2000 and USEPA, 1999).

Short-term exposure to low levels of asbestos is not known to produce acute health effects. The risk of developing an asbestos-related disease increases with the number of asbestos fibres a person breathes in during their lifetime – their ‘cumulative lifetime exposure’. Cumulative lifetime exposure depends on the number of fibres that are breathed in during each exposure (concentration x duration) and how often a person is exposed over their lifetime. A cumulative lifetime exposure to asbestos can increase the likelihood of asbestos related disease (ASTDR, 2001; OEHHA, 2013; enHealth, 2013).

The U.S. Environmental Protection Agency (USEPA) has calculated that, using a linear no-threshold model, lifetime exposure to an airborne asbestos concentration of 0.0001 fibres/millilitre (f/ml) may result in less than 1 excess cancer death above normal cancer incidence rates (lung cancer plus mesothelioma) per 1,000,000 (USEPA, 2001).

In Australia, the measurement of asbestos fibres in the air is conducted in accordance with National Occupational Health & Safety Commission (NOHSC) 2005 “Guidance Note on the Membrane Filter Method for Estimating Airborne Asbestos Fibres” (NOHSC 2005b). A calibrated constant volume sampling pump is used to draw a known volume of air through a gridded membrane filter which is subsequently analysed by Phase Contrast Microscopy (PCM). The limit of detection for this method is 0.01f/ml.

Currently, no guideline concentration exists in New South Wales (NSW), the State in which the sampling was undertaken. However, the Western Australian Department of Health has recommended an asbestos in air limit for protection of the public around contaminated sites of 0.01f/ml, which is limit of detection using the membrane filter method (WA DoH, 2009). SafeWork Australia has a recommended standard eight-hour Time Weighted Average (TWA) of 0.1f/ml for workplace asbestos exposure. This recommended standard is incorporated into NSW legislation.

NOSCH 2005 recommends an airborne asbestos level of 0.01f/ml for both control and clearance monitoring. Control monitoring means air monitoring to measure the level of airborne asbestos fibres in an area during work on ACM, undertaken to assist in assessing the effectiveness of control measures. Clearance monitoring is air monitoring used to measure the level of airborne asbestos fibres in an area following work on ACM. An area is considered safe to enter without personal protective equipment when the level of airborne asbestos fibres is measured as being below 0.01f/ml.

**Airborne Asbestos Fibre Concentrations**

Asbestos is widespread in the environment at very low concentrations as a result of fibre release from natural sources and extensive industrial and commercial use of the material in the past. Members of the public are exposed to asbestos fibres, albeit in small concentrations, throughout their lives. The exposure of asbestos to persons in ambient conditions and inside buildings is several orders of magnitude lower than the concentrations in occupational settings. Airborne asbestos concentrations in remote areas of the United States have been reported to be generally less than 0.0005 f/ml and up to 0.002 f/ml in urban areas, analysed by transmission electron microscopy (TEM) and reported as PCM equivalent fibres (WHO, 1998). Employing the membrane filter sampling method and Phase Contrast Microscopy (PCM) that has higher limits of detection, the asbestos fibre concentration in the outdoor environment of West Australian schools, which had asbestos cement roofs, was <0.01f/ml (WAACHS, 1990).

In regards to asbestos concentrations associated with fires, the Victorian Department of Human Services (VIC DHS, 2006) commissioned an investigation into materials containing asbestos and fire. The main outcome of the investigation was that fires within buildings comprising substantial quantities of ACM do not result in hazardous conditions with respect to respirable asbestos fibres either close to or at a distant to the fire. Fibres can be released during spalling events but, due to the large quantities of air introduced to the combustion zone, fibre concentrations are rapidly reduced to less than 0.01f/ml. Remnant ACM and asbestos fibre bundles are likely to exist after a fire with the possibility of respirable fibres existing within the ash. Any subsequent disturbance may result in the release of respirable fibres, potentially resulting in elevated concentrations (VIC DHS, 2006).
Smith and Saunders (2007) undertook a systematic literature review to identify any available information on both the level of asbestos concentrations that might result from fires in buildings containing ACM and the potential health impact of such exposures to those concentrations. The study used a conservative estimate of 0.1f/ml for a period of 2 days for a member of the public following a fire to determine risk to health. The report concluded that exposures of members of the public to concentrations of respirable asbestos fibres during and following fires involving ACM will be very small if appropriate clean-up operations in accordance with UK Health and Safety Executive (HSE) guidance are undertaken. They also concluded there is no direct evidence of long-term health risks from fires involving ACM (Smith & Saunders, 2007).

Following a structural fire involving asbestos, ACM debris will be present within the building skeleton and footprint and throughout adjacent areas. This presents a risk of exposure if the debris is disturbed and the impacted area is not defined and managed accordingly. Site management and clean-up should be performed in an appropriate manner, under direction and supervision of suitably qualified persons according to relevant legislation guidelines and best practice. Correct management will reduce the potential for any further exposures and the associated risks to health.

Regardless of this evidence, further analysis of static airborne asbestos fibre concentration measurements was undertaken to place the risks into an Eastern Australian context.

Methods
The research was undertaken utilising airborne asbestos fibre concentration measurements collected during 283 sampling events. The data was received in the form of air monitoring certificates and reports from three different independent NATA accredited consulting firms. The air monitoring was undertaken between 22 October and 20 December 2013 at various separate site addresses impacted during the Blue Mountains fires. The impacted structures were confirmed to contain ACM via site investigation, sampling and sampling analysis after the fire events and prior to any management activities.

Sampling and analysis were conducted using the Membrane Filter Method (MFM) in accordance with NOHSC 2005 “Guidance Note on the Membrane Filter Method for Estimating Airborne Asbestos Fibres” (NOHSC 2005b). All air samples were analysed using PCM by NATA accredited laboratories.

All samples were static samples, taken at fixed locations which are usually between one and two metres above floor level. No results for airborne asbestos concentrations in personal breathing zones were received. Static air monitoring was undertaken at the control boundary of the asbestos removal area (set at approximately 10 metres from removal works) and at what were considered to be sensitive locations outside of the control boundary. A set of exposure scenarios based on time and location of sampling were developed. These scenarios (including example activities) were: during a fire event (firefighting, observation); during Make Safe works (installation of control boundary barricades); during Clean-up works (removal of ash and rubble, demolition of the structure); and as background area concentrations (general outdoor activities).

Whether or not a person is exposed to airborne asbestos from a fire requires them to be present in the general vicinity of the fire at the same time airborne asbestos fibres are generated. However, people do not spend all their time in one spot and will spend time both indoors and outdoors. Given that people also move around during the time they spend outdoors, the chance of being present at the location of elevated asbestos fibre concentrations for any extended period of time is quite low. Due to safety precautions, it is also unlikely that individuals not involved in firefighting or site remediation activities would be located within the control boundary of the impacted site during and after a fire. Estimation of personal exposure based on the behaviour of the individual and static sampling is challenging. Therefore, a conservative assumption is made that a member of the general public is potentially exposed throughout the entire fire and remediation process to the highest concentrations measured. This assumption adds conservatism to the risk assessment given the distance maintained from an active fire and the peripatetic nature of activities at the locations.

Measured airborne asbestos fibre concentrations were compared with the Western Australian air quality limit of 0.01f/ml. If the majority of samples collected at a given location or scenario were less than this benchmark, it was concluded that a health impact to the general public is unlikely and further quantitative risk assessment was not required.

Results
Air sampling locations and numbers varied for each site address. Air sampling locations were selected based on the knowledge of the occupational hygienist undertaking the sampling. There were 202 samples taken from the control boundary of the asbestos impacted area and 81 taken from sensitive locations, such as schools, at
a distance of between 0.5km and 1.5km from the fires to establish area background concentrations. In total, analysis results from 283 airborne asbestos fibre monitoring sampling events were received.

Air sampling was undertaken during a fire event; during Make Safe works; during Clean-up, Removal and Demolition works; and as background area concentrations. For all air sampling events across these scenarios, concentrations were reported as being less than 0.01f/ml. Table 1 provides the results of sampling for each exposure scenario.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Samples</th>
<th>Sites</th>
<th>Max Concentration (f/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>During Fire</td>
<td>11</td>
<td>3</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Background</td>
<td>81</td>
<td>31</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Make Safe Works</td>
<td>70</td>
<td>66</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Clean-Up Works</td>
<td>121</td>
<td>23</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

All sample concentrations were below the WA Department of Health guideline for asbestos of 0.01 f/ml (using the membrane filter method of sampling), recommended for protection of the public. In addition, all asbestos concentrations are less than the recommended airborne asbestos fibre levels of 0.01 f/ml for both control and clearance monitoring. Therefore, no further quantitative assessment of the risk was warranted.

Discussion
The results of this investigation demonstrate that airborne asbestos fibre concentrations resulting from fires in buildings containing ACM were below the level of detection for the method used and typically present a very low risk of excess exposure above background levels and impact to public health. Static and para-occupational sampling, off the type assessed in this study, can help demonstrate that site activities are unlikely to have increased risks to adjacent site users and provide confidence in

It is generally acknowledged that isolated exposures, of short durations to low asbestos fibres concentrations (similar to those likely to be found in fire event circumstances), are unlikely to result in the development of an asbestos-related disease. Airborne fibre concentrations and the durations of exposure in such situations are unlikely to be sufficient to increase cumulative lifetime exposures.

Although airborne asbestos fibre concentrations resulting from a fire event have been found to be negligible, pieces of asbestos material and fibres are likely to remain in the resulting ash and debris. This may present an exposure risk if the site is not managed appropriately and the debris is inappropriately disturbed by either persons accessing the site or wind disturbance of debris not kept moist. Additionally, the presence of fire damaged ACM can cause concerns and anxiety to people living nearby the damaged structure. Therefore, risk management measures should be set in place in the event of a fire in a building with ACM. These actions should occur as soon as practical depending on the particular action and the site circumstances.

Recommended management measures for the impacted area should include engaging an appropriately licensed asbestos removal contractor to conduct a Make Safe of the impacted area; engaging an occupational hygienist with experience in asbestos to undertake a site assessment, determine the extent of the impacted area and develop a clean-up program; restricting access to the impacted area; site clean-up in accordance with appropriate guidelines; undertaking asbestos air monitoring at the boundary of the impacted area; and developing a risk communication strategy to provide guidance and reassurance to the concerned or affected public.

Conclusion
The results of this study have shown that airborne asbestos fibre concentrations resulting from fire-damaged buildings that contain ACM and from the immediate aftermath of a fire present a very low risk of excess exposure to airborne asbestos fibres above background levels and impact to public health, given appropriate site clean-up and management in line with recommended guidelines as documented in the Code of Practice for the safe removal of Asbestos 2nd edition (NOHSC 2005b).
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