Report on the Investigation of the Effect of Fire on Asbestos Fibre Contamination

Department of Human Services

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Executive Summary

The Department of Human Services commissioned Noel Arnold & Associates to conduct an investigation into materials containing asbestos and fire. The specific objectives of the project were:

- To determine the type and prevalence of dominant materials containing asbestos in industrial and commercial premises greater than 100m^2 and constructed prior to 1980,
- To determine the effect of elevated temperatures, typical of those experienced in real fires, on the dominant materials – particularly considering whether such temperatures result in the release of respirable fibres, the possible modification of such fibres due to heat (denaturing) and the effect of heat on the post-fire characteristics of materials – in particular, their friability, and
- To determine the likely concentrations of respirable fibres in smoke dispersed by the fire to locations adjacent to the fire assuming that asbestos containing materials are exposed directly to heating from a fire.

The project was conducted in three stages (Stage 1, Stage 2 and Stage 3) that essentially corresponded to each of the above specific objectives. The building survey conducted as part of **Stage 1** of the investigation, found that for 100 randomly chosen buildings with asbestos containing materials (ACM), the most common ACM was A/C[1] sheeting for roofs, walls and eaves (83% of the buildings surveyed), and vinyl tiles (40% of the buildings surveyed). Due to the large areas covered by roofs, walls and floors it is clear that these materials are, by far, the dominant ACM with A/C sheeting being the most dominant. Other forms of non-friable asbestos such as switchboards, splashbacks and gaskets were found in 55% of the total buildings surveyed, however the extent of their use and the area they cover is relatively minor. Accordingly, the ACM chosen for further investigation in Stage 2 of the project were A/C sheeting and vinyl floor tiles.

The second stage of the project consisted of two separate experimental investigations. The first part of this investigation (denoted as **Stage 2(i)**) consisted of exposing 100mm x 100mm specimens of A/C sheeting to various levels of radiant heat similar to that which would be expected in a real fire situation. The equipment used for these tests allowed the air rising from the heated specimens to be analysed using the membrane filter method (MFM) to determine whether respirable fibres were released due to heating. It was found that respirable fibres were only released when a phenomenon known as “spalling” occurred. Spalling occurred for 7 out of the 9 specimens tested and always in the early stages of heating. Spalling may be described as an explosive phenomenon that occurs with cement-based products when exposed to heating. It is thought to be the result of the build-up of steam pressure within the cement matrix. Microscopic examination of respirable fibres collected on the filters showed that no “denaturing” of fibres had occurred due to heating. It is noted that fibres released during heating would only have been exposed to high temperatures for a very short duration. Denaturing of fibres requires the application of sufficient heat for a sufficient time.

In a real fire in a building with A/C roof sheeting, deformation of the supporting rafters may result in cracking and breaking of the supported sheeting. It is expected that respirable fibres could be released due to such a mechanism in addition to those released due to spalling. It

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[1] ‘A/C’ refers to asbestos cement.

was therefore considered necessary to attempt to simulate such breaking of the roof sheeting and to determine whether spalling occurred under real fire conditions. This was the purpose of **Stage 2(ii)** of the project, which involved a large-scale fire test within a test building[2] under controlled conditions. The test rig within the building consisted of a steel frame that supported broken A/C sheeting and the associated dust (to simulate the breaking due to roof deformation), at approximately 2m above the floor. The total area of A/C sheeting supported was 16m². Timber fuel in the form of wood cribs was placed on the floor below the supporting sheeting of the test rig. This was the means by which fire exposure on the underside of the A/C sheeting was to be achieved. The quantity of fuel was chosen to simulate that which would be expected below such an area of roofing in a real warehouse situation. Vinyl tiles, representing the other dominant ACM, were placed below the wooden cribs and covered an area close to 12m². Sufficient roof vents in the test building were opened to ensure that the building did not completely fill with smoke and to allow the measurement of respirable fibres within the smoke at roof level (adjacent to the roof vents). Respirable fibre concentrations within the smoke were measured at the roof level using the MFM (scanning) electron microscopy. Air testing was also performed at ground level within the test building.

The resulting fire was estimated as having a heat release rate[3] of approximately 10MW. Spalling was noted to occur during the first 25 minutes of the test. During this time, no respirable fibres were detected at ground level. Subsequent electron microscopic examination of samples collected at roof level, found one respirable fibre on a total of 6 filters. The resulting respirable fibre concentration has been determined as being less than the average background level and several orders of magnitude less than the detection limit of the MFM of 0.01 fibres/ml. This low concentration is due to the combination of two factors:

(i) although respirable fibres are released due to spalling and breakage, the number of fibres released is relatively low,

(ii) the nature of large fires in buildings is such that vast quantities of air are introduced into the combustion zone and into the plume from adjacent uncontaminated air through a process called entrainment. This brings about substantial dilution.

It is considered that the low concentration associated with the test fire can be taken as typical of that which would be expected for all sizes of fires in buildings with substantial quantities of the dominant ACM materials. This concentration is representative of that associated with the smoke as it leaves the incident site.

Following the fire test, samples of undisturbed ash and residue were collected and analysed. The residue included the remains of vinyl tiles and pieces of A/C sheeting. Asbestos fibre bundles were found within the ash although no respirable fibres were found in the samples analysed. Samples of vinyl tiles and some fragments of A/C sheeting were found to be friable. It is noted that asbestos fibre bundles can be broken up by physical damage and that this could result in the release of respirable fibres. No denatured asbestos fibres were found in the ash.

The final stage of the research project (**Stage 3**) was undertaken to examine the concentrations of respirable fibres away from the incident site, i.e. fire location. This was done using a computational fluid dynamics program (ALOFT) designed to simulate fires of varying sizes and to determine the concentrations of particles away from the site of the fire. The program takes into account the entrainment of air that occurs during a fire. From the above full-scale fire test it was possible to estimate the number of respirable fibres released per unit plan area and to use this information as an input into the model. Fires varying in size (larger fires have larger burning areas) from 25MW to 200MW were considered, these being typical of the sizes that could occur in real building fires. Wind speeds varying from 2m/s to 12m/s

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[2] The test building belongs to the Centre for Environmental Safety and Risk Engineering (CESARE) at Victoria University located at Fiskville in Victoria. It is a large building of dimensions 40m x 70m x 20m.

[3] The term heat release rate (HRR) represents the size of the fire and the quantity of energy released per unit time.

were also considered. The concentrations close to the fire were found to be similar irrespective of the size of the fire and the highest concentration directly adjacent to the fire location was found to be very similar to that obtained from the real fire test conducted as part of Stage 2(ii) – i.e. less than average background levels. Within 100m of the fire location, the concentration of asbestos fibres was found to be two orders of magnitude lower than directly adjacent to the fire for the worst wind condition (i.e. highest winds). Further away, the concentrations were even less.

The findings from the above project demonstrate that:

- Fires within buildings comprising substantial quantities of ACM do not result in hazardous conditions with respect to respirable asbestos fibres either close to the building or away from the building.
- Friable materials will exist after a fire and asbestos bundles and possibly respirable fibres may exist in the ash. Therefore, clean-up operations within the building should be performed in accordance with the Code of Practice for the Safe Removal of Asbestos NOHSC:2002(2005) and the Occupational Health and Safety (Asbestos) Regulations 2003. The application of water will further reduce any exposure risk to nearby personnel working in the area, since wetting down the debris after a fire, reduces the risk of respirable asbestos fibres becoming airborne.

Statement of Limitations

This report has been prepared in accordance with the agreement between Department of Human Services and Noel Arnold & Associates Pty Ltd.

Within the limitations of the agreed upon scope of services, this work has been undertaken and performed in a professional manner, in accordance with generally accepted practices, using a degree of skill and care ordinarily exercised by members of its profession and consulting practice. No other warranty, expressed or implied, is made.

This report is solely for the use of Department of Human Services and any reliance on this report by third parties shall be at such party's sole risk and may not contain sufficient information for purposes of other parties or for other uses. This report shall only be presented in full and may not be used to support any other objective than those set out in the report, except where written approval with comments are provided by Noel Arnold & Associates Pty Ltd.

Report on the Investigation of the Effect of Fire on Asbestos Fibre Contamination

Department of Human Services

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1. Introduction

Over the last few years in particular, the general community and industry have shown a heightened awareness and concern regarding the issues associated with asbestos and asbestos containing materials.

The mere existence of asbestos in buildings or in ash/rubble does not pose a health risk to building occupants or the public. Asbestos fibres must become airborne, be present in sufficient concentration and be of a respirable size to pose a risk to those inhaling fibres.

Currently, there is a lack of definitive information concerning the amount and type of asbestos material used in industrial buildings and the distribution of asbestos fibres during a fire. Research to date, also appears to indicate that there is little health risk associated with such fires, however, no definitive studies have been conducted to support these findings.

This report describes the outcomes of a research project, undertaken on behalf of the Department of Human Services (DHS), to determine the effect of fire on key materials containing asbestos. The specific objectives of the research project were:

- To determine the type and prevalence of dominant materials containing asbestos in industrial and commercial premises greater than 100m^2 and constructed prior to 1980,
- To determine the effect of elevated temperatures, typical of those experienced in real fires, on the dominant materials – particularly considering whether such temperatures result in the release of respirable fibres, the possible modification of such fibres due to heat (denaturing) and the effect of heat on the post-fire characteristics of materials – in particular, their friability.
- To determine the likely concentrations of respirable fibres in smoke dispersed by the fire to locations adjacent to the fire assuming that asbestos bearing materials are exposed directly to heating from a fire.

2. Methodology

The project was conducted in three stages (Stage 1, Stage 2 and Stage 3) that essentially corresponded to each of the above specific objectives. The survey of buildings was the first stage (Stage 1) of the project to be undertaken, and the findings are detailed in **Section 3** of this report.

The second stage of the project consisted of two separate experimental investigations. The first part of this investigation (denoted as Stage 2(i)) consisted of exposing samples of a material containing asbestos to various levels of radiant heat and determining whether respirable fibres were released. This stage and the associated results are given in **Section 4** of this report.

The second part of the experimental program (denoted as Stage 2(ii)) consisted of a large-scale fire test involving asbestos containing materials (ACMs). The aim of this testing was to determine the concentration of respirable fibres within the smoke cloud and to examine the effect of a fire on the nature of the asbestos containing materials. The details of this stage and the findings are given in **Section 5** of this report.

The third stage of the project consisted of undertaking dispersion modelling to determine the respirable fibre concentrations adjacent to a fire location. The findings from this stage of the project are given in **Section 6** of this report.

Section 7 of this report presents the overall conclusions of this research project and **Section 8** presents practical outcomes to be considered based on the project findings. A Glossary is presented in **Section 9** and Reference materials and Appendices are detailed in **Sections 10** and **11**, respectively.

3. Stage 1 - Characterisation of Typical Buildings with Respect to Asbestos Materials

3.1 Introduction

Stage 1 of the project is aimed at characterising the amount and type of asbestos containing materials (ACMs) likely to be encountered in older buildings. This was done by undertaking an assessment of the asbestos content of representative buildings within city and regional areas in Victoria.

This information was then used as the basis for assessing which forms of asbestos material are dominant within representative buildings. The dominant ACMs were then used for the subsequent experimental work to ensure that the test situations and the tested materials would be representative of those likely to be encountered should a fire occur within a building containing ACMs.

3.2 Methodology

Data on ACMs within representative buildings were obtained by interrogating the Noel Arnold & Associates (NAA) records from building surveys and audits, undertaken for buildings within Victoria. These records can be considered to constitute a database (hereafter, referred to as the “NAA database”) and covers commercial, educational and industrial buildings and contains approximately 2,100 entries. It should be noted that 49.4% of these entries have ACMs within the buildings.

From the NAA database, 100 buildings containing ACMs were chosen for the purpose of Stage 1. The buildings were chosen such that they were constructed prior to 1980 and had a floor plan area greater than 100m^2, as per the Department of Human Services’ (DHS) project brief [1]. The latter brief required a random survey of 100 such buildings, and as such, a proportion of these buildings may not have contained ACMs. In contrast the 100 buildings randomly chosen from the NAA database all contained ACMs. The corresponding data included information on building type, use and whether the ACMs were *friable* or *non-friable*. These data were then interrogated using a methodology approved by the Department of Human Services [2].

The actual quantities of asbestos in particular ACMs were determined using reference materials where possible. Reference should be made to Section 3.3 of this report for more detail.

3.3 Results

Details of the interrogation of the 100 entries for buildings containing ACMs are given in Appendix 1. From these data it is found that the dominant materials containing asbestos are A/C[4] sheeting for roofs, walls and eaves (83% of the buildings surveyed), and vinyl tiles (40% of the buildings surveyed). Other forms of non-friable asbestos such as switchboards, *splashbacks* and gaskets are found in 55% of the total buildings surveyed, however as these materials did not contribute to significant quantities of ACM, in terms of area, they were not considered to be a dominant source of ACM (eg. as compared with roofs, floor areas, etc).

Table 1 summarises the findings and results for the 100 buildings surveyed. The table details the type of ACM identified and how many of the buildings surveyed actually contain the particular type of ACM.

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[4] ‘A/C’ refers to asbestos cement.

Table 1: Summary of Building Interrogation

Type of Building	No. of Buildings Surveyed in each Type	Non- Friable Asbestos			Friable Asbestos	
		% of buildings with A/C roofs, walls or eaves	% of buildings with asbestos vinyl floor tiles	% of buildings with other non - friable asbestos materials **	% of buildings with pipe lagging	% of buildings with other friable asbestos materials ^^
Industrial	28	79%	46%	43%	11%	21%
Commercial	39	72%	49%	46%	3%	18%
Educational	33	100%	24%	76%	0%	67%
TOTALS	**100**	**83%**	**40%**	**55%**	**4%**	**35%**

Notes: ** refers to switchboards, splashbacks, gaskets which are used over a very limited area (i.e. compared with vinyl tiles or roof sheeting)

^^ refers to *limpet* and millboard asbestos materials

Based on the information detailed in Table 1, the dominant ACM can be seen to be A/C sheeting. In addition, vinyl floor tiles are a dominant material both in terms of percentage use and quantity (floor area). It therefore follows, that the materials to be used for the experiment in the large-scale fire test should be both A/C sheeting and vinyl floor tiles.

Appendix 2 details the likely asbestos fibre characteristics (type and quantity) in the ACMs noted on Table 1.

4. Stage 2(i) – Testing of Key ACM under High Temperature Conditions

4.1 Introduction

As illustrated in Section 3 of this report, the dominant ACM in buildings is non-friable asbestos cement (A/C) sheeting. It is for this reason that samples of A/C sheeting were tested under elevated temperature conditions. The objective of the testing was to study whether the application of heat would result in the liberation of *respirable fibres* and to see whether the physical nature of these fibres was changed due to the application of heat. The effects of fibre ‘*denaturing*’[5] are thought to be due to the application of high temperatures. If these fibres do become non-respirable then the health effects associated with these denatured fibres may be significantly reduced.

4.2 Methodology

The specimens of A/C sheeting were tested under elevated temperatures using the cone calorimeter at the Centre for Environmental Safety and Risk Engineering at Victoria University. This apparatus is shown in Figure 1 and was used to expose A/C test specimens of approximate size 100mm x 100mm to three levels of radiant heat (namely; 50kW/m^2, 75 kW/m^2 and 100kW/m^2) whilst allowing sampling of the air above the heated specimen.

Figure 1 Cone Calorimeter

Specimens were placed in a steel tray (Figure 2(a)) that was placed below a conical radiant heater i.e. a radiometer (Figure 2 (b)). The air above the specimen was drawn into a hood and then into a horizontal length of duct by means of an extraction fan (Figure 2(c)).

Figure 2(a) Test Tray

Figure 2(b) Radiant Heater

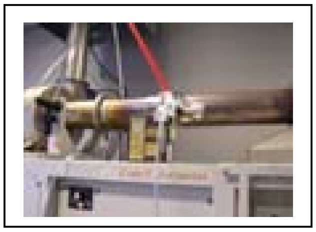

Figure 2(c) Extraction Fan

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[5] ‘Denaturing’ in the context of this report, means that the fibre has been modified such that it is no longer considered a respirable fibre (*conforming fibre*[5a]) i.e. the aspect ratio of length-to-width is less than 3:1.

[5a] A conforming fibre is one which has an aspect ratio of length-to-width of greater than 3:1 and the diameter of the fibre is less than 3 microns, and the length of the fibre is greater than 5 microns.

The velocity of air within the horizontal duct was measured during the tests and could be controlled by adjusting the speed of the extraction fan. For these tests, air was sampled from within the horizontal duct by means of a sampling ring (Figure 3) that consists of a ring with holes around the perimeter.

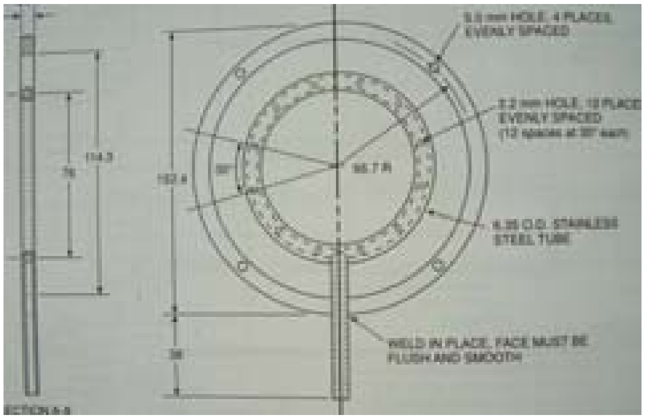

Figure 3 Sampling Ring

The membrane filter method (MFM) [7] was used to estimate the airborne fibre concentration in the air within the horizontal duct. In this method air is drawn from the sampling ring into the filtering equipment (via a pump) at a relatively slow rate. In order to get representative sampling of the air within the duct it is important that the flow within the duct approaches static conditions (often termed “isostatic” conditions) since the presence of an air stream within the duct traveling at high velocities may concentrate flows (and therefore, particles) away from the sampling holes of the ring. For the testing undertaken, the airflow within the duct was set to an average rate of 7.0 Litres/second (L/s) (i.e. close to 1m/s). Higher velocities within the duct may have resulted in non-isostatic conditions and the “impacting” of fibres at the corner bend of the apparatus.[6] For these tests, 13mm filters were used. A sampling time of 60 minutes was used for all tests with a sampling flow rate, on average, of 1640L/min through the filter. This meant that all test specimens were exposed to the chosen level of radiation for one hour.

Fibres were counted by examining the filters using optical microscopy in accordance with Refs [7].

In all, nine A/C test specimens were tested with three being tested at each level of radiation.[7] Given the duration of heating, steady state temperature conditions will eventually be achieved for each of the imposed levels of radiation with approximate corresponding maximum surface temperatures of 680°C (50kW/m^2), 800°C (75 kW/m^2), and 900°C

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[6] Testing undertaken in Sweden [8] on the burning and subsequent fibre release of carbon fibre materials using the cone calorimeter required modification of the associated ductwork and a different method for measuring fibre concentrations due to the much higher air flow velocities required for testing a combustible material: the air must be extracted at a rate such that all of the gases given-off by the burning material are captured within the hood. Such higher velocities have been noted to result in sticking of fibres to sharp bends within the extraction ductwork (termed “impacting”) and in also creating non-isostatic conditions within the duct.

[7] The maximum radiation able to be generated by the cone calorimeter equipment is 100 kW/m^2. The three radiation levels (50, 75 and 100 kW/m^2) were generated by heating the cone to 770°C, 880°C and 975°C, respectively. If the cone behaved as a blackbody these temperatures would result in radiation levels of 67 kW/m^2, 100 kW/m^2 and 137 kW/m^2. However, the cone does not act as a blackbody and the lower incident radiation levels are applicable and were determined prior to testing, by a radiometer located near where the specimen was to be located.

(100kW/m²).[8] These levels of incident radiation and surface temperatures are typical of those likely to be encountered in a real fire.

Prior to, and following each test, each specimen was weighed.

4.3 Test Results

The data obtained during the cone testing as well as general observations during the test, are detailed in Appendix 3.

4.3.1 General Aspects of Performance

The first specimen was exposed to a radiation of 50kW/m². As the radiation was approaching the maximum value, explosive "*spalling*" [9] occurred such that fragments of the specimen separated and landed on the floor. For subsequent tests, a fine mesh was placed over the A/C sheeting (Figure 4) and hooked below the steel specimen tray to prevent fragments landing away from the test specimen. In the context of this report the term "spalling" refers to the sudden cracking and breaking of the specimen. This cracking and breaking is normally associated with "explosive" noises.

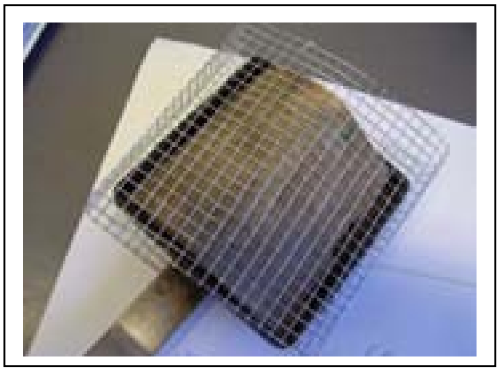

Figure 4 Placement of mesh over specimen

Examination of the filter after testing specimen 'A/C1' indicated that the filter was heavily clogged with cement dust which made it impossible to count respirable fibres using optical microscopy.[10] Following this test it was decided to use four air filters in succession with each filter pump monitoring air for a 15-minute period each (giving a total air monitoring period of 60 minutes) [Section 10.4.7.2 of Ref 7]. This was done for all remaining tests. This approach also reduced the dust loading on each filter such that fibre counting was possible.

4.3.2 Spalling

Spalling occurred for all test specimens except two. The result of the spalling varied, from specimens being fractured in two (Figure 5(a)) to pieces being ejected from the specimen (Figure 5(b)).

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[8] The surface temperature of A/C sheeting specimens increases with time and is a function of the *emissivity* of the cement sheeting as well as the incident radiation. The calculated surface temperatures are based on a surface emissivity of 0.60 (unitless) for A/C sheeting.

[9] 'Spalling' is a common occurrence in fire with concrete elements and may result in the loss of concrete pieces from the surface of the element via an explosive force. It is postulated that this phenomenon may result from the build-up of steam pressure within the material matrix or the presence of reactive aggregates.

[10] The counting of fibres using optical microscopy requires filters to be essentially clean of other contaminant materials.

Figure 5(a) Splitting of specimen

Figure 5(b) Loss of parts of specimen

The time of spalling and the surface radiation at which this occurred is summarised for all specimens in Table 2. It will be noted that in all cases, spalling occurred within the first 10 minutes of testing. This is consistent with observations of spalling with concrete structures. It should be noted that the target radiation levels are not achieved instantaneously since the cone cannot be heated instantaneously. The target radiation levels were typically reached in 8 minutes (50 kW/m^2), 10 minutes (75 kW/m^2) and 11.5 minutes (100 kW/m^2). It follows that spalling occurred shortly after the target radiation levels were achieved or during the build-up to the target value.

Table 2: Time at which Spalling Occurred

Specimen No.	Target Radiation Level (kW/m^2)	Spalling (Y/N)	1st Spalling event	2nd Spalling event	3rd Spalling event
A/C1	50	Y	07.30mins	07.35mins	07.40mins
A/C2		Y	06.00mins		
A/C3		Y	08.10mins		
A/C4	75	Y	09.20mins		
A/C5		Y	06.30mins		
A/C6		Y	07.10mins	07.30mins	
A/C7	100	N			
A/C8		N			
A/C9		Y	07.14mins		

Note: Specimens in **bold** in the table above, refer to A/C test specimens, which spalled during the test.

Spalling is a complicated phenomenon, the nature of which is considered to be outside the scope of this project.

4.3.3 Respirable Fibre Counts

In assessing filters in accordance with NOHSC:3003 (2005) [7] only respirable fibres are counted. The respirable fibre counts and corresponding estimated fibre concentrations for each 15-minute period for each test specimen are summarised in Appendix 4. The following observations can be made from the data presented in Appendix 4:

(a) Spalling occurred for all levels of imposed radiation.

(b) Detectable asbestos fibres were only generated during the first 15-minute monitoring period in tests where spalling occurred.

(c) In the 15-minute monitoring periods, subsequent to a monitoring period when spalling occurred, fibre counts were less than the *detection limit* of the method i.e. less than 10 fibres/field.

(d) For tests where spalling did <u>not</u> occur (i.e. for test specimens A/C7 and A/C8) the resulting fibre concentrations were not detectable using the MFM and therefore similar to those associated with (c).

This testing was undertaken to determine whether respirable fibres were released due to the application of heat. Heat alone, in the absence of spalling, does not release detectable concentrations of fibres. However, if the heating results in spalling then many respirable fibres are released. Release of the fibres from a specimen resulted in fibres travelling upwards into and through the heating cone into the horizontal duct and then into the sampling ring. This meant that released fibres were only subject to radiant heating for a short time (possibly less than a few seconds) as they travelled up through the cone. It is likely that such heating conditions would not be sufficient (in terms of duration) to have any effect on changing the shape (i.e. denaturing) of the fibre, such that it becomes a non-respirable fibre, as fibres did not appear to be denatured as a result of this test.

4.3.4 Specimen Masses

The masses of the test specimens before and after testing, are given in Table A3.1 of Appendix 3. The reduced mass after testing reflects the effect of loss of moisture and material due to spalling. Since spalling did not occur for specimens A/C7 and A/C8, the loss of mass for these specimens reflects the loss of moisture during heating.

4.3.5 Examination of Samples after Cone Testing

Each of the A/C test specimens was subsequently examined after the test. The reason for doing this was to investigate the types of asbestos within the specimens and to see whether the longer-term application of heat to fibres associated with the remaining parts of the specimen and along the fracture lines had any significant effect on those fibres, in terms of melting protruding fibres/fibre bundles.

Following examination by an optical microscope (Zeiss standard 14 microscope, serial no. 084077, last serviced 26.07.06), the following observations were made:

(a) all three types of asbestos fibres (i.e. amosite, chrysotile and crocidolite) were present within the test specimens,

(b) the fibres along the fracture zones did not appear to have been broken down or altered by the application of heat, these fibres were still attached to the host material (i.e. the cement sheeting). However, the exposed ends of some of the fibre bundles (i.e. groups of joined fibres), appeared to have been slightly globularised.

It should be noted that the temperature experienced by an individual fibre or fibre bundle when subject to radiant heat is dependent on its orientation. In real fires, heating is by both radiation and convection, and if a material/or fibres are engulfed by the fire, the heating will be more complete. This is one of the reasons it was considered necessary to conduct the large-scale fire test described in the next part of this report.

4.4 Conclusions

The testing performed using the cone calorimeter revealed that the application of radiant heat (eg. greater than 50 kW/m^2), can result in 'spalling' of the A/C sheeting. Spalling results in the release of respirable fibres. Whilst it is considered possible that asbestos fibres are released in the absence of spalling, the tests found fibres released during these periods to be less than the detection limit of the MFM [7]. Hence, heat alone in the absence of spalling does not result in detectable concentrations of fibres being released.

The fibres released during this heating process did not appear to have been denatured.

5. Stage 2(ii) – Large-Scale Fire Test

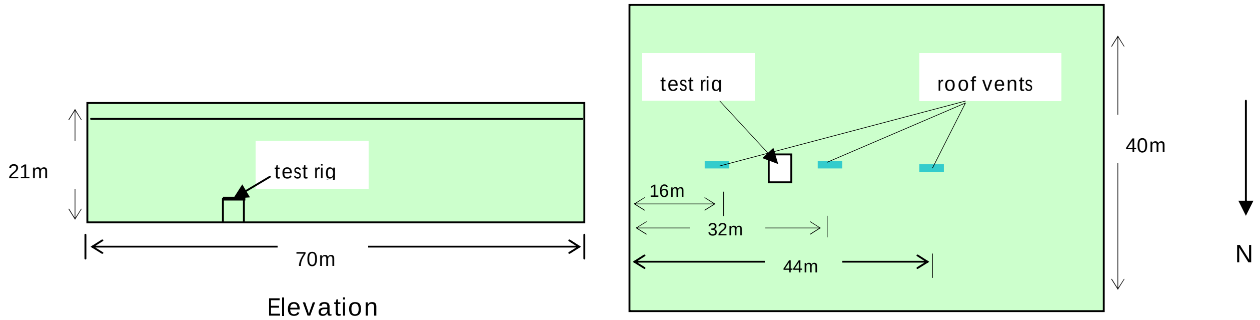
5.1 Introduction

This testing was undertaken to look at the impact of real fires on the dominant materials containing asbestos, viz.: A/C sheeting and vinyl floor tiles, and to determine the resulting concentrations of released respirable fibres. For this, it was necessary to utilise a significant natural fire as experienced with accidental fires in buildings and to expose the A/C sheeting in a manner typical to that which would be expected in a real fire. The testing needed to be conducted in an environment that would allow the measurement of respirable asbestos fibre concentrations throughout the test. Therefore, the test was conducted within the experimental fire test building (hereafter referred to as the "CESARE building") operated by the Centre for Environmental Safety and Risk Engineering at Victoria University of Technology and located at the Country Fire Authority (CFA) training centre at Fiskville, Victoria.

5.2 Test Set-up

5.2.1 Test Rig and Building

The test rig and building are shown schematically in Figure 6. The building in which the test rig was located has a 40m span, is 70m long and has a height to the ridge of 21m. The building has low-level vents around its perimeter and roof vents along the ridge. These vents can be closed or opened and a judicious choice of opened low-level and roof vents will ensure that external wind effects are not experienced within the building whilst allowing sufficient venting of smoke from the building.



Elevation

Plan

Fig. 6 Schematic View of Test Rig and Building

For the fire test, all doors and vents were closed except for three roof vents (each having an opened area of 1.27m^2) and an equivalent area of low-level vents on the south side away from the direction of the wind.

A test rig was designed to support the A/C sheeting and was constructed of structural steel with steel mesh between the roof beams to provide direct support to the A/C sheeting that was placed directly onto the mesh. The mesh was welded around the edges to the edge beams to permit the mesh to utilise catenary action under fire conditions. The edge beams were designed to resist the resulting horizontal forces. The steelwork was protected with fire-resistant plasterboard to ensure that sufficient strength was maintained throughout the fire. A photograph of the test rig prior to placement of the A/C sheeting on the reinforcing mesh is shown in Figure 7. The height of the rig was 2.1m whilst the plan dimensions were 4m x 4m. This meant that approximately 16m^2 of A/C sheeting could be supported approximately 2m above the floor.

5.2.2 Fuel

Figure 7 Supporting Structure

Figure 7a Fuel in form of wood cribs

Well-ventilated timber fires produce relatively low levels of soot compared with other burning materials. In using the Membrane Filter Methodology (MFM) to detect respirable fibres it is important to minimise soot contamination of the filters. It was for this reason that timber (pine) sticks were chosen as the material to be burnt. These sticks were 45mm x 45mm x 900mm long and were arranged in "cribs" to ensure that a significant fire developed. Nine cribs were located within the rig such that flames would directly impinge on the A/C sheeting supported by the reinforcing mesh. The mass of timber in each crib was 93kg. This meant that the total fuel below the supported A/C sheeting was 837kg which gives an average fire load density below the $16m^2$ of A/C sheeting of 52 kg/m^2 – a value considered to be typical of what might be expected in a warehouse or other commercial building. The cribs were placed on fire-resistant plasterboard sheeting to prevent spalling of the concrete floor during the fire. Prior to placement of the cribs on the plasterboard, vinyl floor tiles were placed over this area (see Figure 7), since these, along with the A/C sheeting, were found to be the dominant ACM identified in the building survey conducted in the first stage of the project (refer to Section 3 of this report).

5.2.3 A/C sheeting – Preparation and Placement

The A/C sheeting was the same as that tested in the laboratory using the cone calorimeter, the results of which were reported in the previous section of this report. Sheets of the A/C material were delivered to the CESARE building in sealed plastic wrapping. The free moisture content of the sheeting was determined as 4.% by weight (see Appendix 6). The sheets were then broken to simulate the breakage that would be expected due to deformation of the supporting structure.[11] The broken sheeting was placed by hand on the reinforcing mesh of the supporting structure. The dust and smaller fragments resulting from the breaking process were carefully collected and placed with the broken sheeting on the rig. The reinforcing mesh had wires at 200mm centres in each direction. This wire spacing was chosen so as not to interfere with the heating of the A/C sheeting, whilst allowing some material to fall into the fire, but preventing a significant proportion of the A/C sheeting from collapsing onto the fire and extinguishing it.

Figure 8 shows the A/C sheeting after it was placed on the test rig. Prior to testing, a fine steel protective mesh was placed over the *top* of the A/C sheeting to assist in confining fragments of A/C sheeting that might be ejected due to spalling during the fire, see Figure 9.

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[11] In the presence of a sufficiently severe fire, the structure supporting a roof of A/C sheeting will deform. Since A/C sheets are brittle, any such deformation will result in the cracking of the sheeting and subsequent break down of the sheeting, into a range of smaller pieces.

Figure 8 A/C sheeting placed on test frame

5.2.4 Measurements

a. Temperatures

The temperature of the fire was measured by mineral insulated thermocouples. One thermocouple was located close to the centre of the test rig approximately 200mm below the A/C sheeting (denoted as thermocouple (T/C5)) and this registered the maximum temperature (i.e. approximately 1,100°C). A thermocouple tree, consisting of four thermocouples was located at the edge of the test rig. These thermocouples were located 500mm (T/C4), 1,000mm (T/C3), 1,500mm (T/C2) and 2,000mm (T/C1) from the level of the floor slab. Refer to Figure 9.

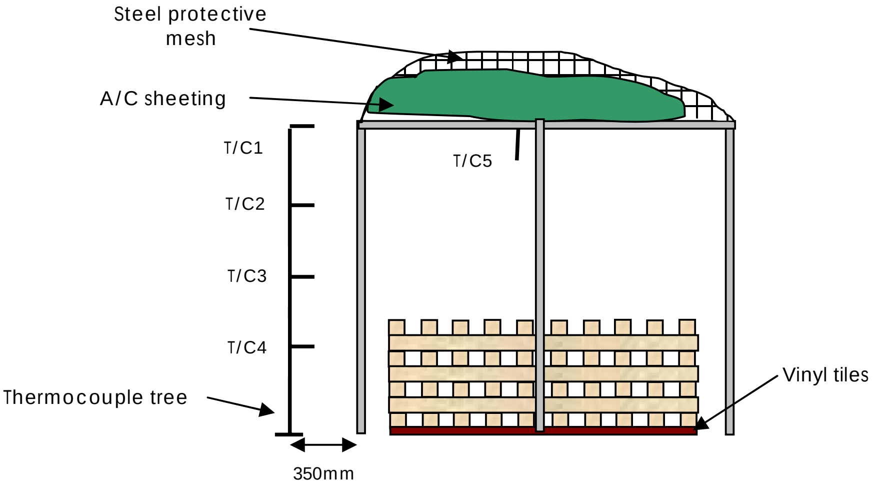

Figure 9 Thermocouple Locations

b. Respirable Fibres

The concentration of respirable fibres within the smoke cloud and below the smoke cloud was measured using the MFM. Due to the soot within the smoke it was necessary to use gold-coated filters to permit subsequent electron microscopy, since the soot layer would prevent fibres being counted using optical microscopy. These filters were used at measuring points

1 – 8 near the roof of the CESARE building as shown in Figure 10. Sampling tubes were located approximately 2m below the ridge line with six samples being taken at the open roof vents (two per vent) and one at each end of the building from access platforms located within 2m of the ridge. For measuring points 1 – 8, 25mm filters were used and continuous sampling was undertaken for approximately 240 minutes as required by the MFM for this size filter.

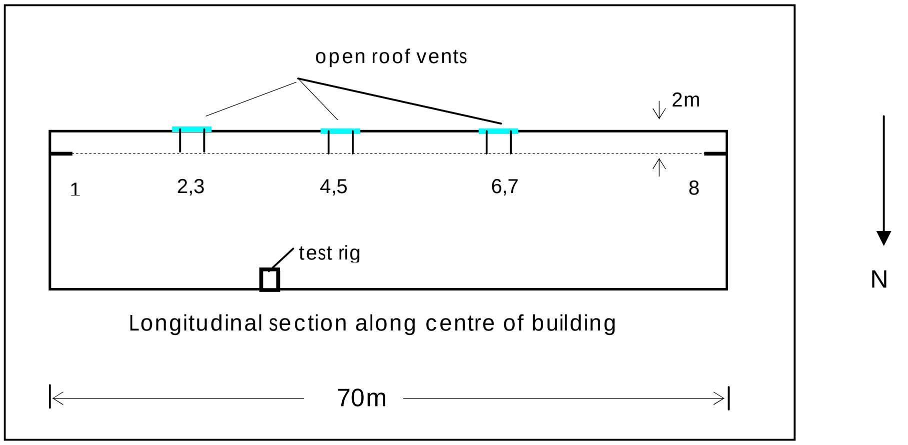

Figure 10 Filter Measuring Point locations near Roof of CESARE Building

Additional filter measurements were taken near ground level within the building and 25mm filters were also used. In total there were eight ground level filter-monitoring pumps located as detailed in Figure 11. These filters were replaced approximately 25 minutes after the fire had been ignited, when the spalling had ceased. The replacement filters were used until the test ended. The total monitoring period for the replacement filters was approximately 3.5 hrs.

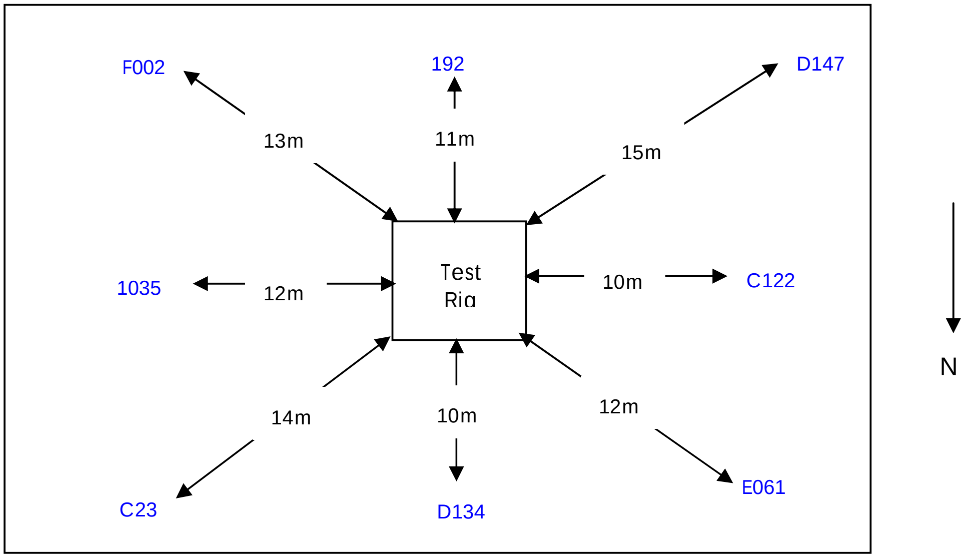

Figure 11 Ground Level Filter Monitoring Pump Locations, in blue

5.3 Test Methodology

Prior to igniting the fire, the CESARE building and its immediate surroundings were denoted as being "out-of bounds" except for persons directly involved in the test and wearing suitable personnel protective equipment. All filter-monitoring pumps were started approximately one hour prior to ignition of the fire.

Approximately 500ml of methylated spirits (ethanol) was placed in a tray below each of the nine wooden cribs and another 500ml was poured over each crib. This was done to enhance the chance of the cribs burning together so as to get uniform burning below the A/C sheeting. The fire was ignited by lighting each of the trays of fuel with a gas lighter.

At the conclusion of the test, the test rig and associated materials were not disturbed for two days, so that the ash could cool down. After the ash had cooled for two days, numerous samples of the ash and A/C sheeting and vinyl tiles within the ash were collected in bags for analysis. This was done in order to assess whether or not respirable fibres were present in the ash and burnt material and whether the A/C sheeting and vinyl tiles should be considered to be friable or not. The detailed methodology of how the ash and cooled debris was analysed is described in Appendix 6.

5.4 Test Results

5.4.1 Fire Observations and Temperatures

Figure 12 shows the fire shortly after ignition and then during its fully developed stage of burning.

Figure 12 Early fire development and established burning

It is estimated that the peak heat release rate (HRR) was 10.5 Megawatts (MW) with the burning being sustained around this level for approximately 15 minutes, after which the HRR dropped dramatically due to most of the fuel being consumed. The peak HRR was estimated from the following factors:

- The effective heat of combustion of dry pine timber (of 16 MJ/kg)
- The knowledge of the total quantity of fuel
- An assumption that HRR is proportional to maximum air temperature
- Total fuel burnt, the time of burning.

The measured temperatures associated with the fire are shown in Figure 13. The maximum temperatures obtained are similar to those that would be experienced in a fire in a building.

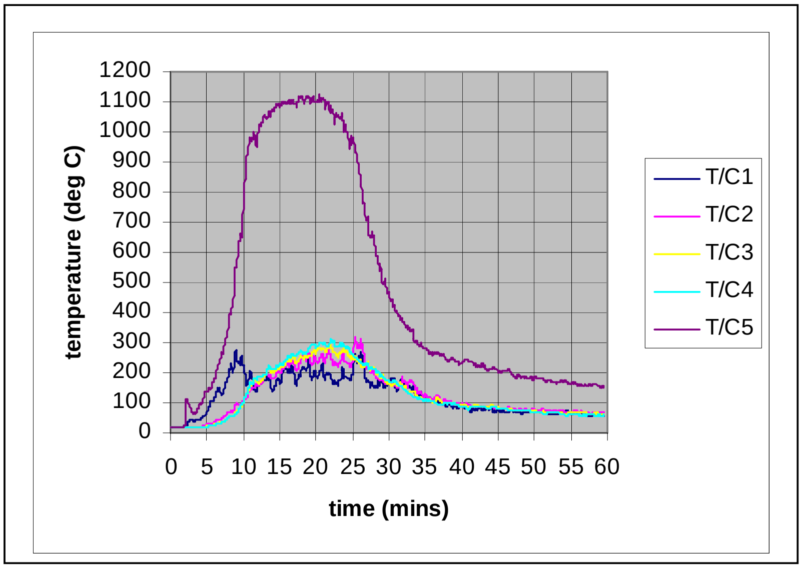

Figure 13 Temperature Profile during the Test

During the test, smaller pieces of A/C sheeting dropped through the supporting reinforced mesh into the fire and into the timber fuel. Despite spalling (see Section 4.3.2) and material dropping through the mesh, a significant area of the A/C sheeting remained in place on top of the supporting structure throughout the fire. Figure 14 demonstrates this.

Figure 14 A/C Sheeting remaining on Support Rig at End of Fire

5.4.2 Spalling of A/C Sheeting

Loud explosive spalling was experienced throughout the initial phases of the fire test, with pieces of A/C sheeting being projected from the supported structure. Much of this spalled material was contained by the fine protective mesh placed over the top of the A/C sheeting, however some pieces were projected from the underside of the A/C sheeting and landed away from the test rig (see Figure 15). Pieces of A/C sheeting were found as far away as 5m from the test rig.

Figure 15 Spalled pieces of A/C sheeting on floor, away from Test Rig

5.4.3 Respirable Fibre Concentrations in Air

a. At roof level

As noted in Section 5.2.4, in total eight gold-coated filters were used during the large-scale test experiment. However, of the eight filters, only six of these filters could be analysed, as two of the gold-coated filters became void due to damage to the filter membrane during the test. Table 3 shows the gold filters analysed, their location during the test and the results obtained from the gold filter analysis performed by Pickford & Rhyder Consulting [10]. The detailed test report is given in Appendix 7.

In summary, the electron microscopy analysis found virtually no evidence of asbestos product on the six filters with only one respirable fibre being identified. This corresponds to an estimated concentration of respirable fibres within the smoke of 1 x 10^{-6} fibres/ml (see Appendix 8) which can be compared with the limiting values of 0.01 fibres/ml [11) or 0.1 fibres/ml [12].

Table 3 Gold Filter Analysis

Sampling Point Location	Filter Id No.	Volume of Air (millilitres, ml)	Respirable Asbestos Fibres Found (Y/N)	Number of Respirable Asbestos Fibres Found
1 (east landing)	#E43	504,000	N	-
2	#A54	464,100	N	-
3	#A38	466,050	Y	1
4	#A48	468,000	N	-
5	#A46	NA	-	-
6	#A51	488,025	N	-
7	#A31	471,900	N	-
8 (west landing)	#A67	NA	-	-

Note: NA refers to filter was damaged and could not be analysed; therefore there are no results for these filters.

b. Near floor level

In total eight ground level filters were located around the test rig (refer to Figure 11). The results of the filters analysed in the first 25 minutes after the test had started showed the number of asbestos fibres were less than the detection limit of the method [7]. Details of the results are presented in Appendix 9.

The ground level filters were replaced when spalling had ceased. The replacement filters became overloaded with soot as they were in place for the remainder of the test (i.e. approximately 3.5 hours) and therefore, could not be analysed under the microscope. The replacement filters were denoted as 'void'.

5.4.4 ACM Analysis After Exposure to Large-Scale Test Experiment

5.4.4.1 Respirable Fibre Concentrations within Ash

Following the large-scale fire test and after the ash had cooled (2 days), samples of the ash were removed to determine the respirable asbestos fibre concentrations within the ash debris. The location of where the samples of ash and debris were taken is illustrated and labelled in Figure 16.

The results of the ash analysis and the detailed methodology are presented in Appendix 6.

According to the results presented in this Appendix, asbestos fibre bundles[12] were found in all samples but no respirable fibres were detected according to the analysis methods used.

It is possible that the asbestos fibre bundles could be broken down further and become respirable asbestos fibres during clean-up processes after a building fire. This would only be possible if the asbestos fibre bundles present in the ash debris after a fire, were exposed to further mechanical degradation as a result of pedestrian traffic, driving over the ash or possibly sweeping activities. This further shearing and separation of the asbestos fibre bundles would be enhanced if the surface where the ash debris had collected was a hard surface, for example a concrete slab.

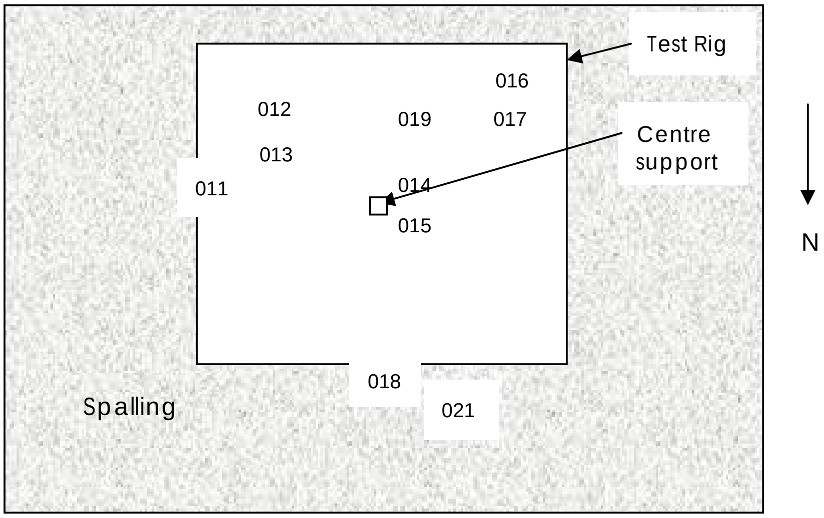

Figure 16 Ash Sample Locations and Identification

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[12] Asbestos is a mineral composed of long tubular like structures referred to as bundles. These incorporate many fibres, and if broken, may release smaller fibres which are respirable.

5.4.4.2 Friability of A/C Sheeting and Vinyl Tiles after the Large-Scale Fire Test

The friability of the A/C sheeting and vinyl tiles remaining after the fire test and located either within the ash or on the adjacent floor was assessed. These results are given in Table 4.

Table 4 Friability Assessment for ACM samples (not ash)

Identification Label	Sample Description / Location	Friability Test (Friable = crushed with hand pressure, Y)
010	Vinyl Tile **not** exposed to large-scale fire	N
011	Vinyl Tile / Under ash pile	Y
012	A/C sheeting / East upper portion of ash pile, approx. 1m from scaffold	Y
013	A/C sheeting / East lower portion of ash pile, approx. 1m from scaffold	Y
014	A/C sheeting / West of centre support, centre portion of ash pile	Y
015	A/C sheeting / West of centre support, lower portion of ash pile	Y
016	A/C sheeting / West upper portion of ash pile, approx. 0.5m from scaffold	Y
017	A/C sheeting / West lower portion of ash pile, approx. 0.5m from scaffold	Y
018	A/C sheeting / North spalled material, approx. 0.3m from scaffold	N
019	A/C sheeting / Top portion of ash pile	Y
020	A/C Sheeting / On top of scaffold	Y
021	Spalled A/C sheeting / North of scaffold	N

Note: Sample Id 010 in Table 4 was not exposed to the large-scale fire test, all other samples were exposed.

It can be seen from Table 4 that the majority of the A/C sheeting, which was exposed to the fire, became friable after the test. However, prior to the test, the A/C sheeting was not assessed to be friable. The vinyl tile exposed to the heat of the fire, and which remained under the ash pile, was also identified to be friable after being exposed to the fire.

5.5 Relevance of Testing Findings to Real Fire Situations

During the fire test, large quantities of uncontaminated air were entrained into the plume as well as being consumed by the combustion process. This is illustrated in Figure 17. Air is required for combustion but a fire plume acts as a “pump” drawing in cooler surrounding air. It is estimated that approximately 75,000m^3 of air was drawn into the plume during the test (see Appendix 10). This estimate has been determined by solving the zone modelling equations taking into account the area of the roof vents, the HRR versus time response and the observed smoke layers within the building throughout the test. A discussion of the test in relation to the entrainment of air into the plume is given in Appendix 10. The volume of entrained air has been estimated as being approximately equal to the volume of the building, and resulted in considerable dilution of concentrations of respirable fibre that may have been introduced into the plume as a result of spalling or breaking of the sheeting.

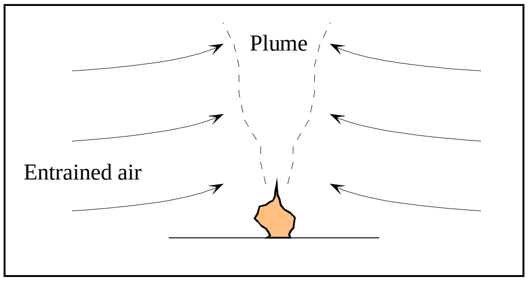

Figure 17 Air entrained into plume

The measured concentrations associated with the "smoke cloud" at the roof of the building represent the effective concentration coming from the top of the plume. As noted in Section 5.4.3(a), this value is extremely low.

The question is: Is the concentration associated with the above test representative of that associated with typical fires in buildings where the A/C sheeting is subject to significant heating?

In considering this question, it is important to understand that exposure of a roof to heat, such that deformation of the roof supporting members and spalling of the sheeting occurs, will result in the creation of significant vents in the roof. This will allow entrainment of air into the fire within the building envelope and then further entrainment of air into the flames/plume coming from the vent (see Figure 18) such that the total volume of air entrained, for a given fire size, will approach that which would be expected in the open under relatively still air conditions.

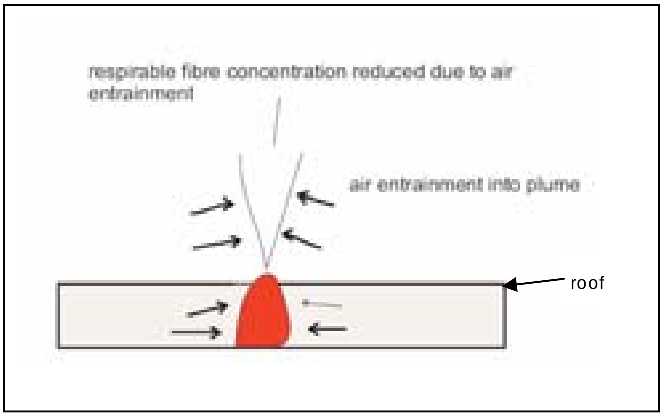

Figure 18 Fire within Building with Roof Vented

It is reasonable to make the following assumptions:

(a) The number of respirable fibres released is directly proportional to the area of roof exposed to heating. This is reasonable since roof deformation and spalling require heat exposure to the effected part.

(b) Given sufficient venting, the HRR of the fire is directly proportional to the area of burning fuel. This is reasonable since the fire, in this case, is largely fuel controlled.

(c) Given sufficient venting, the quantity of air entrained into the plume is proportional to the HRR of the fire. Appendix 10, which gives details regarding the air entrainment into a plume, provides a justification for this assumption.

Fires within buildings may be much larger than that associated with the test (i.e. more fuel may be involved). This means that the HRR is much greater (with plenty of ventilation the fire size is dictated by the mass of fuel burning) and therefore, the amount of air entrained into the external plumes will increase proportionately due to increases in the plume height and the convective component of the HRR (assumption (c)). However, a large fire will affect proportionately more of the roof (assumption (b)) and therefore (potentially) more respirable fibres will be released (assumption (a)). The resulting concentration will be approximately the same since bigger fires release more fibres yet more air is entrained.

On the basis of the above reasonable assumptions, it can be argued that the concentration of respirable fibres resulting from air entrainment in real fire incidents should be approximately the same as the concentration associated with the fire test.

5.6 Conclusions

The testing performed in the CESARE building revealed that the respirable fibre concentrations emitted by the fire are very low being orders of magnitude less than limiting values set by various regulatory organisations. The levels appear to be less than *average background* levels. This concentration is considered to be representative of what would be experienced above a fire plume associated with real fires in building containing A/C sheeting and vinyl tiles.

Sampling of the ash residue after the fire indicated that although asbestos fibre bundles were present, there was no evidence of respirable fibres within the sieved ash samples. However, A/C sheeting and vinyl tiles that had been subjected to the fire for its duration and had been located within the hot ash were noted as being friable.

6. Stage 3 – Dispersion Modelling

6.1 Introduction

Normally, smoke consists of particulate matter (soot), combustion gases and air. It is composed mostly of air that is drawn into the fire as part of the burning process or by entrainment into the hot plume. It is common experience that smoke from a fire disperses as it moves away from the source. This results in the concentration of the products of combustion, including that of any particulate matter, being reduced due to mixing with air. Respirable asbestos fibres that are released due to a fire can be considered to behave as soot particles (see Section 6.2) and will be dispersed as they travel away from the fire. Such dispersion will again result in reduction of the respirable fibre concentration as the fibres move further from the fire source location.

The purpose of the investigation described in this part of the report was to determine the effect of dispersion on respirable fibre concentrations away from a fire location.

6.2 Modelling Approach

The dispersion of respirable asbestos fibres away from a fire location must be determined using a model that considers the dispersion of particles. ALOFT is one such program that has been developed by the National Institute of Standards and Technology (NIST) in the USA [13,14]. The program allows the dispersion of smoke particles to be traced and solves forms of the Navier Stokes equations that are derived from fundamental physical principles. This approach is a sophisticated approach to modelling the dispersion of particles due to fire. Thus it provides guidance as to the likely distribution of particles due to a fire. This contrasts with most dispersion models that assume that particles issue from a point source such as the top of a stack rather than from a fire. The predictions of ALOFT have been tested against large pool fire experiments but have not been tested against data from other fires. Within the program smoke particles are characterised as a range of equivalent[13] spherical particles having a density of 1,000kg/m^3.

Appendix 11 discusses the relationship between respirable asbestos fibres and spherical smoke particles. It is concluded that the range of respirable fibres can be represented by spherical smoke particles having a diameter varying from 1 to 15 microns with the most likely sizes being between 2 and 10 microns. The range of smoke particles modelled by the default option within ALOFT allows particles of 2.5 microns or less and 10 microns or less to be modelled and therefore this can be used to give guidance on the respirable asbestos fibre dispersion.

ALOFT calculates the concentration of particles (in micrograms per m^3 of air) having a size of PM2.5 (less than or equal to 2.5 microns), or PM10 (less than or equal to 10 microns), due to a fire with a given HRR. Wind speed and the HRR can be varied. The program calculates the concentration of particles at various distances and heights from the fire.

6.3 Cases Analysed

ALOFT has been used to examine the effect of wind and fire size on the distribution of particles away from a fire location and to understand how the concentration will vary as distance from the fire source increases. Analyses have been undertaken for wind speeds of 2.5m/s, 7m/s and 12m/s and for fire sizes of fires of 25, 50, 100 and 200MW. The wind speeds chosen correspond to sustained wind speeds (as opposed to gusts[14]) for the Melbourne area and correspond to a typical wind speed (2.5m/s), the average over a year (7m/s) and a value close to the maximum over a year (12m/s). The probability of having a fire and

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[13] Smoke particles are not spherical in shape and it is necessary to characterise them as a spherical particle having the same motion characteristics in still air.

[14] A wind gust speed corresponds to the speed measured over a 3 second period whereas the sustained wind speed is measured over a 10 minute interval at 9am and 3pm each day.

maximum wind at the one time is quite small. It is much more likely that a fire will coincide with an average wind speed. The fire sizes reflect the range of fires that could be experienced in practice. Mostly, fires in the buildings of interest to this project will be 100MW or greater based on the amount of fuel available for burning.

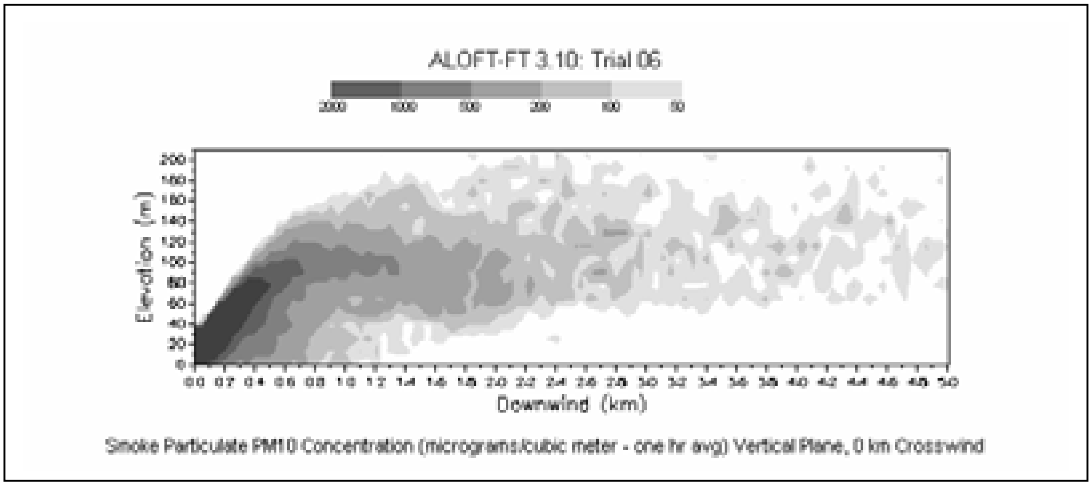
6.4 Results

As noted previously, ALOFT determines the dispersion of smoke particles having a diameter of 10 microns or less (termed a PM10 particle) and 2.5 microns or less (termed a PM2.5 particle). For all fires modelled, the mass of PM10 particles released per kg of fuel was 130g per kg of fuel pyrolised and fuel was assumed to be pyrolised at a rate of 0.015kg/m^2/s in the fire area. The burning of the pyrolised gases was assumed to release 0.4MW of heat per m^2 of burning fuel. The exact values of these variables are not all that important, however the values have been chosen to be more representative of timber fires which may not release as much heat per unit area of burning fuel as hydrocarbon fuels.

The results presented below give the concentrations of smoke particles not asbestos particles. However, as will be discussed in Section 6.5, this concentration data can be used to determine the likely concentrations of respirable fibres at various locations by applying a simple conversion. At this stage therefore, the concentration results relate only to smoke particles.

The longitudinal section plots showing the distributions for PM10 particles for a wind speed of 7m/s, are shown in Figures 19(a) – (d) for fires increasing in severity from 25MW to 200MW. Each of the fires is assumed to be steady state and the concentrations are those averaged over a one hour period. The vertical axis of each graph is in metres whilst the horizontal axis has the units of kilometres and covers a range of 5km. The concentrations are indicated by the bar chart at the top of the graph and are expressed in micrograms per cubic metre of air. The dynamics of PM10 particles represent the dynamics of respirable asbestos fibres. Therefore, the relative concentrations of PM10 reflect those that would be expected for respirable asbestos fibres.

It should be noted from these figures that as the fire increases in severity, there is a lesser likelihood of PM10 particles (which are representative of respirable asbestos particles) contaminating close to the ground level. At 100MW, the concentrations at ground level are very low, even quite close to the fire.



Smoke Particulate PM10 Concentration (micrograms/cubic meter - one hr avg) Vertical Plane, 0 km Crosswind

Figure 19(a) Vertical Slice – 7m/s and 25MW fire

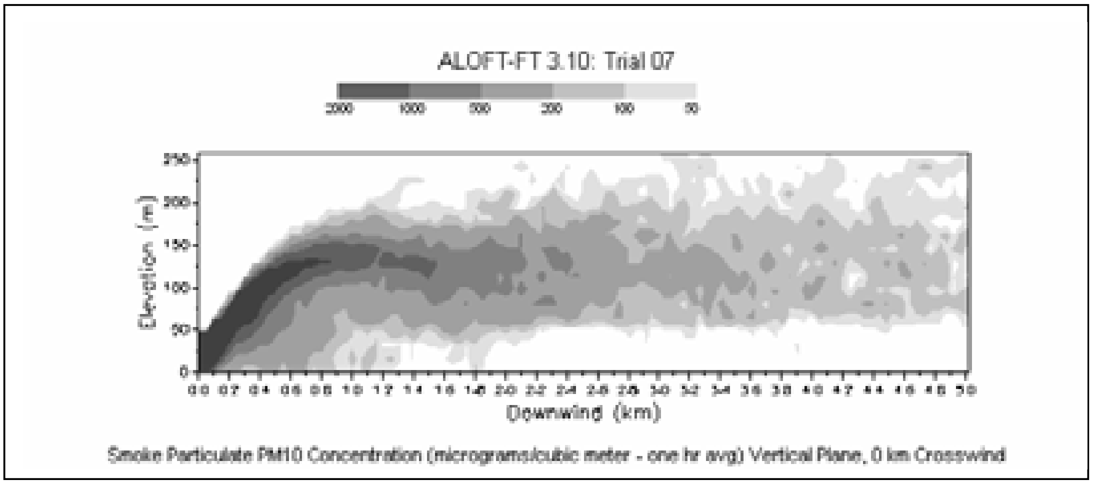


Figure 19(b) Vertical Slice – 7m/s and 50MW fire

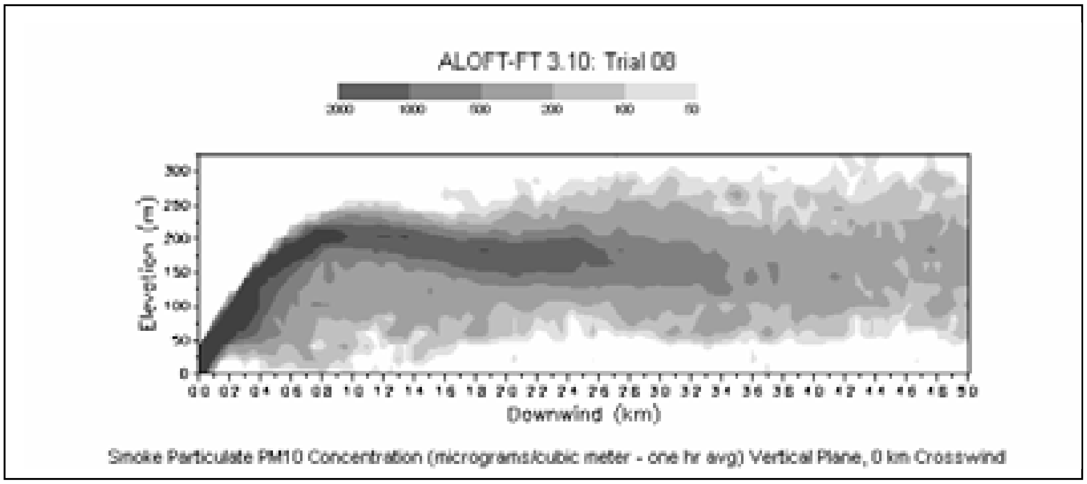


Figure 19(c) Vertical Slice – 7m/s and 100MW fire

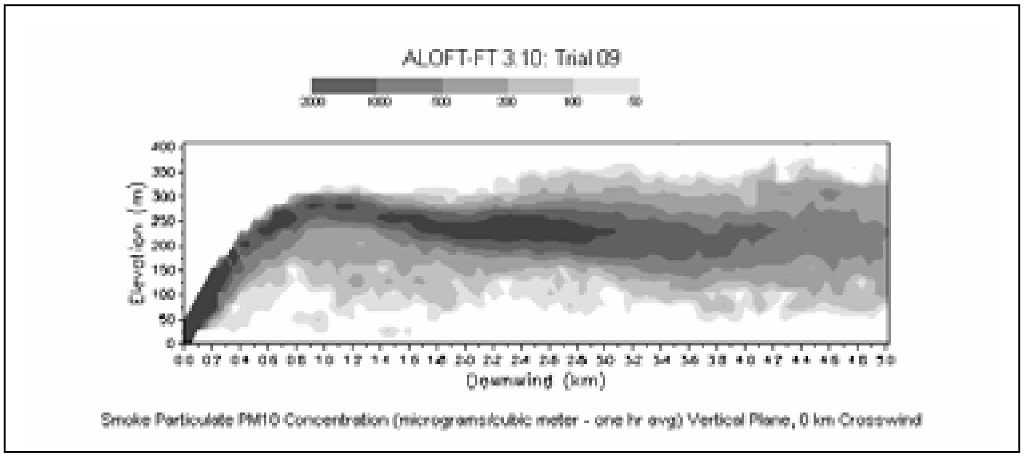


Figure 19(d) Vertical Slice – 7m/s and 200MW fire

Figures 20(a) – (c) show vertical sections through the dispersed PM10 particles with increasing wind speed. These figures show that as the wind speed increases, the PM10 particles are pushed closer to the ground such that contamination at ground level occurs for over a kilometre from the site of the fire. The significance of these concentrations in respect of respirable fibre concentrations is considered in Section 6.5.

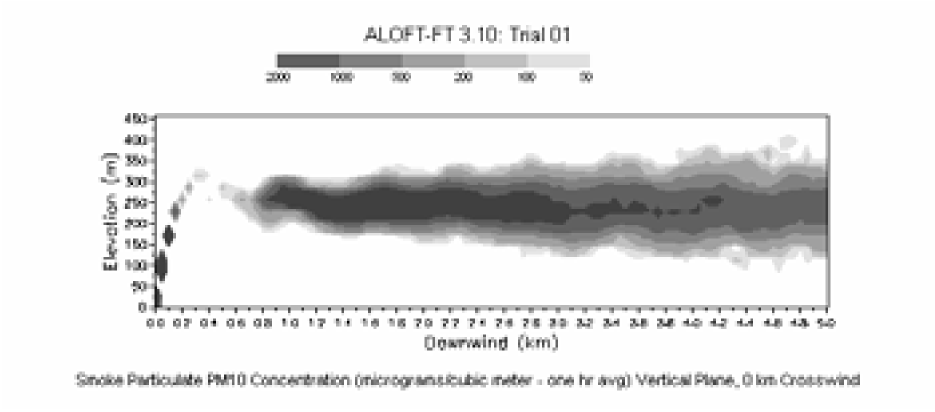


Figure 20(a) Vertical Slice – 2.5m/s and 100MW fire

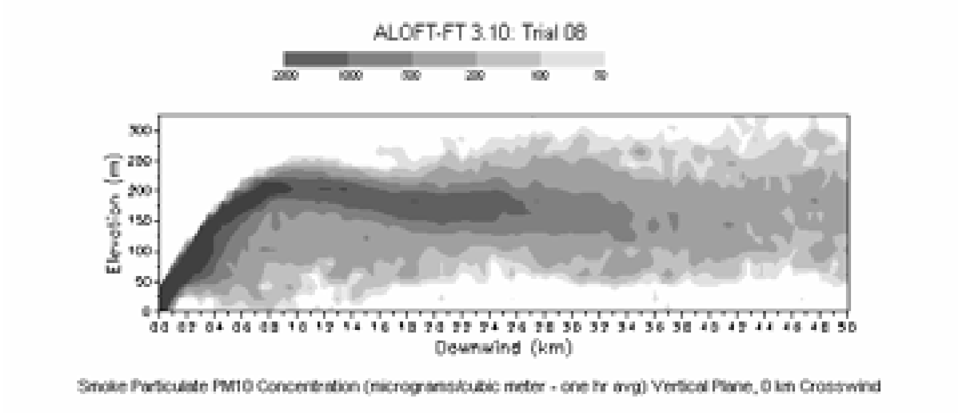


Figure 20(b) Vertical Slice – 7m/s and 100MW

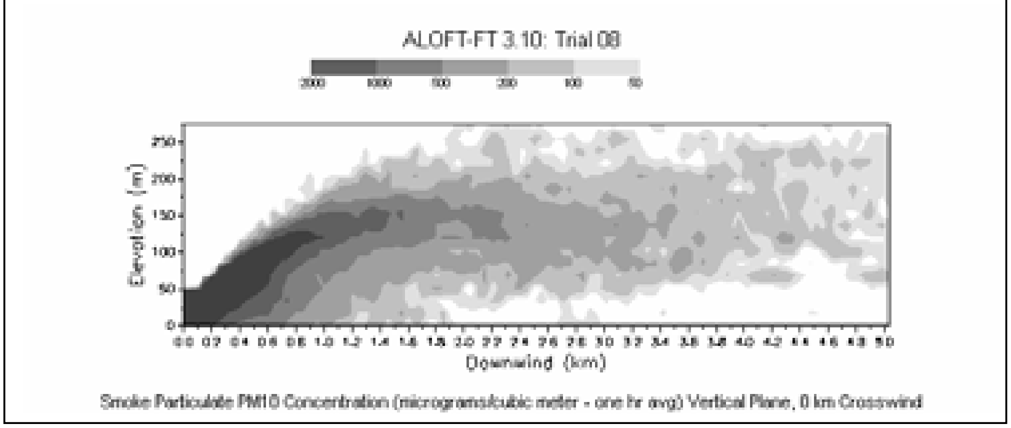


Figure 20(c) Vertical Slice – 12m/s and 100MW

Figures 21(a) and (b) show horizontal sections through the dispersed PM10 particles at ground level and at a height above ground level. These figures illustrate how localised (in plan) the distribution of smoke particles is for a 100MW fire and a wind speed of 7m/s. Figure 22(a) and (b) show the similar horizontal sections through the dispersed PM10 particles for a wind speed of 12m/s.

The difference in the distribution of PM2.5 and PM10 smoke particles is shown in Figures 23(a) and (b) for a wind speed of 7m/s and a 100MW fire. It is difficult to see much difference in the distribution of particles. The relative distribution of PM10 particles will be taken as representative of that which would be expected for respirable asbestos fibres.

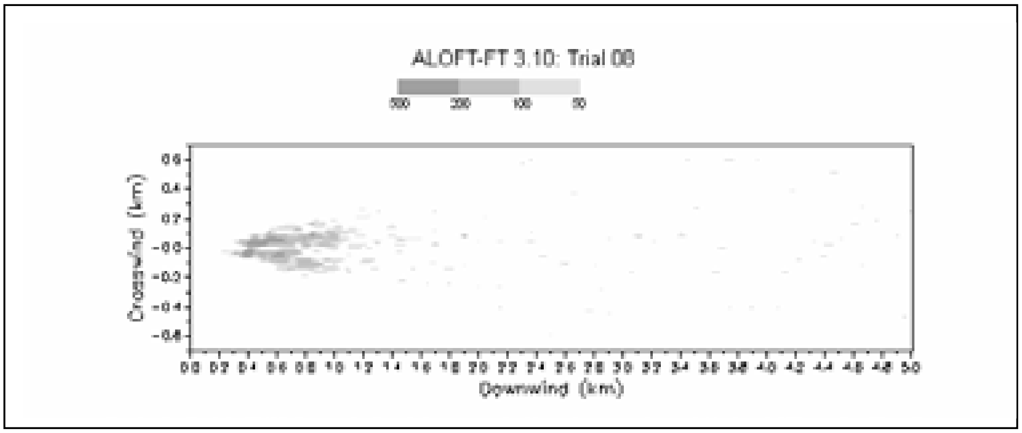
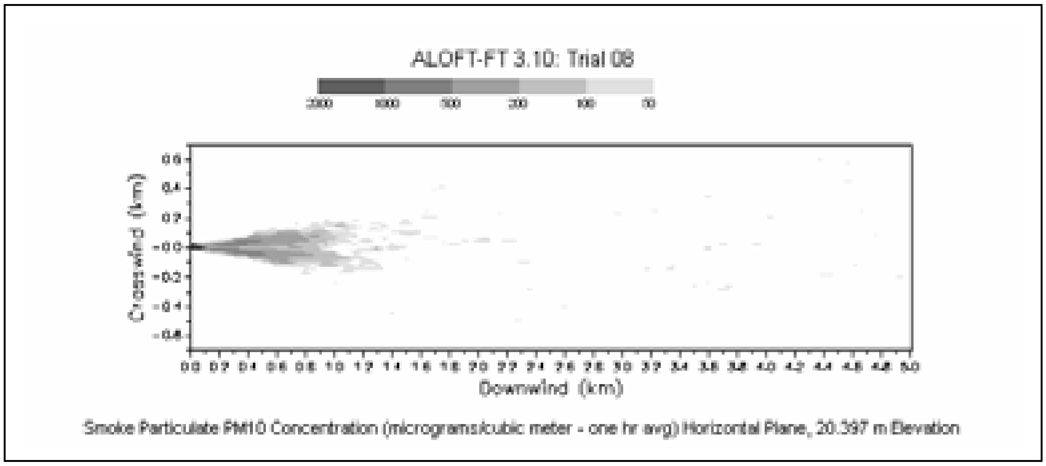


Figure 21(a) Horizontal Slice at Ground Level – 7m/s and 100MW fire



Smoke Particulate PM10 Concentration (micrograms/cubic meter - one hr avg) Horizontal Plane, 20.397 m Elevation

Figure 21(b) Horizontal Slice above Ground Level (21m) – 7m/s and 100MW fire

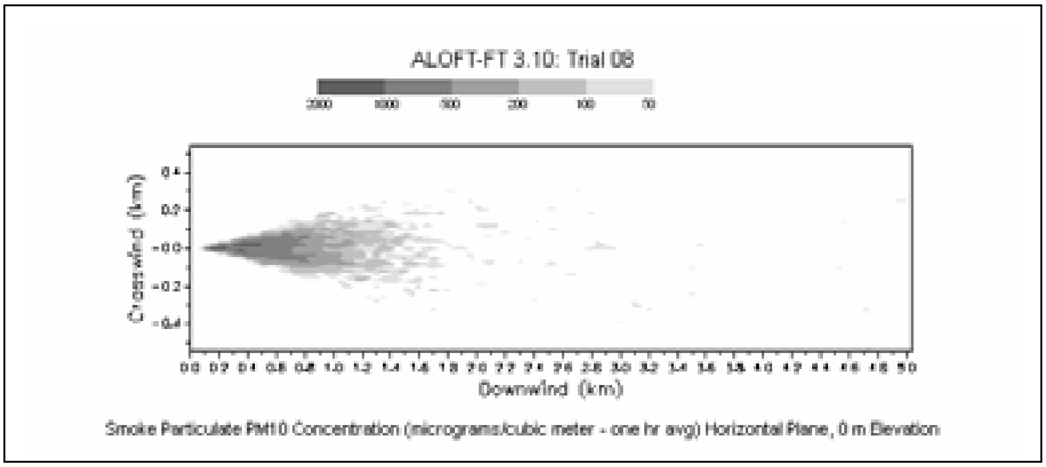


Figure 22(a) Horizontal Slice at Ground Level – 12m/s and 100MW fire

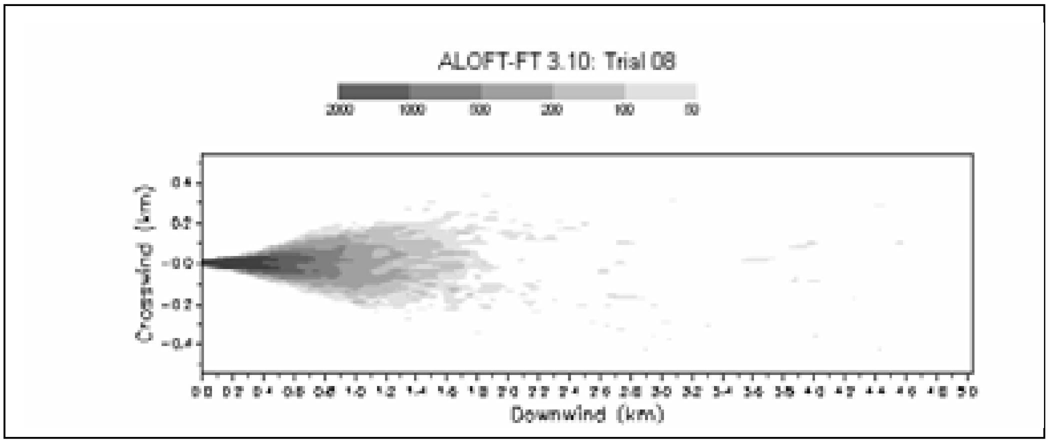


Figure 22(b) Horizontal Slice above Ground Level (17.5m) – 12m/s and 100MW fire

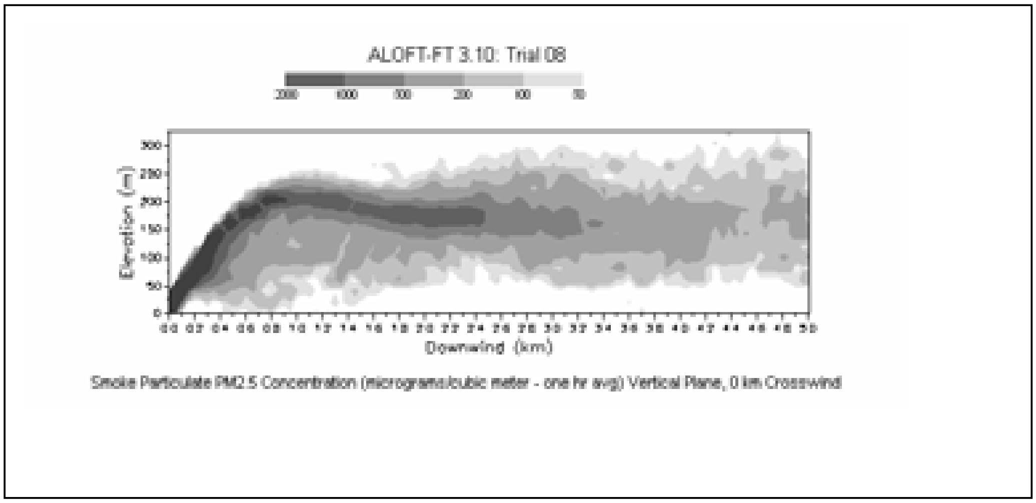


Figure 23(a) Vertical Slice (PM2.5) – 7m/s and 100MW fire

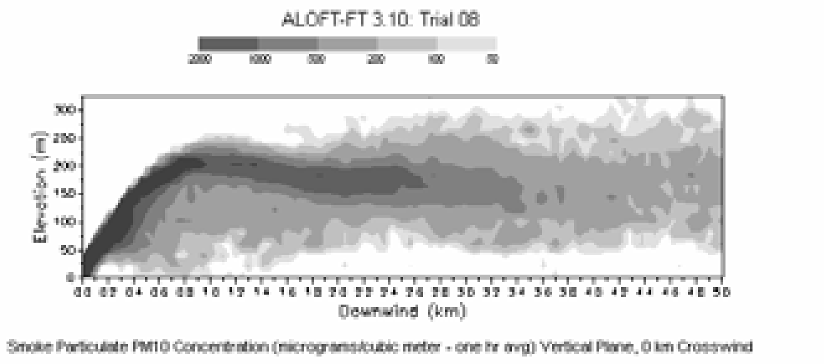


Figure 23(b) Vertical Slice (PM10) – 7m/s and 100MW fire

6.5 Application of ALOFT Modelling to Respirable Fibre Concentrations

As explained in Section 6.4, the mass of PM10 particles released at the fire location assumed for the analyses was 130g/kg (= r_1) of fuel pyrolised. Given that the pyrolysis rate assumed is 0.015kg/m^2/s (=r_2) of fuel involved in the fire, it follows that 130g x 0.015m^2/s = 1.95g/m^2/s (r_1 x r_2 = C_p) of PM10 particles were released. If, for a given size fire, this value was halved, all of the resulting concentrations of PM10 throughout the smoke would also be halved. If the value was reduced by a factor of 10, then all of the concentrations of PM10 throughout the distribution would be reduced by a factor of 10. It follows therefore, that to determine the concentrations of respirable fibres distributed by the fire, it is necessary to estimate r_1 considering respirable asbestos fibres and then to estimate r_2 for real fires (based on the test fire). This will enable the calculation of a representative value of C_p which will then enable concentrations to be calculated away from the fire by comparing this value of C_p with that adopted for the ALOFT PM10 particle smoke calculations.

Since the volume of air entrained into the plume is known for the fire test, it is possible to use the measured respirable fibre concentrations[15] to determine the total number of fibres released during burning. Assuming that such respirable asbestos particles are represented by 10 micron smoke particles, the total mass of respirable fibres can be estimated. The latter assumption will lead to an overestimate of the total mass of respirable fibres and therefore higher than actual concentrations. Since the fuel consumed during the main part of the fire is known, a value for r_1 can be estimated. The pyrolysis rate of the fire test can be fairly accurately estimated and this value should be taken as r_2. These values are calculated in Appendix 12, as is the conversion factor for converting the ALOFT PM10 concentrations (micrograms/m^3) to respirable fibres/ml. The conversion factor is 2.1 x 10^{-12}.

Considering all of the cases analysed by ALOFT and getting as close to the fire as possible (within 20m), the greatest calculated PM10 concentration found was 300,000 micrograms/m^3. This translates to a maximum respirable fibre concentration of 0.63 x 10^{-6} fibres/ml. This value can be compared with the value estimated from measurement within the smoke cloud

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[15] The measured concentrations assume that well mixed smoke was present for the entire monitoring period (approximately 240 minutes). In fact, well mixed smoke potentially containing respirable asbestos fibres was only present for approximately 80 minutes. The measured concentrations should therefore, be tripled to give a more realistic estimate of actual concentration within the smoke cloud.

obtained directly from the fire test of 1 x 10^{-6} fibres/ml (see Section 5.4.3(a)). These values are of the same order.

As can be seen from the PM10 plots, the concentrations drop rapidly away from the fire. For example, considering a 100MW fire and a 12m/s wind (see Figure 20(c)) it can be seen that within 200m of the fire origin, the PM10 concentration at ground has dropped to 1,000 – 2,000 micrograms/m^3 and by 0.5km has dropped to 200 – 500 micrograms/m^3. These concentrations are orders of magnitude less than the maximum estimated concentrations close to the fire of 300,000 micrograms/m^3. The same relativity exists for respirable asbestos fibre concentrations.

6.6 Conclusions

The plume modelling results demonstrate that the respirable fibre concentrations close to the fire are extremely small being very similar to that determined directly during the fire test described in Section 5. The resultant concentrations are much lower than the various acceptable limits and appear to be less than average background levels. The concentrations reduce further away from the fire being theoretically, orders of magnitude lower again.

7. Overall Conclusions

It is considered that the outcomes from this research project are consistent and provide a sound basis for responding to the key questions that prompted the initiation of this project.

The mere existence of asbestos in buildings or in ash/rubble does not pose a health risk to building occupants or the public. Asbestos fibres must become airborne, be present in sufficient concentration and be of a respirable size to pose a risk to those inhaling fibres.

The following conclusions can be drawn from the research findings.

7.1 The building survey conducted as part of Stage 1 of the investigation found that for 100 randomly chosen buildings containing asbestos containing materials (ACM), the most common ACM were A/C sheeting for roofs, walls and eaves (83% of the buildings surveyed), and vinyl tiles (40% of the buildings surveyed). Due to the areas covered by roofs, walls and floors it is clear that the these materials are, by far, the dominant ACM with A/C sheeting being the most dominant. Other forms of non-friable asbestos such as switchboards, splashbacks and gaskets were found in 55% of the total buildings surveyed, however the extent of their use is relatively minor. Accordingly, the ACM chosen for further investigation in Stage 2 of the project were A/C sheeting and vinyl floor tiles.

7.2 From the material testing undertaken in Stage 2(i) where 100mm x 100mm samples were subject to various levels of radiant heating, it was found that respirable fibres were not detected except during “spalling” events. Spalling occurred for 7 out of the 9 specimens tested and always in the early stages of heating. Spalling is an explosive phenomenon that occurs with cement-based products when exposed to heating such that the sample fragments. It is thought to be the result of the build-up of steam pressure within the cement matrix of the material. Microscopic examination of respirable fibres collected on the filters showed that no “denaturing” of fibres had occurred due to heating.

7.3 The large-scale test conducted in Stage 2(ii) and described in Section 5 involved both A/C sheeting and vinyl floor tiles which were subject to a realistic fire. Spalling was noted to occur during the first 25 minutes of the test. During this time, no respirable fibres were detected at ground level. Subsequent analysis of filters at roof level detected only 1 respirable fibre. The resulting respirable fibre concentration has been determined as being less than the average background level and several orders of magnitude less than the detection limit of the MFM (0.01 fibres/ml). This low concentration is due to the combination of two factors:

(i) although respirable fibres are released due to spalling and breakage, the number of fibres released is relatively low

(ii) the nature of large fires in building is that substantial quantities of air are introduced into the combustion zone and into the plume from adjacent uncontaminated air through a process called entrainment. This brings about substantial dilution.

7.4 It is considered that the low respirable fibre concentration associated with the test fire can be taken as typical of that which would be expected for all sizes of fires in buildings with substantial quantities of the dominant ACM materials. This concentration is representative of that associated with the smoke as it leaves the incident site.

7.5 Following the fire test, samples of undisturbed ash and residue were collected and analysed in the laboratory. The residue included the remains of vinyl tiles and pieces of A/C sheeting. Asbestos fibre bundles (these are not respirable) were found within the ash although no respirable fibres were found in the samples analysed. Samples of vinyl tiles and some fragments of A/C sheeting were found to be friable. It is noted that asbestos fibre bundles can be broken up by physical damage and that this could result in the release of respirable fibres. No sign of denatured asbestos fibres were found in the ash.

7.6 The dispersion modelling undertaken as Stage 3 and described in Section 6 confirmed the very low respirable fibre concentrations obtained from the large-scale fire test. The modelling found that the concentrations are substantially reduced even further as the distance from the fire location increases.

7.7 The outcomes from the large-scale fire test and the dispersion modelling demonstrate that fires within buildings having substantial quantities of A/C sheeting and/or vinyl tiles do not result in hazardous conditions with respect to respirable fibres downstream of the fire.

7.8 Analysis of the material within the ash following the large-scale fire test demonstrated that for fires within buildings containing dominant ACMs such as A/C sheeting and vinyl tiles, these materials may become friable after a fire. Asbestos fibre bundles will more than likely be present and respirable fibres may exist in the ash. Therefore, clean-up operations within the building should be performed in accordance with the Code of Practice for the Safe Removal of Asbestos NOHSC:2002(2005) [15] and the Occupational Health and Safety (Asbestos) Regulations 2003 [16]. The application of water will further reduce any exposure risk to nearby personnel working in the area, since wetting down the debris after a fire, reduces the risk of respirable asbestos fibres becoming airborne [17].

8. Practical Outcomes

As a result of the above overall conclusions, there are a number of practical outcomes in relation to the public, fire brigade personnel and those associated with cleaning up a site containing asbestos debris, following a building fire.

The following sections detail the practical outcomes associated with each of these groups of persons.

8.1 General Public/Environment

It is important to note that the addition of water will not result in the further degradation of any asbestos fibre bundle. In particular, Ref [17] shows that the application of water is very effective in reducing the likelihood of asbestos fibres from becoming respirable in soils and sands. Land contamination issues as a result of water washing asbestos fibre bundles or pooling water in an area (as a result of a fire in the area) are possible. It is unlikely however, that the asbestos bundles would be sufficient in terms of fibre size and form to generate respirable dust cloud particles, when the water evaporated.

8.2 Fire Brigade Intervention

When the fire brigade arrives at a fire scene they are likely to put on their breathing apparatus masks. Wearing these masks protects fire brigade personnel from the risk of breathing in respirable asbestos fibres, should they be present. It is possible that due to the fire brigade activities of gaining access into a building, that they may disturb and cause mechanical degradation of ACM by breaking down a door or wall. It is not possible to quantify the severity of such activities, as it will largely be building and activity specific.

Some of the fire brigade activities include the application of water over a fire and burning building. This very activity is considered to be one of the dust minimisation techniques [17], which reduces the risk of respirable asbestos fibres becoming airborne. The application of water therefore, further reduces the exposure risk to nearby personnel working in the area.

8.3 Clean-up Activities

As a result of the large-scale fire test in the CESARE building, and the analysis of the ash debris collected, it was found that respirable asbestos fibres were not found in the ash, however asbestos fibre bundles were present. These fibre bundles, while in their bundlet form, are not respirable, however they could become respirable fibres through the clean-up process if the fibre bundles are exposed to further mechanical degradation. Therefore, subsequent to a fire, the asbestos fibre bundles in the ash debris should be treated in the same manner as ACM during the clean-up process. That is, the clean-up process should be done in accordance with the Code of Practice for the Safe Removal of Asbestos NOHSC:2002(2005) [15] and the Occupational Health and Safety (Asbestos) Regulations 2003 [16].

The testing performed does not indicate that *'passive' disturbance* would result in the bundlets further shearing and becoming respirable asbestos fibres. 'Passive' disturbance would include disturbance through environmental (non-human) activities such as wind, rain and sun.

9. Glossary

A/C	Asbestos cement.
Average Background	In this context, average background levels of asbestos fibres refers to between 0.0002 – 0.0012 fibres/ml (i.e. $2x10^{-4}$ – $1.2x10^{-3}$ fibres/ml) Ref [18].
Conforming Fibre	See ‘Respirable Fibre’.
Denaturing	The fibre has been modified/altered such that it is no longer considered a respirable fibre i.e. the aspect ratio of length-to-width is greater than 3:1.
Detection Limit	Ref [7] details how to count the number of fibres on a filter for the Membrane Filter Method. Appendix 5 gives further examples and a detailed explanation, where the detection limit is 0.01 fibres/ml.
Emissivity	Is the property of a surface that determines the proportion of radiation that can be emitted or released. A blackbody has an emissivity of 1.0.
Exposure Standard	Means 0.1 fibre/ml of air measured in a person’s breathing zone and expressed as a time weighted average fibre concentration of asbestos calculated over an 8 hour working day and measured over a minimum period of 4 hours in accordance with the MFM or in accordance with a method as determined by the Authority.
Friable	Asbestos containing materials which when dry, is or may become crumbled, pulverised or reduced to powder by hand pressure. Once broken down (to a dust/powder form), the material also has the potential for the fibres to be exposed and become airborne, thereby posing a possible health risk. An example of friable material is pipe lagging.
Limpet	Sprayed on asbestos containing material.
Non-friable	A solid sample of material which does not break-down/disintegrate upon being rubbed in the hand. An example of non-friable material is vinyl tiles.

Non-homogeneous	Bulk samples containing small, discrete amounts of asbestos distributed unevenly in a large body of non-asbestos material. Examples include: floor sweepings, dust collected with a vacuum cleaner, soil samples, ore samples, and non-asbestos fibres or dust 'contaminated with asbestos.
Passive Disturbance	Further degradation of a material as a result of environmental activities such as wind, rainfall or sun. That is, non-human activities.
Respirable Fibre	Is a fibre with a width less than 3 microns, a length greater than 5 microns and a length/width ratio of greater than 3:1, and which does not appear to touch any particle with a maximum width (i.e. the smaller of the two dimensions) greater than 3 microns. A conforming fibre is also considered a respirable fibre.
Spalling	Is a phenomenon which can occur when a specimen/material has been exposed to high temperatures, resulting in the sudden cracking and breaking (degrading) of the specimen as a result of loss of moisture, such that it 'explodes' (i.e. spalls) into smaller pieces. Spalling is also typically associated with concrete materials.
Splashback	A surface backing in a wet area (eg. Kitchen sink area, bathroom, toilet area, etc).

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