

## 11. Appendices

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

**Department of Human Services**

**Appendix 1: Building Survey Data**

Table A1.0: 100 Buildings Surveyed

Note: '1' indicates that the ACM is present. It does not indicate the quantity of that ACM.

Site #	Building Type	Building Use	Non- Friable					Friable		
			Roofs, walls, eaves	Vinyl tiles	Switch-boards	Splash back	Gasket	Pipe lagging	Limpet	Mill board
1	Educational	Educational	1	1	1	1	1			1
2	Educational	Educational	1		1					
3	Educational	Educational	1							
4	Educational	Educational	1			1				1
5	Educational	Educational	1	1		1	1			
6	Educational	Educational	1		1					1
7	Educational	Educational	1							1
8	Educational	Educational	1							
9	Educational	Educational	1			1	1			
10	Educational	Educational	1		1	1				1
11	Educational	Educational	1							1
12	Educational	Educational	1	1		1				1
13	Educational	Educational	1		1	1				1
14	Educational	Educational	1	1		1				
15	Educational	Educational	1		1					1
16	Educational	Educational	1		1					1
17	Educational	Educational	1	1	1	1	1			1
18	Educational	Educational	1		1	1				1
19	Educational	Educational	1	1	1	1				
20	Educational	Educational	1	1	1	1				1
21	Educational	Educational	1							
22	Educational	Educational	1							
23	Educational	Educational	1		1					1
24	Educational	Educational	1		1					1
25	Educational	Educational	1		1					1
26	Educational	Educational	1		1	1				1
27	Educational	Educational	1		1					
28	Educational	Educational	1		1					
29	Educational	Educational	1		1					1
30	Educational	Educational	1							1
31	Educational	Educational	1		1					1
32	Educational	Educational	1	1						1
33	Educational	Educational	1		1					1
34	Commercial		1	1	1	1	1		1	
35	Industrial	Warehouse			1					

Site #	Building Type	Building Use	Non- Friable					Friable		
			Roofs, walls, eaves	Vinyl tiles	Switch-boards	Splash back	Gasket	Pipe lagging	Limpet	Mill board
36	Commercial		1							
37	Industrial	Treatment plant	1							1
38	Industrial		1	1				1		
39	Commercial	Hospital		1	1					
40	Commercial	Hospital	1		1					
41	Commercial		1	1	1					
42	Commercial		1							
43	Commercial	Market	1		1					
44	Commercial		1							
45	Commercial	Hall	1		1					
46	Commercial	Football Rooms	1							
47	Commercial	Dental Clinic	1	1	1					1
48	Commercial	former Police Station/ Court House	1	1						
49	Industrial	Warehouse	1							
50	Industrial	Warehouse	1							1
51	Commercial	Fire pump house	1							1
52	Industrial	Manufacturing building	1	1						
53	Commercial	Hospital		1	1					
54	Commercial	Workshop	1			1	1			
55	Commercial		1							
56	Commercial	Pavilion	1	1						
57	Commercial	Pavilion	1	1						
58	Commercial	Pavilion								
59	Commercial	IVF Building		1						1
60	Commercial	Hut				1	1			
61	Commercial	Hospital	1	1						
62	Commercial	Sports clinic	1	1	1					
63	Commercial	Sports clinic	1			1				
64	Commercial		1							
65	Commercial		1						1	
66	Commercial	Hospital		1						
67	Commercial	Hospital		1	1			1		

Site #	Building Type	Building Use	Non- Friable					Friable		
			Roofs, walls, eaves	Vinyl tiles	Switch-boards	Splash back	Gasket	Pipe lagging	Limpet	Mill board
68	Industrial						1			
69	Industrial	former Quarantine Building	1		1					
70	Industrial	Warehouse	1	1			1			1
71	Industrial	Warehouse	1	1						
72	Industrial	Warehouse	1	1						
73	Industrial		1	1	1					
74	Commercial				1					1
75	Industrial		1	1	1					1
76	Industrial	Warehouse	1		1					
77	Industrial	Warehouse	1	1	1					
78	Industrial		1	1			1			
79	Industrial								1	
80	Industrial	Gatehouse & Guard House	1	1			1		1	
81	Industrial		1	1						
82	Commercial	Church	1	1						
83	Commercial	Hospital	1							
84	Commercial						1			
85	Commercial		1	1						
86	Commercial				1					
87	Commercial	Hospital	1	1	1		1			
88	Commercial	Cancer Centre		1			1		1	
89	Commercial	Health Centre	1	1						
90	Commercial		1	1						
91	Commercial	University	1							
92	Industrial	Warehouse	1	1						
93	Industrial		1		1					
94	Industrial		1							
95	Industrial				1					
96	Industrial		1							



Site #	Building Type	Building Use	Non- Friable					Friable		
			Roofs, walls, eaves	Vinyl tiles	Switch-boards	Splash back	Gasket	Pipe lagging	Limpet	Mill board
97	Industrial		1							
98	Industrial			1				1		
99	Industrial	Warehouse	1							
100	Industrial							1		
<b>TOTAL (%)</b>			<b>83%</b>	<b>40%</b>	<b>41%</b>	<b>17%</b>	<b>14%</b>	<b>4%</b>	<b>5%</b>	<b>30%</b>

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

**Department of Human Services**

**Appendix 2: Quantity of Asbestos in Products and Use of Products**

## A2.1 Asbestos in Various Products

The likely asbestos fibre characteristics (type and quantity) in the ACM noted in Table 1 of this report are presented in this Appendix. This information has been obtained from the literature [3-5] and the findings are summarised in Table A2.0. For the ACM as identified in Table 1, eg. the roofing, walls, vinyl tiles, lagging, etc, it was not always possible to identify the actual quantity of asbestos within these materials. Where this information could be sourced it has been detailed and referenced in the table below.

**Table A2.0: Asbestos in Various Products**

Asbestos Containing Material (ACM)	Quantity and Type of Asbestos in ACM
<b>Non-Friable</b>	
Cement Sheet (roofing, walls, eaves)	Use of crocidolite asbestos ceased in the late 1960's [3] Then chrysotile was used until in cement sheeting until the mid 1980s [3] 10-20% probable chrysotile asbestos [4]
Vinyl Tiles	Pre 1980s, contained approximately 28% chrysotile asbestos [3] Early 1980s, contained approximately 8% asbestos [3] Approximately 1985, chrysotile asbestos no longer used in tiles [3] 12% weight/weight chrysotile asbestos [5]
Switchboards	15-40% probable amosite asbestos [4]
Splashbacks	Not Available – probably similar to cement sheet
Gaskets	30-60% probable chrysotile asbestos [4]
<b>Friable</b>	
Pipe lagging	Not Available
Limpet	60-90% probable amosite and crocidolite asbestos [4]
Millboard	70% weight/weight chrysotile asbestos, ~3% crocidolite asbestos [5] 30-65% probable amosite asbestos [4]

## A2.2 Information on the Use of Asbestos Containing Materials in Victoria

The Victorian Occupational Health and Safety Commission Inquiry [6], states that between 1960 and the mid 1970s, approximately 30-40% of the multi-storey buildings in the Melbourne central business district had their structural beams sprayed with asbestos for fire protection. The subsequent refurbishment of such buildings, if this has taken place, will have required the removal of such materials.

It was also estimated that 15-20% of buildings within the City of Melbourne contained significant quantities of asbestos insulation.

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## **Appendix 3: Cone Test Data and Observations**

### A3.1 Introduction - Background of Test Equipment and Test (on test day)

Prior to the first test starting, the cone exhaust fan was turned on to generate 6.9L/s (this flow rate for the duct was chosen in order to have the minimum flow within the cone [i.e. approximately 1m/s], thereby effectively generating a static state condition). The cone temperature was set to 400°C and the radiometer was shielded. This was done to confirm that the cone was reading the correct temperature i.e. 400°C.

Each specimen was weighed before and after the test. Each test specimen was placed inside a metal tray before being placed inside the cone. The external base of the metal (specimen) tray was also insulated. Between each test, the cone temperature was reduced to 300°C. As the A/C test specimen was placed under the radiometer, the cone temperature was then ramped up to the test temperature (eg. 770°C, 880°C or 975°C).

Monitoring pump locations within the room were as follows:

A = in exhaust duct

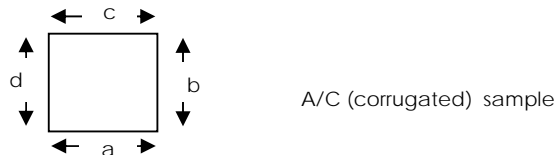
D = lid of bin, approx. 1.7m from cone

B = in exhaust duct

E = on bench, approx. 1.2m from cone

C = sampling ring of cone

F = outside test room



**Table A3.1. Specimen Weights before and after Testing**

Specimen No.	Specimen Size (mm)	Weight of A/C specimen (g) <i>before test</i>	Weight of A/C specimen & mesh in tray (g) <i>before test</i>	Weight of A/C specimen & mesh in tray (g) <i>after test</i>	Difference in Weight (pre test – post test) (g)
#1	a = 95mm, b = 101mm c = 107mm, d = 98mm	130.7	-	-	-
<b>A/C1 (#2)</b>	a = 75mm, b = 99mm c = 83mm, d = 98mm	97.9	757.0	731.7	25.3
<b>A/C3 (#3)</b>	a = 100mm, b = 100mm c = 87mm, d = 97mm	122.7 (with mesh)	803.0	780.6	22.4
<b>A/C4 (#4)</b>	a = 100mm, b = 100mm c = 99mm, d = 101mm	133.8 (with mesh)	816.4	774.8	41.6
<b>A/C5 (#5)</b>	a = 90mm, b = 93mm c = 70mm, d = 92mm	91.1 (with mesh)	708.4	682.9	25.5
<b>A/C6 (#6)</b>	a = 90mm, b = 93mm c = 86mm, d = 92mm	96.6 (with mesh)	777.4	757.7	19.7
A/C7 (#7)	a = 83mm, b = 96mm c = 89mm, d = 98mm	111.7 (with mesh)	791.9	765.4	26.5
A/C2 (#8)	a = 90mm, b = 97mm c = 91mm, d = 96mm	106.8 (with mesh)	857.8	770.3	87.5
<b>A/C8 (#9)</b>	a = 95mm, b = 95mm c = 95mm, d = 90mm	103.1 (with mesh)	983.9	752.0	231.9
<b>A/C9 (#10)</b>	a = 97mm, b = 96mm c = 90mm, d = 97mm	103.6	782.8	753.5	29.3
#11	a = 87mm, b = 98mm c = 84mm, d = 100mm	112.5	-	-	-
#12	a = 98mm, b = 98mm c = 93mm, d = 90mm	102.7	-	-	-

**Bold** specimens in table above refer to A/C specimens, which spalled during the test.

Legend for (Measured) Test Results from Cone:

The cone software used to take the various test measurements was Cone4\_95. Multiple measurements were taken of the variables of interest (eg. temperatures and flows) to ensure that the cone equipment was operating consistently.

'Start Time' = when the test specimen was put into the cone instrument.

HRR ( °C) = heat release rate (corresponding approximate temperature)

DP = differential pressure (Pa)

*Items in italics* = refers to readings taken from the Cone software on the computer

**Red Test Time** = refers to when the set temperature was reached

**Date: 30.08.2006**

**Test 1 Specimen #2 (A/C1)** Start Time 10:50:30s AM      HRR set to: 50 kW/m<sup>2</sup> (770°C)  
End Time 11:51:00s AM

**Table A3.2. Cone Variables during testing Specimen #2 (A/C1)**

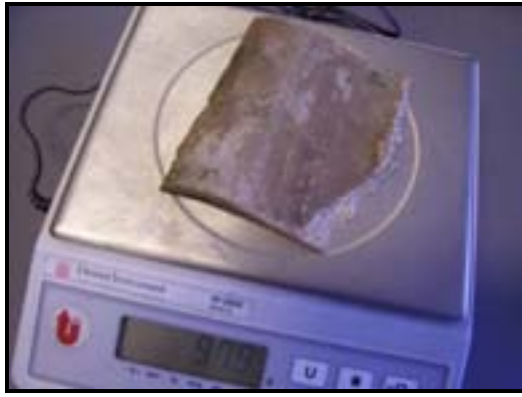
Test Time (mins), using stop watch <sup>^</sup>	Before Test Starts (1)	08.30	15.30	25.00	35.00	40.30	50.10	57.20	1.01.00 (2)
Cone Temp. on equipment (°C)	770	770	770	770	770	770	770	770	
DP (Pa)	12.0	12.1	12.3	11.2	10.8	10.8	11.2	10.7	
Stack Temp. (°C)	49.9	59.0	69.0	75.6	76.7	77.8	78.9	78.1	
Mass flow in duct (g/s)	7.6	7.4	7.3	7.1	7.0	6.9	7.0	5.9	
Volume flow rate at orifice (L/s)	7.0	7.0	7.1	7.0	6.9	6.8	6.9	6.8	
Cone Heater Temp. (°C)	771.0 (1)	771.9	771.9	771.9	771.4	771.7	771.4	771.3	
Smoke Temp. (°C)		81.7	94.0	100.9	99.7	101.4	101.9	100.6	

Notes:

<sup>^</sup> The stopwatch time starts when the test specimen is placed underneath the radiometer.

(1) Cone temperature was dropped to 300°C in order to put the test specimen into the cone instrument and then the temperature was ramped up to the test temperature, i.e. 770°C.

(2) Cone temperature was ramped down to 300°C after the specimen was taken out of the cone instrument.



Test 1, Specimen #2 (before test)



Test 1, Specimen #2 (exposed fibre after test)



Test 1, Specimen #2 (after test)

### **Test 1, Specimen #2 - Observations**

At 700°C, the test specimen exploded (i.e. began to spall) approximately 07.30mins after the test started. Some of the A/C sheeting broke into smaller pieces. Soon after, the specimen exploded at 715°C and then again at 770°C. Due to these explosions, it was decided that a mesh covering (gutter guard) should be placed over the test specimen, to reduce the possibility of spalled A/C sheeting contaminating the environment.

Physically, during the test, it was possible to see the asbestos fibres lifted/swaying from the A/C specimen, in the convected heat flow. See photo.

At 19.30mins the exhaust flow was adjusted for the cone to 6.9L/s.

At 36.30mins we could see the A/C specimen sparking.

At 44.30mins the exhaust flow was adjusted for the cone to 7.0L/s, and could not physically see the buoyancy of the heat (i.e. convected heat flow) anymore.

### **Filter Results**

The two filters, in the cone exhaust duct, were identified as 'void' after this test as they were overloaded with (cement) dust. The filter in the cone ring was also void as it was overloaded due to dust. This was based on the microscopic analysis of the filters. It appears that the A/C test specimen was non-friable after this test.

**Test 2 Specimen #8 (A/C2)** Start Time 13:35:20s PM HRR set to: 50 kW/m<sup>2</sup> (770°C)  
End Time 14:36:00s PM

For this test, due to the contamination issues associated with Test 1 (and using the one filter for 60 minutes), it was decided that from now on, every 15 minutes the cone sampling ring filter would be changed so that the amount of contamination on the filter was reduced. From hereon in, the two cone exhaust monitoring pumps were not used, only pumps labelled C, D, E and F were used, where C was the cone-monitoring pump.

The test specimen was also covered in a protective mesh.

**Table A3.3. Cone Variables during testing Specimen #8 (A/C2)**

Test Time (hr, mins)	Before Test Starts	13.43	13.50	14.00 (1*)	14.04	14.15 (2*)	14.20	14.27 (3*)	14.31
Cone Temp. on equipment (°C)		770	770	770	770	770	770	770	770
DP (Pa)		11.5	12.2	11.6	9.8	9.9	10.7	10.5	10.3
Stack Temp. (°C)		57.2	66.8	74.0	76.3	77.4	77.8	79.4	79.6
Mass flow in duct (g/s)		7.2	7.4	7.1	7.1	6.5	6.8	6.8	6.9
Volume flow rate at orifice (L/s)		6.8	7.1	7.0	7.2	6.6	6.7	6.8	6.7
Cone Heater Temp. (°C)		771.9	772.0	771.8	771.8	771.7	771.8	771.7	772.7
Smoke Temp. (°C)		79.0	91.3	99.5	102.4	103.1	103.5	104.0	103.7

Notes:

- (1\*) Pump change 1 at location C, at 13:51:50s
- (2\*) Pump change 2 at location C, at 14:06:50s
- (3\*) Pump change 3 at location C, at 14:21:55s



**Test 2, Specimen #8 (before test)**

### Test 2, Specimen #8 - Observations

At 670°C, the test specimen exploded at approximate time 13:41mins (i.e. 6 minutes after the test started).

At time 13:55:30mins the exhaust flow was reduced as it was reading 7.3L/s.

At 14:10mins we could see the A/C specimen sparking.

### Filter Results

The preliminary analysis of the filters exposed to 15min intervals of the test revealed that fibres had been released.

**Test 3 Specimen #3 (A/C3)** Start Time 14:59:00s PM      **HRR set to: 50 kW/m<sup>2</sup> (770°C)**  
End Time 15:59:00s PM

**Table A3.4. Cone Variables during testing Specimen #3 (A/C3)**

Test Time (mins), using stop watch	Before Test Starts	08.00 08.50	12.50	19.00 (1*)	25.00	33.10 (2*)	42.30	55.10 (3*)	60.00
Cone Temp. on equipment (°C)		770	770	770	770	770	770	770	
<i>DP (Pa)</i>		11.5	10.9	10.8	10.8	10.8	11.1	11.2	
<i>Stack Temp. (°C)</i>		61.0	67.0	74.2	77.7	78.6	81.3	80.6	
<i>Mass flow in duct (g/s)</i>		7.1	7.1	6.8	6.9	6.9	6.7	6.9	
<i>Volume flow rate at orifice (L/s)</i>		6.7	6.8	6.6	6.9	6.8	6.8	6.9	
<i>Cone Heater Temp. (°C)</i>		771.7	771.5	771.6	771.6	771.9	771.6	771.9	
<i>Smoke Temp. (°C)</i>		82.5	90.6	100.6	103.8	102.0	106.5	104.9	

Notes:

(1\*) Pump change 1 at location C, at 15:145:10s

(2\*) Pump change 2 at location C, at 15:29:10s

(3\*) Pump change 3 at location C, at 15:44:10s



Test 3, Specimen #3 (before test)



Test 3, Specimen #3 (shearing of A/C)



Test 3, Specimen #3 (spalled debris)

### Test 3, Specimen #3 - Observations

At approx. 750°C, the test specimen exploded approximately 08:10mins after the test started. Photos were taken of the A/C sheet shearing.

At 16:30mins after the test started, could see the buoyant heat of convection.

At 19:30mins after the test started, the exhaust flow was increased because it had dropped to 6.7L/s.

### **Filter Results**

The preliminary analysis of the filters exposed to the first 15min interval showed that there was asbestos fibres released.

**Test 4 Specimen #4 (A/C4)** Start Time 16:29:45s PM      HRR set to: 75 kW/m<sup>2</sup> (880°C)  
End Time 17:29:00s PM

Table A3.5. Cone Variables during testing Specimen #4 (A/C4)

Test Time (mins), using stop watch	Before Test Starts	10.30 10.50	15.30 (1*)	23.00	31.00 (2*)	39.00	46.30 (3*)	55.00	
Cone Temp. on equipment (°C)		880	880	880	880	880	880	880	
DP (Pa)		11.2	10.6	10.7	10.7	10.7	10.6	10.9	
Stack Temp. (°C)		71.3	82.4	90.9	95.7	98.6	98.3	99.8	
Mass flow in duct (g/s)		7.0	6.8	6.7	6.7	6.7	6.7	6.7	
Volume flow rate at orifice (L/s)		6.7	6.9	6.9	7.0	7.0	7.0	7.0	
Cone Heater Temp. (°C)		881.4	881.2	881.4	881.4	881.2	881.4	881.3	
Smoke Temp. (°C)		104.7	118.3	126.6	131.6	133.0	131.8	133.7	

Notes:

(1\*) Pump change 1 at location C, at 15:05

(2\*) Pump change 2 at location C, at 30:05

(3\*) Pump change 3 at location C, at 45:10



Test 4, Specimen #4 (before test)

#### Test 4, Specimen #4 - Observations

At 827°C, the test specimen exploded approximately 09:20s after the test started.

#### **Filter Results**

The last 15mins interval filter was found to be void, as the filter was damaged.

**Test 5 Specimen #5 (A/C5)** Start Time 17:49:20s PM HRR set to: 75 kW/m<sup>2</sup> (880°C)  
End Time 18:49:10s PM

**Table A3.6. Cone Variables during testing Specimen #5 (A/C5)**

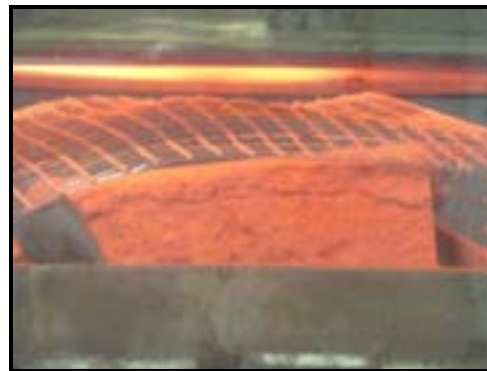
Test Time (mins), using stop watch	Before Test Starts	10.00 13.50	20.30 (1*)	25.00	34.00 (2*)	41.00	50.00 (3*)	56.00	
Cone Temp. on equipment (°C)		880	880	880	880	880	880	880	
DP (Pa)		10.6	9.6	10.6	10.7	10.9	10.9	10.9	
Stack Temp. (°C)		80.4	88.2	91.9	96.0	96.0	98.1	98.7	
Mass flow in duct (g/s)		6.7	6.4	6.7	6.8	6.7	6.7	6.8	
Volume flow rate at orifice (L/s)		6.8	6.5	7.0	7.0	7.0	7.0	7.1	
Cone Heater Temp. (°C)		881.0	881.0	881.3	881.3	881.3	881.3	881.2	
Smoke Temp. (°C)		112.4	121.7	124.0	127.4	126.6	128.7	129.3	

Notes:

- (1\*) Pump change 1 at location C, at 15:05
- (2\*) Pump change 2 at location C, at 30:03
- (3\*) Pump change 3 at location C, at 45:04



Test 5, Specimen #5 (before test)



Test 5, Specimen #5 (at 25:00mins)

### Test 5, Specimen #5 - Observations

At 687°C, the test specimen exploded approximately 06:30s after the test started.

Took video footage of this test (while spalling) and at 10:30 could see convection jets.

At 21:30mins after the test started, the exhaust flow was increased because it had dropped to 6.5L/s.

### **Filter Results**

No preliminary results were taken on test day.

Date: 31.08.2006
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**Test 6 Specimen #6 (A/C6)** Start Time 08:03:20s AM      HRR set to: 75 kW/m<sup>2</sup> (880°C)  
End Time 09:03:20s AM

**Table A3.7. Cone Variables during testing Specimen #6 (A/C6)**

Test Time (mins), using stop watch	Before Test Starts	10.00 12.40	18.00 (1*)	25.00	31.30 (2*)	37.00	43.00	50.00 (3*)	
Cone Temp. on equipment (°C)	300	880	880	880	880	880	880	880	
DP (Pa)	13.2	11.9	11.9	10.6	10.3	10.4	9.8	9.5	
Stack Temp. (°C)	27.5	76.0	86.6	91.2	93.9	94.8	94.5	95.6	
Mass flow in duct (g/s)	8.1	7.2	7.2	6.9	6.7	6.9	6.7	6.7	
Volume flow rate at orifice (L/s)	7.0	6.8	6.5	7.0	7.0	7.0	7.0	7.1	
Cone Heater Temp. (°C)	301.0	881.4	881.3	881.3	881.4	881.0	881.2	881.2	
Smoke Temp. (°C)	34.4	113.6	126.6	127.7	129.8	127.1	126.7	127.7	

Notes:

- (1\*) Pump change 1 at location C, at 15:02
- (2\*) Pump change 2 at location C, at 30:10
- (3\*) Pump change 3 at location C, at 45:10



Test 6, Specimen #6 (before test)



Test 6, Specimen #6 (at 16:45mins)

### Test 6, Specimen #6 - Observations

Took video footage of this test, starting at 600°C, which occurred at approximately 05:15mins after the test started.

At 710°C, the test specimen spalled at approximately 07:10s. At 735°C, the test specimen spalled again at approximately 07:30s, after the test started.

At 18:50mins after the test started, the exhaust flow was decreased because it was 7.2L/s.

At 20:00mins after the test started, could see the convection jets rising.

At 32:00mins after the test started, the exhaust flow was increased because it was 6.6-6.7L/s.

### Filter Results

No preliminary results were taken on test day.

**Test 7 Specimen #7 (A/C7)** Start Time 09:29:40s AM      HRR set to: 100 kW/m<sup>2</sup> (975°C)  
End Time 10:29:45s AM

**Table A3.8. Cone Variables during testing Specimen #7 (A/C7)**

Test Time (mins), using stop watch	Before Test Starts	11.35 24.00 (1*)	31.00 (2*)	39.00	46.30 (3*)	1.01.30	
Cone Temp. on equipment (°C)		975	975	975	975	975	
DP (Pa)		10.7	10.5	10.4	9.5	9.9	
Stack Temp. (°C)		103.1	107.9	110.0	111.7	113.6	
Mass flow in duct (g/s)		6.6	6.5	6.3	6.1	6.2	
Volume flow rate at orifice (L/s)		7.0	7.0	6.9	6.8	6.8	
Cone Heater Temp. (°C)		976.1	976.3	976.0	976.0	976.1	
Smoke Temp. (°C)		145.0	147.7	149.5	149.8	151.2	

Notes:

(1\*) Pump change 1 at location C, at 15:03

(2\*) Pump change 2 at location C, at 30:03

(3\*) Pump change 3 at location C, at 45:03



Test 7, Specimen #7 (before test)



Test 7, Specimen #7 (after test in bag)

### Test 7, Specimen #7 - Observations

Test specimen #7 appeared to be slightly thicker than the previous A/C specimens tested.

Took video footage of this test, starting at 600°C, which occurred at approximately 05:15mins after the test started.

This specimen did not spall.

### Filter Results

No preliminary results were taken on test day.

**Test 8 Specimen #9 (A/C8)** Start Time 11:05:14s AM      HRR set to: 100 kW/m<sup>2</sup> (975°C)  
End Time 12:05:15s PM

**Table A3.9. Cone Variables during testing Specimen #9 (A/C8)**

Test Time (mins), using stop watch	Before Test Starts	11.40 17.00 (1*)	21.30	28.30	32.00 (2*)	40.00	46.30 (3*)	55.00	
Cone Temp. on equipment (°C)		975	975	975	975	975	975	975	
DP (Pa)		11.5	11.1	10.8	10.7	10.3	10.4	9.5	
Stack Temp. (°C)		97.4	104.8	110.5	112.0	114.5	116.4	116.9	
Mass flow in duct (g/s)		6.9	6.7	6.7	6.3	6.3	6.3	6.2	
Volume flow rate at orifice (L/s)		7.2	7.1	7.3	7.0	7.0	6.9	6.7	
Cone Heater Temp. (°C)		975.4	975.8	975.9	975.9	976.0	976.0	976.1	
Smoke Temp. (°C)		139.4	147.7	151.5	152.6	155.7	156.7	157.6	

Notes:

- (1\*) Pump change 1 at location C, at 15:01
- (2\*) Pump change 2 at location C, at 30:02
- (3\*) Pump change 3 at location C, at 45:04

The edge of the radiometer had weakened during this test.



Test 8, Specimen #9 (before test)



Test 8, Specimen #9 (during test)

#### **Test 8, Specimen #9 - Observations**

Took video footage of this test, starting at 600°C, which occurred at approximately 05:15mins after the test started.

At 21:00mins a spark was seen from the A/C specimen.

This specimen did not spall and when the specimen was being placed in the plastic bag (after cooling down), it broke in the test auditor's hands.

#### **Filter Results**

No preliminary results were taken on test day.

**Test 9 Specimen #10 (A/C9)** Start Time 13:08:30s PM      HRR set to: 100 kW/m<sup>2</sup> (975°C)  
End Time 14:08:30s PM

The edge of the radiometer was adjusted as it had weakened in the previous test.

**Table A3.10. Cone Variables during testing Specimen #10 (A/C9)**

Test Time (mins), using stop watch	Before Test Starts	12.15 13.30	20.00 (1*)	25.30	33.10 (2*)	43.30	48.00 (3*)	57.00	
Cone Temp. on equipment (°C)		975	975	975	975	975	975	975	
DP (Pa)		12.9	13.8	10.3	9.9	8.9	9.7	8.8	
Stack Temp. (°C)		96.4	115.4	121.5	126.6	131.2	131.6	132.6	
Mass flow in duct (g/s)		7.4	7.3	6.3	6.0	5.8	6.1	5.8	
Volume flow rate at orifice (L/s)		7.7	8.0	7.0	6.8	6.6	7.0	6.7	
Cone Heater Temp. (°C)		976.0	975.6	975.5	975.8	975.5	976.4	975.8	
Smoke Temp. (°C)		145.8	169.3	180.6	186.2	187.1	186.0	185.0	

Notes:

(1\*) Pump change 1 at location C, at 15:01

(2\*) Pump change 2 at location C, at 30:01

(3\*) Pump change 3 at location C, at 45:02

The edge of the radiometer had weakened again during test.



Test 9, Specimen #10 (before test) x2



Test 9, Specimen #10 (after spalling)



Test 9, Specimen #10 (after test)



**Test 9, Specimen #10 - Observations**

Took video footage of this test, starting at 600°C, which occurred at approximately 05:15mins after the test started.

At 724°C, the test specimen spalled at approximately 07:14s after the test started (appears as if the specimen sheared into four long pieces).

At 21:00mins after the test started, the exhaust flow was decreased from 8.0L/s to 6.9L/s.

At 43:30mins after the test started, the exhaust flow was increased as it had dropped to 6.6L/s.

**Filter Results**

No preliminary results were taken on test day.

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

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## **Appendix 4: Cone Testing Asbestos Fibre Release Data**

## A4.1 Introduction

The results of the cone testing for each 15-minute monitoring time-period are presented in Table A4.0. Test specimen numbers highlighted in bold are for situations where spalling occurred. The column headings presented in Table A4.0 have been labelled in accordance with the naming requirements of Ref [7].

**Table A4.0: Results of Fibre Evaluation for Cone Testing**

Specimen No	Monitoring Stage <sup>(1)</sup>	Total Fibres	Reportable Fibres per Stage (N) <sup>(2)</sup>	Number of Fields (n) <sup>(3)</sup>	Av Pump Flow Rate, r (ml/min)	N/n	Calculated Result (fibres/ml) <sup>(4)</sup>	Reportable Concentration (fibres/ml) <sup>(5)</sup>
<b>A/C1</b>							overloaded	overloaded
<b>A/C2</b>	Stage 1	101.5	101.5	49	1670	2.1	0.9	0.3
	Stage 2	2	<10	100	1615	0.1	0.05	
	Stage 3	4	<10	100	1635	0.1	0.05	
	Stage 4	3	<10	100	1660	0.1	0.05	
<b>A/C3</b>	Stage 1	101.5	101.5	29	1610	3.5	1.6	0.4
	Stage 2	1	<10	100	1640	0.1	0.05	
	Stage 3	2	<10	100	1630	0.1	0.05	
	Stage 4	3	<10	100	1605	0.1	0.05	
<b>A/C4</b>	Stage 1	104.5	104.5	29	1625	3.6	1.7	0.5
	Stage 2	3	<10	100	1675	0.1	0.05	
	Stage 3	3	<10	100	1625	0.1	0.05	
	Stage 4	2	<10	100	1605	0.1	0.05	
<b>A/C5</b>	Stage 1						overloaded	<0.05
	Stage 2	3	<10	100	1715	0.1	0.04	
	Stage 3	0	<10	100	1600	0.1	0.05	
	Stage 4	0	<10	100	1580	0.1	0.05	
<b>A/C6</b>	Stage 1	102.5	102.5	22	1675	4.7	2.1	0.6
	Stage 2	4	<10	100	1635	0.1	0.05	
	Stage 3	3	<10	100	1655	0.1	0.05	
	Stage 4	0	<10	100	1605	0.1	0.05	
<b>A/C7</b>	Stage 1	3.5	<10	100	1630	0.1	0.05	<0.05
	Stage 2	1	<10	100	1670	0.1	0.05	
	Stage 3	4	<10	100	1630	0.1	0.05	
	Stage 4	0	<10	100	1690	0.1	0.05	
<b>A/C8</b>	Stage 1	3.5	<10	100	1550	0.1	0.05	<0.05
	Stage 2	0	<10	100	1660	0.1	0.05	
	Stage 3	1	<10	100	1635	0.1	0.05	
	Stage 4	0	<10	100	1665	0.1	0.05	
<b>A/C9</b>	Stage 1	101	101	53	1670	1.9	0.9	0.2
	Stage 2	2	<10	100	1625	0.1	0.05	
	Stage 3	4	<10	100	1665	0.1	0.05	
	Stage 4	6	<10	100	1635	0.1	0.05	

(1) Each monitoring stage was for 15 minutes or one quarter of the total monitoring time required by Ref [7] given a 13mm filter and a pump flow rate between 1550ml/min – 1715ml/min.

(2) This refers to the number of conforming fibres (N) counted over the number of fields (n) examined. Refer to Appendix 5 for more detail.



- (3) The number of fields (n) refers to the number of 100-micron diameter fields examined under the microscope. These fields are chosen at random. Note there are many 1000's of such fields. In counting fibres it is necessary to look at sufficient random fields to count 100 fibres. If 100 fibres are not counted then it is necessary to consider up to 100 random fields.
- (4) This is calculated using equation 1 of Ref [7] i.e.  $C = A/a \times N/n \times 1/r \times 1/t$ , where C = concentration (fibres/mL), A = effective filter area (mm<sup>2</sup>), a = projected eyepiece graticule area (mm<sup>2</sup>), N = total number of fibres counted, n = number of graticule areas observed, r = flow rate of air through filter (mL/min), t = single sample duration (mins). Eg. A/C2:  $C = 11300 \times 2.1 \times (1/1670) \times (1/15) = 0.9$
- (5) The reportable concentration is the sum of the calculated result for each specimen divided by the number of stages. Eg. A/C2:  $Reportable\ Concentration = (0.9+0.05+0.05+0.05)/4 = 0.3$  (1 significant figure, as per Ref [7], Part 9).

Note: In Table A4.0, the Reportable Concentration presented is the time weighted average over the monitoring period (i.e. typically 60 minutes). These concentrations cannot be compared to the *exposure standard* as persons would not be exposed to these concentrations at the distance measured from the A/C sheeting during the actual experiment.

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**Appendix 5: Background to Asbestos Fibre Counting**

## A5.1 Reportable Results

In line with the MFM [7], the reportable result is the total number of fibres on a filter per number of fields assessed through the microscope. The minimum reportable detection limit when assessing the number of fibres on a filter, is 10 fibres. If 100 fields are counted before 100 conforming fibres, then the minimum detection limit of 10 fibres/100 fields are recorded. This assumes then that less than 10 fibres were counted for the monitoring period. *For example, if 5 fibres / 100 fields are counted, then the reportable level is known as 10 fibres / 100 fields.*

However, if 100 fibres are counted before 100 fields, then the actual number of fibres per number of fields are recorded, in order to comply with the MFM. *For example:*

*a. if 23 fibres / 100 fields are counted, then the reportable level is 23 fibres / 100 fields*

*b. if 102 fibres / 52 fields are counted, then the reportable level is 102 fibres / 52 fields.*

Fibre counting was done in accordance with Ref [7] and the "NAA Laboratory Quality Manual Vol IV (Test Method 1) Asbestos Fibre Counting".

### A5.1.1 Minimum Loading

Traditionally, for reliable counting a fibre loading on a filter should exceed 40 fibres/100 fields (this would equate to an airborne concentration of 0.04 fibres/ml). It is permissible to lower the acceptable fibre loading to 10 fibres/100 fields, and it is common to have sample counts of zero fibres/100 fields.

If the actual fibre count is less than 10 fibres/100 fields, then the figure of 10 fibres/100 fields is the minimum that can be used to calculate the airborne fibre concentration.

Analysts must not count any more than 100 fields if a total of 100 fibres is not reached.

### A5.1.2 Maximum Loading

Average filter loadings between 5 and 10 fibres/field tend to result in under-estimation of the fibre concentration, due to obscuring problems, and should be treated with caution. Average filter loadings exceeding 10 fibres/fields can be accepted, providing the dust loading is sufficiently light so that it does not interfere with any of the countable fibres.

Analysts must count a minimum of 20 fields even if more than 100 fibres are counted.

### A5.1.3 Calculation of Dust Concentration

$$\text{Concentration of fibres/ml (C)} = \frac{A}{a} \times \frac{N}{n} \times \frac{1}{r} \times \frac{1}{t}$$

Where:	N =	total number of fibres counted
	n =	number of graticule areas or fields observed
	A =	effective filter area (mm <sup>2</sup> )
	a =	eyepiece graticule area (mm <sup>2</sup> )
	r =	flowrate of air through filter (ml/min)
	t =	single sample duration (minutes)

The 'A/a' value in the above formula, which is the microscope constant, has been calculated for the NAA Melbourne microscopes, as 46,900 for 25mm filters, and 11,300 for 13mm filters.

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

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**Appendix 6: Analysis of Asbestos in Ash**

## A6.1 Methodology

For each ash/charcoal sample collected from the CESARE building, the sample was split into two (known as Split 1 and Split 2) so that two specimens were assessed for each sample. This therefore, increased the accuracy of the results as opposed to only taking one sample to be analysed. The range of mass concentration measured was between 0.1- 5g/kg of asbestos fibre mass to the total mass of the ash sample (i.e. that is, 0.01% to 0.5% by weight).

Photos of the ash samples were taken prior to the analysis and prior to splitting into two samples. Refer to Photos A6.1 – A6.6).



A6.1 Sample Id 011



A6.2 Sample Id 012



A6.3 Sample Id 013



A6.7 Sample Id 014



A6.8 Sample Id 015



A6.9 Sample Id 016



A6.4 Sample Id 017



A6.5 Sample Id 018



A6.6 Sample Id 019

From each of the bags containing the cooled ash and A/C sheeting, the larger A/C sheeting was removed in order to conduct a friability test. The methodology used to assess the respirable fibre concentration in the ash was in accordance with the *non-homogenous* methodology detailed in AS4964-2004 [9]. A description of the methodology is presented below.

Note: All sieving of dust/ash samples was carried out in fume cabinet (with an air flow of  $\geq 0.5\text{m/sec}$ )

1. The complete sample from the bag was emptied into a laboratory (Endicott) three-tiered test sieve, the top section had a grid size 10mm, the middle section had a grid size 2mm, and the base section was the collection container.
2. The sample was sieved thoroughly by an analyst for 2 minutes into the middle sieve section of grid size 2mm.
3. The top section of the sieve, which held the larger material (size  $\geq 10\text{mm}$ ) was removed and the ACM was returned to the sample bag for archival purposes.
4. The remainder of the sample (material size  $\leq 10\text{mm}$ ) was sieved thoroughly again for 2 minutes by an analyst, so that the material collected was  $\leq 2\text{mm}$  in the base of the sieve.
5. The middle section of the sieve was removed and all material pieces  $\geq 2\text{mm}$  was re-bagged with the earlier larger collected material ( $\geq 10\text{mm}$ ) for archival purposes.
6. The collected dust (material pieces  $\leq 2\text{mm}$ ) was separated out into approximately two even portions and placed into two petri dishes, and labelled as sub-samples 'Split 1' and 'Split 2'.
7. The sub-samples 'Split 1' and 'Split 2' were weighed using a sartorius balance and the results were recorded (to 3 decimal places).
8. The sub-samples 'Split 1' and 'Split 2' were analysed in accordance with AS4964 – 2004 [9], using stereo microscopy, dispersion staining and trace analysis techniques. This is the "trace analysis" mentioned in A6.2 below.
9. The tiered sieve unit was thoroughly washed, rinsed and oven-dried.
10. Steps 1-9 were repeated for all samples.

In summary two types of analysis were undertaken for each specimen – a sieve analysis (as per above steps 1-7) and a trace analysis (step 8).

#### **A6.2 Ash Analysis Results**

The results shown in Table A6.1 illustrate the two types of analysis performed for the non-homogeneous ash samples. The two types of analysis performed included sieving the bulk ash sample (to assess the mass of asbestos) and then conducting a trace analysis, as described in AS4964:2004 [9]. The larger fractions of ash (i.e. greater than 2mm) were not analysed as only identification of the respirable fibres and loose fibres were considered for this part of the assessment.

For the bulk ash sample sieved to 2mm, it was identified that for all samples, the mass of non-respirable asbestos bundles was greater than the lower reporting limit of 0.1g/kg. Therefore, it was concluded that all of the samples contained asbestos. For the majority of the ash samples taken, the type of asbestos identified in the form of asbestos bundles was chrysotile, although the ACM tested contained all forms of asbestos.

Table A6.1 Respirable Fibre Results in Ash

Identification Label	Sample Type / Location	Split 1			Split 2		
		Non-Homogeneous Analysis		Trace Analysis (2)	Non-Homogeneous Analysis		Trace Analysis
		Above 0.1g/kg? (1)	Type of Asbestos	Respirable Fibre	Above 0.1g/kg?	Type of Asbestos	Respirable Fibre
011	Vinyl Tile Ash / Under ash pile	Y	Chrysotile	None detected	Y	Chrysotile	None detected
012	Ash / East upper portion of ash pile, approx. 1m from scaffold	Y	Chrysotile	None detected	Y	Chrysotile	None detected
013	Ash / East lower portion of ash pile, approx. 1m from scaffold	Y	Amosite	None detected	Y	Chrysotile	None detected
014	Ash / West of centre support, centre portion of ash pile	Y	Chrysotile Amosite	None detected	Y	Amosite	None detected
015	Ash / West of centre support, lower portion of ash pile	Y	Amosite	None detected	Y	Chrysotile Amosite	None detected
016	Ash / West upper portion of ash pile, approx. 0.5m from scaffold	Y	Chrysotile	None detected	Y	Chrysotile Amosite	None detected
017	Ash / West lower portion of ash pile, approx. 0.5m from scaffold	Y	Chrysotile Amosite Crocidolite	None detected	Y	Chrysotile Amosite	None detected
018	Ash / North spalled material, approx. 0.3m from scaffold	Y	Chrysotile Amosite Crocidolite	None detected	Y	Chrysotile Amosite Crocidolite	None detected
019	Ash / Top portion of ash pile	Y	Chrysotile Amosite	None detected	Y	Chrysotile Amosite	None detected

Notes (1) In accordance with AS4964:2004 and assessing non-homogeneous samples, the mass of the observable asbestos fibres is to be recorded as less than or more than the reporting limit of 0.1g/kg.

(2) Trace analysis was needed to determine whether respirable fibres were contained within the sieved samples. From the trace analysis assessment it was identified that in all cases, 'no respirable asbestos fibres' were detected. The term 'None detected' refers to a result where 'less than 5 fibres' were identified using the polarised light microscopy (PLM) and dispersion staining (DS) trace analysis techniques (as detailed in AS4964-2004).

### A6.3 Additional Analysis

#### Moisture Content Analysis

The moisture content of the A/C sheeting used for the test was determined in the laboratory. Four samples of A/C sheeting were exposed to 120°C (in an oven) for 4 hours. These samples were sourced from the same host material as used in the large-scale fire test in the CESARE building. None of these samples had previously been heat-treated. These samples were weighed prior to heating in the oven and after heating, in order to assess the approximate moisture content of the A/C sheeting used in the large-scale fire test. The results are shown in Table A6.2.

**Table A6.2: Moisture Content Analysis**

Heating Cycle	A/C Sample No.	Weight (g) before Heating	Weight (g) after Heating	Difference (g)	% free moisture content
Exposure to 120°C for 4 hrs	1	188	179	9	4.8%
	2	172	160	8	4.7%
	3	294	281	13	4.4%
	4	203	194	9	4.4%
<b>Average Moisture Content</b>					4.6%

### A6.4 Additional Analysis

#### Friability Test

As detailed in Table 4 of this report (Section 5.4.4.2), a friability test was performed on the ACM samples subsequent to the large-scale test. For each sample, the ACM was tested for friability twice. If one of the two friability tests resulted in the sample being friable, overall the test sample was described as 'friable', in Table 4.

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**Appendix 7: Gold Filter Analysis (Pickford & Rhyder Consulting)**

### **A7.1 Introduction**

Eight gold-coated filters were obtained from Pickford & Rhyder Consulting [10]. These filters were mailed to NAA and secured in their cowl attachment as described in AS4964-2004 [9]. After the large-scale test, the gold filters were hand delivered to Pickford & Rhyder Consulting, Lane Cove, NSW for analysis. The remaining two gold filters were identified as having their filter membrane broken as a result of the test and therefore, could not be analysed.

### **A7.2 Pickford and Ryder Report**

Following Pages



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9 November 2006

Ms. Elissa Fazio  
 Senior Consultant  
 Noel Arnold & Associates  
 Level 3 / 818 Whitehorse Road  
 BOX HILL VIC 3128

Fax: 9659-0995

Our reference: NAA-061102-48181/86- XL30 analysis

Dear Elissa,

### Analysis of Filters for Asbestos Fibres by Polarised Light Microscopy (PLM) and Scanning Electron Microscopy (SEM)

---

#### A. INTRODUCTION

As requested, six polycarbonate sample filters exposed to smoke particulate from a combustion fire under controlled conditions were supplied to our laboratory for determining the presence of asbestos fibres. Each of the filters had been prepared for SEM analysis by gold coating before sampling.

As per your earlier instructions we were to look at each filter and report on the number of respirable fibres found for each of the filters by SEM. However, there was a high particulate loading on each of the filters which occluded the respirable fibre determination.

Further discussions with you suggested that following a preliminary investigation of the filters by Stereomicroscopy and PLM that we investigate the surface of the filters for fibre composition by SEM.

#### B. BACKGROUND

Asbestos is a naturally-occurring, mineral fibre composed of hydrated magnesium silicate,  $Mg_3(Si_2O_7)(OH)_4$ . It is chemically inert up to 500° C.

Thermal degradation of chrysotile (ch) reacts to heat in a two stage manner:

1. In the range of 600-780° C, the compound dehydroxylates (i.e dehydrates or loses water). This means that after the loss of water it becomes porous and the remaining oxygen accommodates all of the Mg and Si ions forming an anhydride compound.
2. At 800-850° C, the anhydride breaks down into forsterite and silica. This means there is a change in the molecular structure (packing geometry) whereby the Mg and Si ions begin to

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differ in opposite directions, forming rich Mg and Si regions. Therefore, the individual fibres are recrystallised with a change in the crystalline structure to a more non-crystalline or amorphous silica.

At temperatures greater than 850° C, there are further phase or chemical changes where there is a co-existence between forsterite and enstatite increasing in silica-rich amorphous areas.

The process of change is as follows:

chrysotile	→	forsterite	→	forsterite & silica	→	enstatite & forsterite
(< 600° C)		(600- 780° C)		(800-850° C)		(850-1300° C)
Crystalline		amorphous fibrils & flakey crystallites		crystal structure disappears from fibrils		silica enriched (loss of straight fibre profile)

The effect of temperature on morphology as observed under high resolution electron microscopy is as follows<sup>1</sup>:

- Below 600° C there is no change in the appearance or crystalline structure of chrysotile.
- At 600° C the fibrils are still crystalline, displaying morphologic characteristics of typical chrysotile
- At 650° C there are no changes in external morphology, irregular shaped patches start to appear along the fibril length
- At 700° C the external morphology of the fibrils is still present, the elongated patches cover larger areas but are still irregularly distributed along the fibre length.
- At 800° C, the external morphology of fibre bundles remain but individual fibrils have coalesced to form thicker fibres in which voids are present. The elongated patches increase in length and diameter.
- At 900° C the walls of the fibril have lost their straight profile and have a scalloped appearance with large elongated patches filling the fibril, probably the growth of forsterite grains.
- At 1000° C the fibrils are thick and curved, a new material with tiny grains mix with forsterite grains. Growth of enstatite and amorphous areas occur. Co-existence of forsterite, enstatite and silica rich areas.
- From 1000 -1300° C, the original fibrils are completely twisted into single twisted, ropelike fibres, consisting of a series of 'knots', enhanced enstatite growth and therefore completely amorphous

There are oxidation changes for crocidolite and amosite at high temperatures but not to the extent for change of structural characteristics and transformation of crystallinity as there is for chrysotile

<sup>1</sup> Refer; "Thermal Transformation of Chrysotile Studied by High Resolution Electron Microscopy, Helena De Souza Santos , published in The Clay Minerals Society, 1979.

**C. GRAVIMETRIC ANALYSIS OF DUST ON FILTERS**

Following your instructions supplied to us the filters were weighed following the deposition of particulate from the combustion test to approximate the mass of material on each of the filter.

Each filter was conditioned before each mass determination and a pre-coated gold polycarbonate 25mm filter was selected as a reference filter or field blank during the weighing. The blank filter was checked periodically during the weighing session to ensure the balance was stable and accurate.

The gravimetric analysis of the filters was carried out using a Cahn 26 microbalance, which is a six-place balance with a practical detection limit of 0.01 milligrams.

The results of the weighing after taring the blank filter against the sample filters, are as follows:

Filter No.	Lab No.	Mass on Filter (mg)
A51	48181	18.11
A48	48182	6.54
A31	48183	15.44
A54	48184	7.49
E43	48185	5.23
A38	48186	5.05

**D. MACROSCOPIC APPEARANCE**

The six samples were initially examined with a low power stereomicroscope at magnification of 7X to 20 X. All filters contained a deposition of black carbonaceous matter in the form of a filter cake.

The surface of the filter cake material was scanned for the presence of fibres. A fibre bundle was found on the surface of filters A48 and A51.

For filter A51, a fibre bundle of approximate dimensions 10 µm in length and less than 1µm in width which was visually classified as exhibiting the colour and morphology of typical chrysotile. The fibre bundle was teased from the surface of filter and analysed using polarised light microscopy with dispersion staining.

The fibre bundle found on filter A48 was left in-situ on the filter surface for examination by SEM.

**E. POLARISED LIGHT MICROSCOPE (PLM) ANALYSIS.****1. Identification of Fibre Type for Filter No. A51**

For A51, the fibre bundle was examined using Polarized Light Microscopy (PLM) with Dispersion Staining (DS) in accordance with AS 4964-2004: - 'Method for the qualitative identification of asbestos in bulk samples' as outlined in Laboratory Method ID/1.

A slide was prepared with the matching refractive index oil of 1.55 for chrysotile with the fibre dispersed in the fluid and covered with a coverslip.

The slide was then examined by placing the fibre bundle into the lightpath under polarised light at magnification of 125x. The individual fibres or fibrils were observed under the optical criteria for chrysotile to obtain confirmation of the fibre type.

When observed the basic morphology of the fibres in the fibre bundle were characteristic for chrysotile with kneebends and wavy features, however, the fibres exhibited crinkled microfolds along the length of the individual fibrils.

The fibres were not typical of the optical characteristics for standard commercial chrysotile asbestos fibres, and therefore, could not be unequivocally identified and reported as chrysotile asbestos.

In addition, standard reference chrysotile asbestos fibres were placed in a muffle furnace at 800 ° Celsius overnight and examined by PLM with DS. Analytical results for this analysis were similar for the type of fibre found on filter A51. Therefore, the fibres on filter A51 are likely to be heat effected chrysotile.

## **2. Trace Asbestos Analysis of Filter No. E43**

In discussions with yourself, it was suggested Filter E43 was chosen for trace analysis of mineral fibres. This method is used to detect mineral fibres or 'respirable' asbestos fibres (i.e. less than 3 micrometres in width) which may be present at very low concentrations, or may be distributed throughout the sample, even though they may not be visible under general examination by stereomicroscopy.

Examination of the filter surface of Filter E43 with low and high power stereomicroscopy to locate fibrous material for identification indicated no visible fibres observed on the surface of the filter.

Subjecting the sample filter to trace analysis, a representative section of the filter was taken and dispersed on five glass slides with RI fluid 1.55 for chrysotile. Each sub-sample when examined by PLM and DS did not detect any evidence of asbestos fibres on the slides.

## **E. SCANNING ELECTRON MICROSCOPE (SEM) ANALYSIS**

### **1. General**

After communicating the PLM results with you, we were instructed to investigate the type of fibre by using a more comprehensive analytical technique. Scanning Electron Microscope (SEM) allows examination of detailed size and morphology and positive identification of the type of fibre. Four of the six filters were chosen for analysis.

### **2. Sample Preparation**

Gold pre-coated sample filters, A38, A48, A51 and A54 were selected for SEM examination. Each of the filters was affixed to a 25 mm aluminium stub using double sided tape and then wet carbon dagged to avoid charging of the specimen. The filters were then examined under SEM.

After the filters were examined, representative sections of two of the filters were dispersed onto two carbon adhesive 13 mm stubs for further SEM examination.

### 3. Instrument Description and Methodology

The samples were examined using a Philips XL30 analytical Scanning Electron Microscope located in the Madsen building, University of Sydney.

Magnifications between 200 and 4,000 times were used to inspect the fibres and particles on the filter surface, and then excite selected fibres with a very fine, high energy electron beam.

The XL30 is the perfect instrument for this application being fully automated with integrated advanced electron optics. The intermediate chamber has a multiple specimen rotational drive stage which enables changing between specimens and optimisation of the sample surface. The detector was set to a 10 mm working distance which was the eucentric position and optimum position for Energy Dispersive Spectrum (EDS) analysis.

Using a 20kV accelerating voltage and a 4 nanometre spot size the mineral fibres were analysed using Energy Dispersive X-Ray Analysis (EDAX).

The collected elemental spectrum was displayed on screen for each fibre analysed and referred to standard elemental spectra. Characteristic x-rays emitted by this process were compared against standard diagnostic criteria, in order to determine whether the fibres were chrysotile asbestos, amphibole asbestos (including amosite and crocidolite), inorganic non-asbestos fibres, or organic fibres.

Fibrous minerals present were identified on the basis of morphology and elemental composition. Fibre length and diameter were measured directly off the screen using the precalibrated mode of the instrument.

Ms. Linda Apthorpe and I conducted the analysis on 2 November 2006.

### 4. Summary of Results

General observation of the sample filters at low magnification under SEM indicated that all of the filters exhibited moderate to heavy particulate loadings of carbonaceous matter with small agglomerate particulate on the surface of each filter. SEM has greater resolution capabilities than light microscopy and it is possible to distinguish fibres from other particulate matter more readily. Therefore, when a fibre was detected the SEM magnification was further increased depending upon fibre size and particle agglomeration. A cross-section of each filter was scanned using computer based defined stepped presets to observe the full frame selected area.

For each of the filters, all fibres exhibiting typical morphology were observed. Each fibre was probed and analysed using EDS.

Fibre lengths ranged from approximately 20 micrometres to 200 micrometres and fibre diameters ranged from 0.1 micrometres to 10 micrometres.

The fibres when observed were irregular shaped single fibres or splayed bundles with unusual definition, some fibres exhibited characteristics of distinct exfoliation. When subjected to elemental analysis the fibres showed a definite absence of silicon in their chemical composition, which indicated that they were not silicate based minerals and therefore non-asbestos.

Although, there may be a change in the formation of asbestos fibres with regard to morphology and crystallinity at temperatures from 600° C to 1300° C, the thermal transformation of asbestos fibres, even at temperatures exceeding 1300° C will not destroy the presence of silicon.

The presence of strong carbon and chlorine peaks in the resulting spectra for each of the fibre types analysed confirmed the material was amorphous with no definite crystalline structure. In

addition to the main peaks for chlorine and carbon there were smaller peaks, which indicated traces of sodium, potassium and calcium.

The same spectral pattern was observed for a spherical particle with dimensions of approximately 3 µm diameter on the surface of the filter. Areas of the filters were also analysed where no particulate or fibre-type formations occurred, which were predominately the black soot matrix or host material. The resultant spectra were the same for the fibre and particle-type formations.

However, a fibre bundle was found on filter A38, with approximate dimensions 40 µm in length and 2 µm in width which exhibited morphology and characteristics not unlike typical chrysotile asbestos. The sample spectra, when compared to reference spectra for chrysotile showed strong matching Mg and Si peaks in the ratio of 0.8:1.0. The analysis of the fibre also depicted interfering elements for chlorine and carbon with minor sodium, potassium and calcium, which were present on and along the fibres lengths of the fibre bundle. There was also an absence of iron in the spectra, which is found at trace level, which may have been due to the presence of the interfering elements or a characteristic of heat degradation.

It is unknown why there was a strong anion presence of Chlorine and traces of other ions in the fibre and the carbonaceous matter. Although, this may be attributed to the combustion process materials.

The fibre on filter A38 was similar in characteristics and morphology for the type of fibre found on filter A51 during the PLM examination.

No further asbestos or asbestiform types of mineral fibres were detected on the four filters during the analysis.

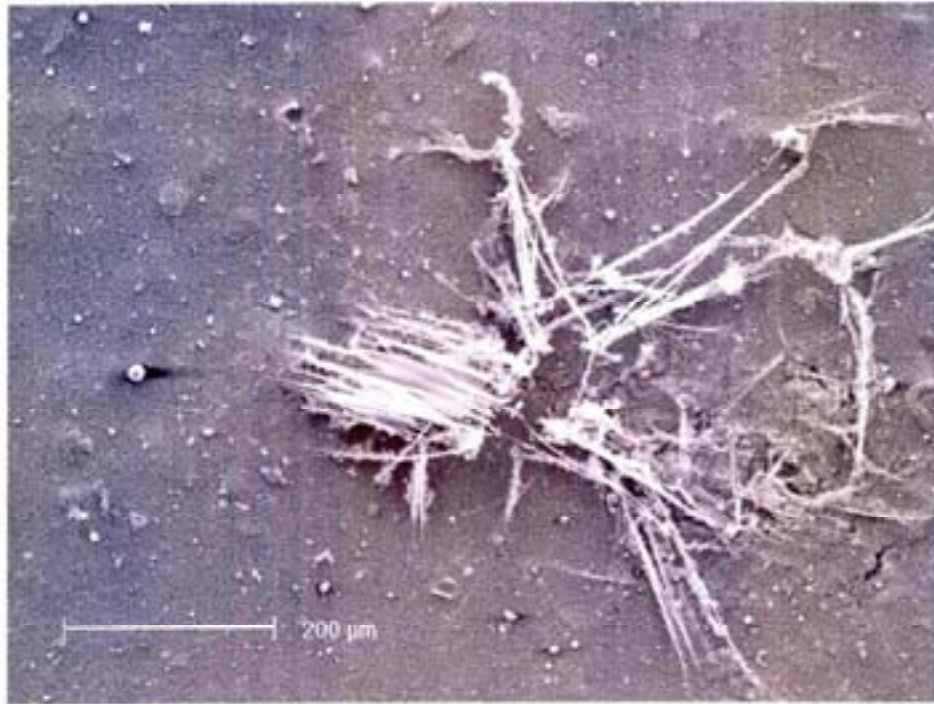
Sub-samples of the filters A38 and A48, which were redeposited onto smaller stubs were examined for the presence of fibres in the filter cake. No observable fibres were found.

The attached micrographs taken with relevant EDAX spectra show typical examples of fibres within the samples.

Report prepared by,



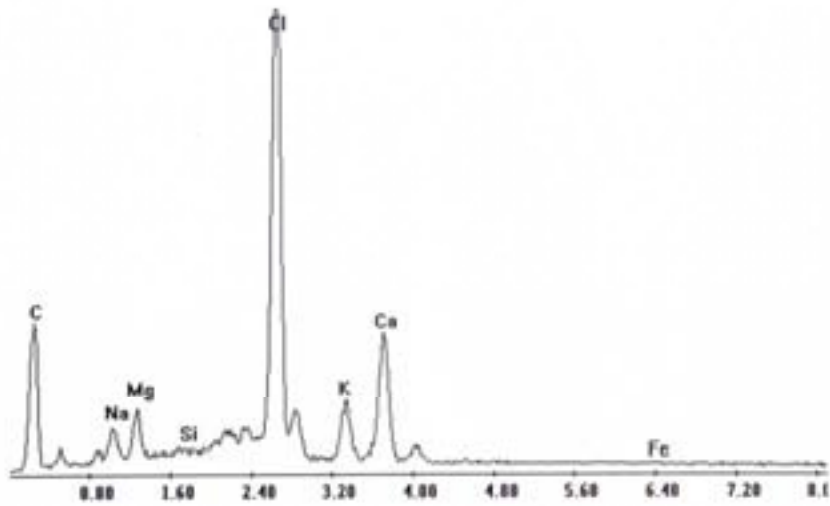
Gary Conaty



Filter No. A48, Exfoliated fibre bundle with no crystalline structure, EDAX spectrum shown

I:\d30\GC\analy\A48 Fibre bundle01.spc

Label A: A48 Fibre bundle 01

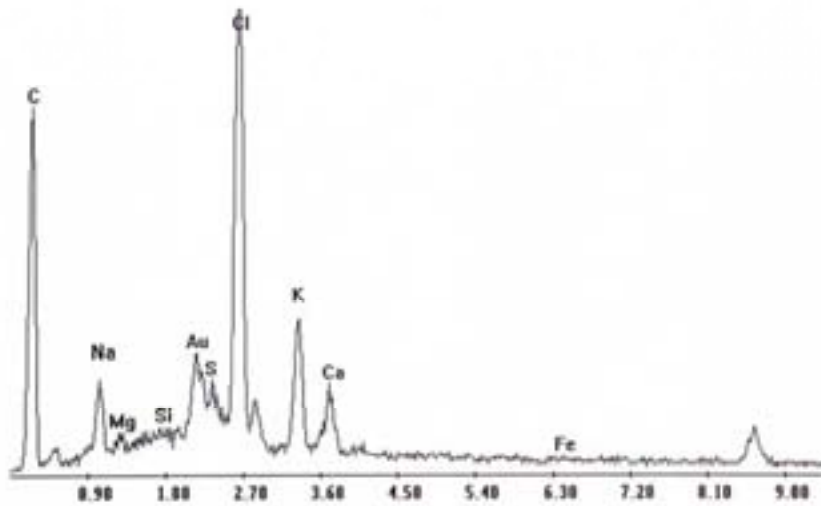




Filter No. A48, Fibre bundle with no crystalline structure, EDAX spectrum shown

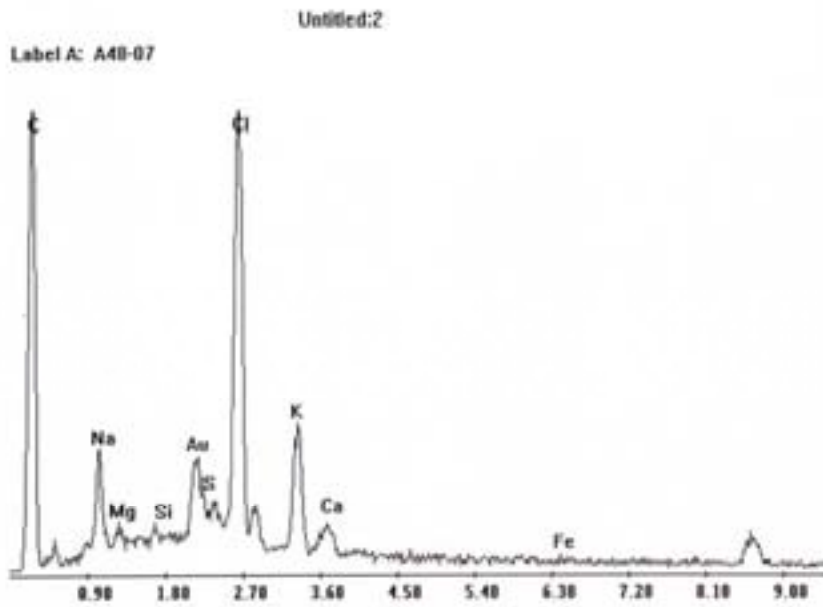
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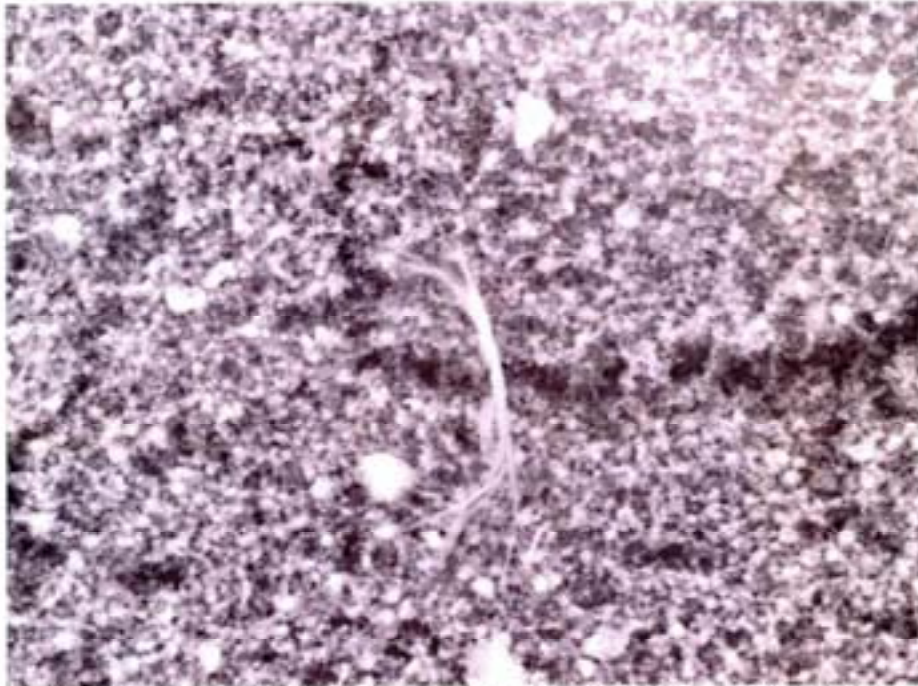
Label A: A48-08





Filter No. A48, Fibre found with no crystal structure, EDAX spectrum shown

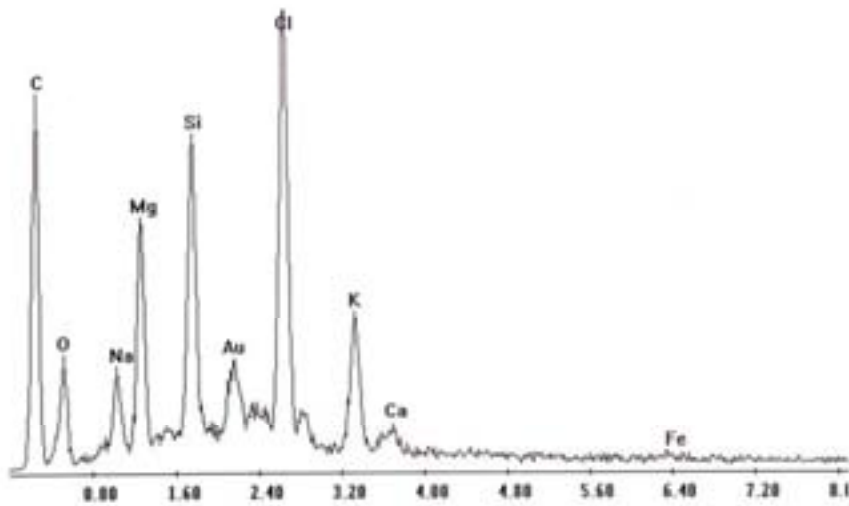




Fiber No. A38, Fibre found with crystalline structure, possibly chrysotile, approximately 40  $\mu\text{m}$  in length and 2  $\mu\text{m}$  in diameter. EDAX spectrum shown

Untitled:1

Label A: A38-03

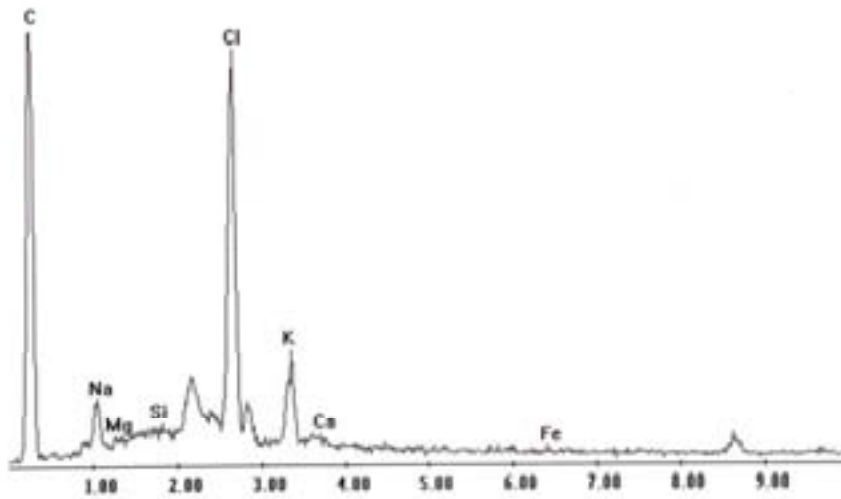




Filter No. A38, Fibre found with no crystalline structure, approximately 18  $\mu\text{m}$  in length and 6  $\mu\text{m}$  in diameter. EDAX spectrum shown

Untitled:1

Label A: A38-04

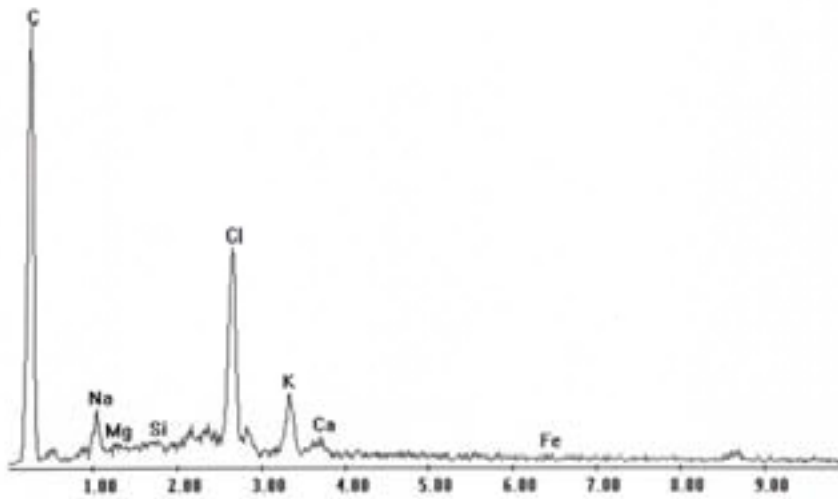


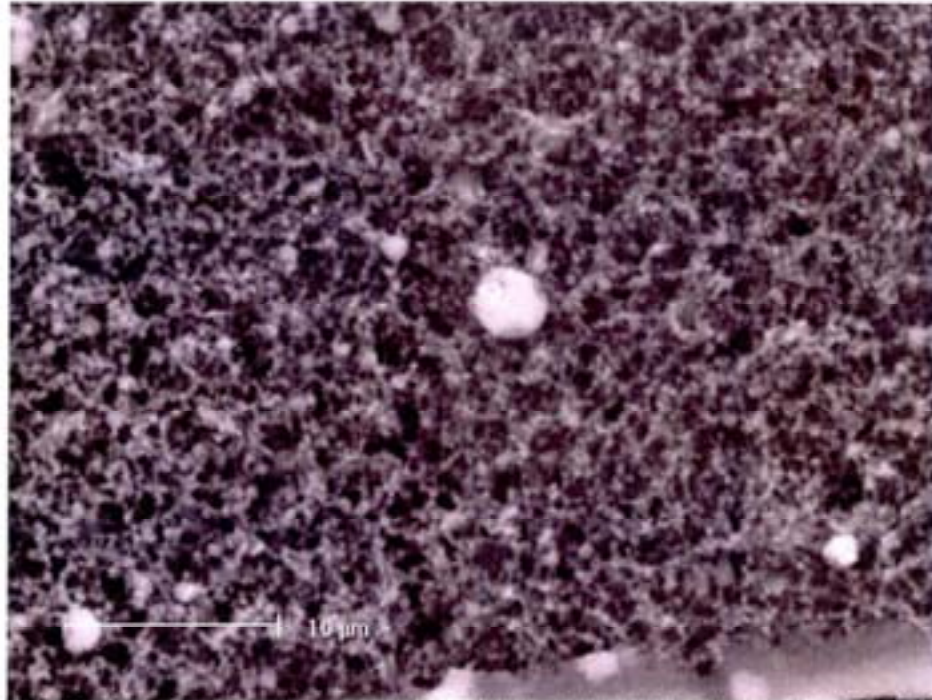


Filter No. A38. Scalloped fibre found with no internal structure, approximately 200 µm in length and 10 µm in diameter. EDAX spectrum shown

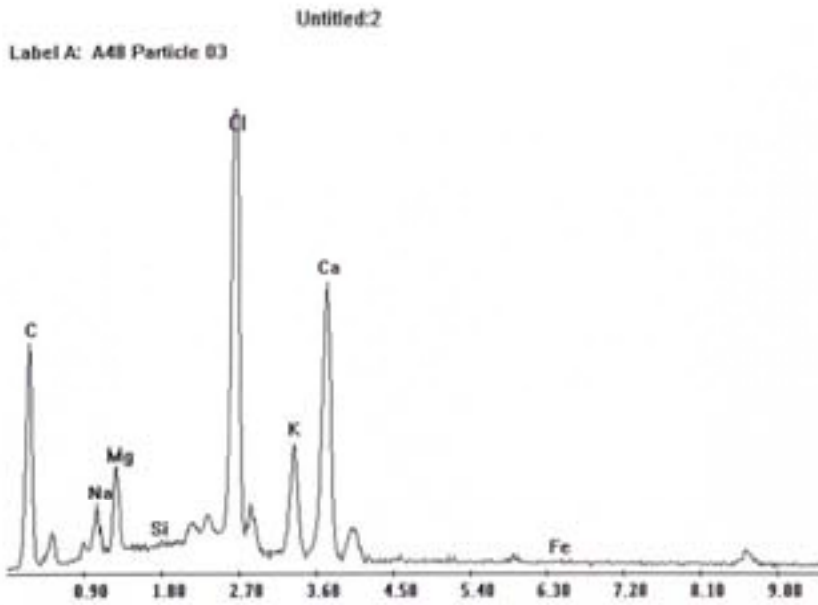
I:\x130\GCenaty\A38-05.spc

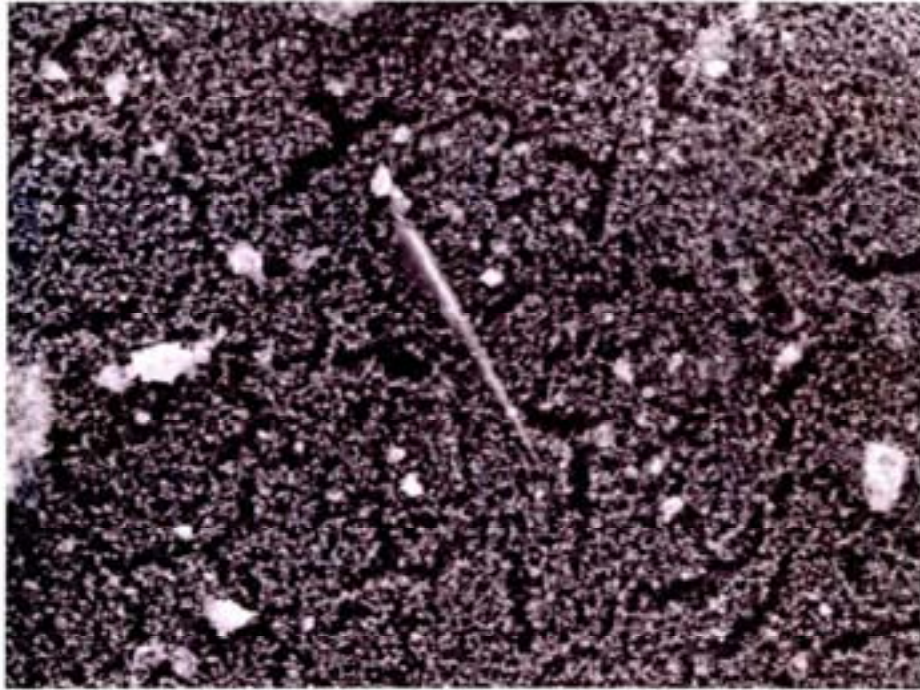
Label A: A38-05





Filter No. A48, Spherical particle on surface of filter, approximately 3µm in diameter. EDAX spectrum shown.

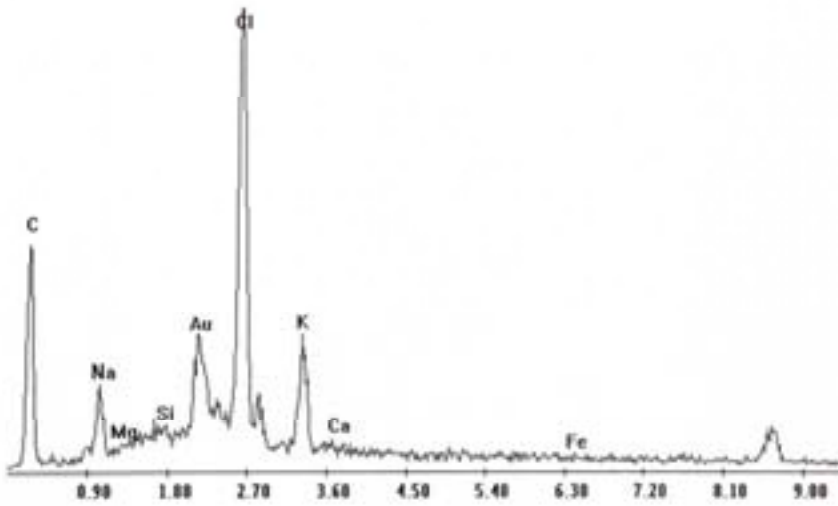


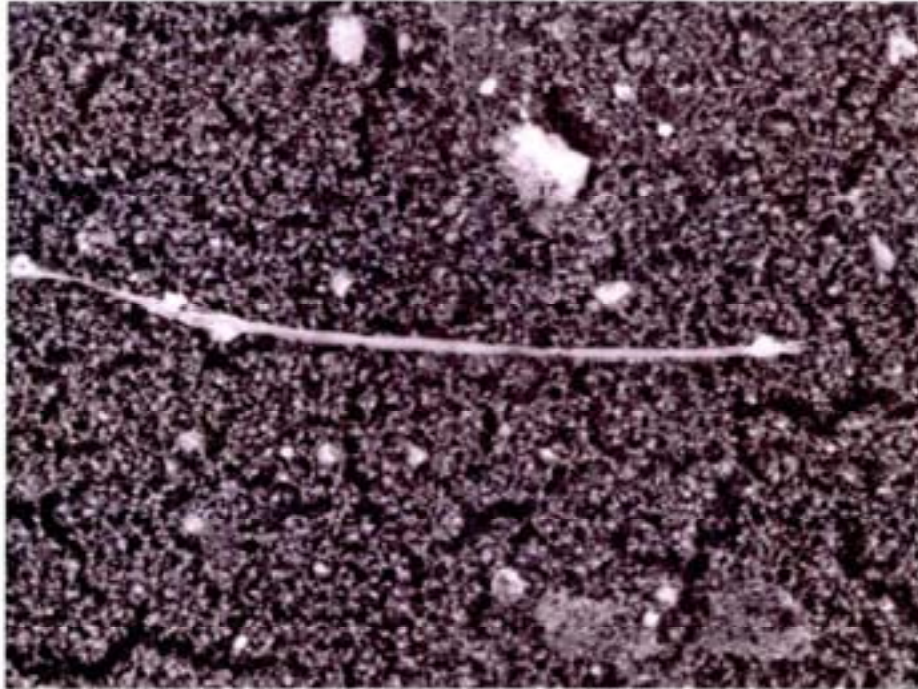


Filter No. A54, Fibre found with no crystalline structure, approximately 50 µm in length and 3 µm in diameter. EDAX spectrum shown.

Untitled:1

Label A: A54-02

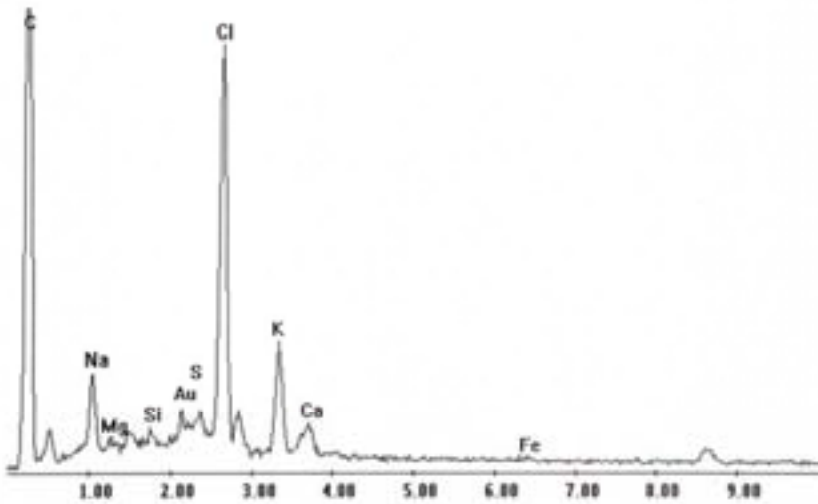




Filter No. A51, Fibre found with no crystalline structure, approximately 80 µm in length and 2.5 µm in diameter. EDAX spectrum shown

Untitled:2

Label A: A51-01

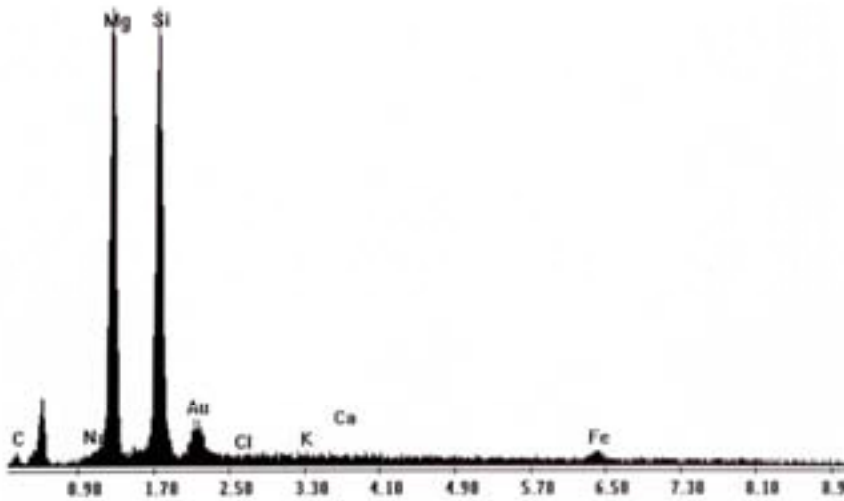


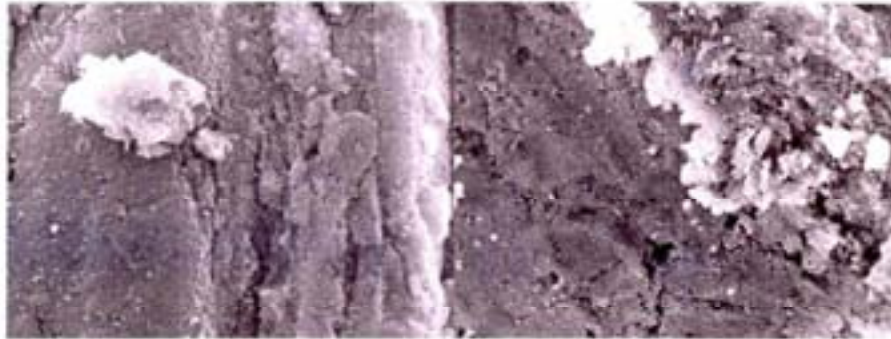


Reference sample of heat affected chrysotile (approx. 800 °C). EDAX spectrum shown.

Untitled:1

Label A: heat affected Chrysotile





Filter No. A38 & A48, redeposited particulate at 873x magnification



Filter No. A54, Overall view of filter surface area shown at approximately 260x magnification.

<sup>1</sup>Scale Bars

<sup>1</sup> Note: Some scale bars are missing from micrographs due to instrument software failure and using graphics conversion programs to recover image files.

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

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**Appendix 8: Respirable Fibre Concentration Calculations**

## A8.0 Introduction

The respirable fibre concentration associated with the test as measured by the filters located in the smoke cloud near the roof is estimated as follows:

Total air sampled by the 6 functioning filters from the start of the fire = 2,826 L, however due to the lesser length of burning and the presence of the roof vents, the smoke at the roof level only existed for approximately 1/3 of the total sampling time. To allow for this, we need to multiply the total number of detected fibres by 3.

Only 1 respirable fibre was detected.

Therefore, respirable fibre concentration is  $\frac{3 \times 1}{2826} \approx 1 \times 10^{-3} \text{ fibres / litre} = 1 \times 10^{-6} \text{ fibres / ml}$ .

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**Appendix 9: Large-Scale Fire Test, Floor Level Filter Analysis**

## A9.0 Introduction

The results of the eight ground level filters used during the large-scale fire test are presented in Table A9.0. The results shown are for the first 25 minutes of the test, after which spalling of the A/C sheeting had ceased.

**Table A9.0: Filter Analysis after First 25 minutes of Large-Scale Test**

Filter Id.	Filter Location	Average Flow (ml)	Fibres/Field	Reportable Concentration (fibres/ml)
#D134	North, 10m from test rig	2000	1/100	<0.03
#C23	North-east, 14m from test rig	2000	0/100	<0.03
#1035	East, 12m from test rig	2000	0/100	<0.03
#F002	South-east, 13m from test rig	2000	0/100	<0.03
#192	South, 11m from test rig	2000	1/100	<0.03
#D147	South-west, 15m from test rig	2000	0/100	<0.03
#C122	West, 10m from test rig	2000	0/100	<0.03
#E061	South-west, 12m from test rig	2000	0/100	<0.03

The above table illustrates that the number of fibres found were less than the detection limit of the method.

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**Appendix 10: Relevance of Large-Scale Test to Realistic Situations**

### A10.1 Aspects of Plume Modelling and Fires

Oxygen is necessary for combustion and it is known that each kilogram of oxygen consumed in a fire will release approximately 12.5MJ of energy. This fact is the basis of fire calorimetry. Given that the oxygen concentration of air is 21% by mass (i.e. 1 kg of air has approximately 0.21kg of oxygen) it follows that the amount of air that must be involved in combustion is

$\frac{\dot{Q}}{12.5 \times 0.21} \approx 0.4 \dot{Q} \text{ kg/sec}$ . Note:  $\dot{Q}$  refers to the magnitude of the fire. However, this amount of air is relatively small compared with that entrained into the plume. For example, in the fire test, a 10.5MW fire burning at this rate for 15 minutes would consume  $0.4 \times 10.5 \times 15 \times 60 = 3,780 \text{ kg}$  of air or  $3,150 \text{ m}^3$  of air. This needs to be compared with the estimated  $75,000 \text{ m}^3$  of air entrained into the plume.

One of the common plume equations due to Zukoski's equation [Ref A10.1] is given by:

$$\dot{m}_{air} = 0076 \times (\dot{Q}_{conv})^{\frac{1}{3}} \times z^{\frac{5}{3}} \quad [10.1]$$

where  $z$  is the height above the fire origin (in metres) and  $\dot{Q}_{conv}$  is the convective component of the HRR in kW. Clearly, there must be a limit to  $z$  since an infinite height will give an infinite mass entrainment rate. This cannot be the case.

If we consider a localised fire within a very large and very tall space, it should be clear that the mass of air entrained within the enclosure cannot be any different to that which would be entrained if the fire occurred in the open under still air conditions. As noted above, it is apparent that the length over which air entrainment occurs is not infinite but has a finite maximum value. This can be taken as being reasonably represented by the plume height which is considerably greater than the visible flame height. Thus  $z$  in the above air entrainment equation should be taken for the situation within a tall building as being the lesser of the height to the underside of the smoke layer or the plume height for the fire, assuming it is in a very tall space.

If it is assumed that the plume height is directly proportional to the flame height (but much greater), then it can be inferred that the plume height is a direct function of

$$(\dot{Q}_{conv})^{0.4} \quad [10.2]$$

where this is the correlation between the flame height and the convective component of the HRR [Ref A10.2]. Substituting this into Equation 10.1 suggests that the maximum entrainment rate is directly proportional to  $\dot{Q}_{conv}$ . This, in turn, is directly proportional to  $\dot{Q}$  (HRR). This means that the mass of air entrained is directly proportional to the HRR of the fire for a fire in the open or within a tall space.

### A10.2 Aspects of the Fire Test

For the test situation, Equation [10.1] has been solved iteratively given the HRR versus time relationship allowing for venting of smoke at the roof level. It has been assumed that smoke is vented from the vents according to Hinkley's equation for the mass rate of flow through the vents. As can be seen, this is a function of smoke temperature ( $T_s$ ), ambient temperature ( $T_a$ ), height of enclosure ( $H$ ), height to the smoke layer ( $Z_i$ ), the discharge coefficient ( $C_d$ ), ambient air density ( $\rho_a$ ) and the area of opening ( $A_o=A_i$ ):

$$\dot{m}_o = \frac{C_d A_o \rho_a [2g(h-z_i)(T_s - T_a)T_a]^{1/2}}{T_s^{1/2} [T_s + (A_o/A_i)^2 T_a]^{1/2}} \quad [10.3]$$

This calculation has been done considering that the plume height is a function of  $(\dot{Q}_{conv})^{0.4}$  and by trialling various maximum plume heights to get agreement with the observed level of smoke within the building during the test. It was found that an effective maximum plume height of 7.5m (much greater than the observed flame height) was required to give agreement with the observations. It should be noted that this plume height is much less than the height of the building. It was only in the latter stages of burning that the smoke layer height drops below the maximum plume height.

### References

- A10.1 The SFPE Handbook of Fire Protection Engineering, Society of Fire Protection Engineers, 2<sup>nd</sup> edn, 1995.
- A10.2 Drysdale, D., "An Introduction to Fire Dynamics", John Wiley and Sons, 2<sup>nd</sup> edn, 1999.

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

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**Appendix 11: Relationship between Respirable Fibres and Smoke Particle Size**

The movement of smoke particles in air is undertaken by considering that smoke particles are spherical in shape and have a density equal to that of water (1,000kg/m<sup>3</sup>). The diameter clearly relates to the mass of the particle and will influence the speed that a particle will fall in still air when it has reached its terminal speed. This is termed the settling velocity. Of course, smoke particles are not spherical in shape and it is necessary to determine the equivalent spherical diameter.

ALOFT, the program that is being used for dispersion modelling, tracks the movement of smoke particles having various spherical diameters. This program has been used to track the movement of respirable asbestos fibres by considering them to be equivalent smoke particles. To do this it is necessary to determine the range of spherical diameters that are applicable to respirable asbestos fibres. Similar to smoke particles, respirable fibres are not spherical.

Carpenter and Wilson [A11.1] look at the characteristics of fibres generally in relation to inhalation toxicity. They present a review of the scientific literature. The movement of fibres in air is a key issue and this is affected by the aerodynamic diameter. The following equation is given with respect to treating a long thin fibre as an equivalent sphere as far as its aerodynamic performance is concerned. This expression is:

$$d_{eq} = d_{act} \times 66 \times \left( \frac{\beta}{2 + 4\beta} \right)^{2.2} \quad [11.1]$$

where  $\beta$  is the ratio of length of fibre to diameter,  $d_{act}$

The authors recognise that long thin fibres are more respirable. In this regard, they note that amphibole asbestos (such as tremolite), which exists in rods [A11.2] rather than coiled sheets for chrysotile, is capable of splitting to form thinner fibres of the same length – thus creating even more respirable fibres. Aspect ratios of more than 100:1 are possible with this form of fibre. According to Schneider et al [A11.3] asbestos particles that must be considered to be respirable are those with an aspect ratio greater than 3 and a length greater than 5 $\mu$ m and a width less than 3 $\mu$ m.

The free fall velocity of a particle is described by Stokes' Law which describes the free fall velocity of particles in a fluid, namely:

$$\omega = d^2 g \frac{(\rho_s - \rho)}{18\mu} \quad [11.2]$$

where  $\mu$  is a viscosity term,  $d$  is the diameter,  $\rho_s$  is the density of the particle and  $\rho$  is the density of the fluid

It can be seen that the fall velocity (which is the key parameter relating to movement of a particle or fibre) is dependent on a number of parameters including the density of the particle, the diameter of the sphere and the density of the fluid. The density of air is 1.2 kg/m<sup>3</sup>, which is negligible compared with that of a standard smoke particle (1,000 kg/m<sup>3</sup>) or an asbestos fibre (3,000 kg/m<sup>3</sup>) [A11.4].

Using Equation [11.1] and allowing for the difference in density between smoke particles and asbestos fibres, it is possible to determine the equivalent standard particle diameters that are associated with a range of respirable asbestos fibres. This is given by 1.73 $d_{eq}$  where  $d_{eq}$  is determined from Equation [11.1].

The results are tabulated below for a range of hypothetical respirable asbestos fibres.

Table A11.0: Equivalent Standard Particle Diameter

Fibre geometry (microns)	Equivalent Dia. (microns)
2.9 x 9 (dia. by length)	11.3
2.9 x 18	13.2
2.9 x 36	14.4
2.9 x 72	15
2.9 x 144	15.3
2.9 x 300	15.5
1.5 x 150	8.0
1.5 x 200	8.1
2 x 6	7.7
1 x 6	4.5
0.1 x 6	0.5
2 x 12	9.1
1 x 12	4.9
0.1 x 12	1.1
2 x 24	9.9
1 x 24	5.2
0.25 x 24	1.34
2 x 48	10.3
1 x 48	5.3
0.25 x 48	1.3
1 x 100	5.3
0.5 x 100	2.7

It can be seen that the equivalent standard particle diameter varies between approximately 1 and 15 microns and the behaviour of this range of particles needs to be considered. It will be noted that the multiplier on diameter is approximately 5 for longer fibres.

It is therefore, concluded that modelling the dispersion of smoke particles having diameters close to 1 – 15 microns will give a good feel for the likely distribution of respirable asbestos fibres away from the fire site.

#### References

- A11.1 Carpenter, R. L. and Wilson, C. L., "The Inhalation Toxicity of Glass Fibers – A Review of the Scientific Literature", Naval Health Research Centre Detachment (Technology), Report No. TOXDET 99-7, 1999.
- A11.2 Schneider et al, "Development of a method for determination of low content of asbestos fibres in bulk material", Analyst, vol 123, pp 1393 – 1400, 1998.
- A11.3 Bernstein, D.M., "Understanding Chrysolite Asbestos: A New Perspective Based on Current Data", IOHA 2005 Symposium, Pilanesberg, paper J3.
- A11.4 Construction Materials Reference Book, Butterworth Heinemann, 1992, Chapter 9 – Asbestos, p 9/1-9/17.

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

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## **Appendix 12: Conversion Factor Calculations for Respirable Fibre Concentrations**

### A12.1 Number of fibres released

Based on the measured concentration of fibres in the fire test ( $1 \times 10^{-3}$  fibres/litre) and the fact that an estimated  $75,000\text{m}^3$  of air was entrained into the smoke cloud, it follows that a total of  $75,000\text{m}^3 \times 1,000 \text{ litres} \times 1 \times 10^{-3} = 75,000$  fibres released during the test.

### A12.2 Mass of fibres released

Assume that all fibres have a diameter of 10 micron (PM10) and a density of  $1,000\text{kg}/\text{m}^3$ .

The mass is given by the product of the volume and the density:

$$\frac{4}{3} \pi (5 \times 10^{-6})^3 \text{m}^3 \times 1000 \text{kg} / \text{m}^3 \times 1000 \text{g} / \text{kg} = 5.234 \times 10^{-10} \text{g}$$

Therefore, the total mass released is  $75,000 \times 5.234 \times 10^{-10} = 3.92 \times 10^{-5} \text{g}$

### A12.3 Calculation of Conversion Factors $r_1$ , $r_2$ and $C_p$

In the case of the test fire, the total mass of fuel consumed during the fire was 837kg. If it is assumed that 90% of this was consumed during the main burning stage, then the yield for the test with respect to respirable asbestos at the fire source is  $3.92 \times 10^{-5} / (0.9 \times 837) \text{g}/\text{kg}$  or  $5.3 \times 10^{-8} \text{g}/\text{kg}$  ( $=r_1$ ). This needs to be compared with the PM10 particle yield of  $130\text{g}/\text{kg}$  used for the ALOFT analysis.

As far as  $r_2$  is concerned, the burning rate associated with the test (in  $\text{kg}/\text{m}^2/\text{s}$ ) is conservatively overestimated as  $\frac{0.9 \times 837}{20 \times 60 \times 16} = 0.04 \text{kg} / \text{m}^2 / \text{s}$  which is almost three times greater

than that assumed in the ALOFT analysis. Nevertheless, this value will give higher predictions of respirable fibres and is seen as being an upper limit for real fires. This value has therefore been adopted.

The associated value for  $C_p$  for respirable fibres is given by  $r_1 \times r_2 = 2.12 \times 10^{-9} \text{g}/\text{m}^2/\text{s}$  which can be compared with  $1.95 \text{g}/\text{m}^2/\text{s}$  associated with PM10 particles for the ALOFT analysis.

### A12.4 Conversion of PM10 Concentrations to fibre concentration/ml of Respirable Fibres

The ALOFT concentrations for PM10 can be used to infer the respirable fibre concentrations in micrograms/ $\text{m}^3$  of air by multiplying the calculated concentrations (CC) by  $2.12 \times 10^{-9} / 1.95$ . Let the latter ratio be R. However, it is necessary to determine the resulting concentration of respirable fibres in fibres/ml.

This is done as follows:

$$\text{The concentration of respirable fibres at a point} = \text{CC} \times R \times 10^{-6} \text{g}/\text{m}^3$$

By dividing by the mass of a 10 micron particle (as originally assumed for respirable fibres) this becomes  $\text{CC} \times R \times 10^{-6} / 5.234 \times 10^{-10} \text{ fibres}/\text{m}^3$  which is converted to respirable fibres per ml by multiplying by  $10^{-6}$ .

Therefore the conversion factor to multiply the ALOFT concentration (CC) to get respirable fibres per ml is:

$$= 2.1 \times 10^{-12}$$