# The Investigation of Potential Wood Smoke Impact on Air Quality in a Melbourne Suburb

Paul Torre, Chris Bydder, Eamonn King, Bert Zerbst and David Cohen[1]
EPA VICTORIA, Centre for Environmental Sciences, Ernest Jones Drive, Macleod, Victoria, 3085,
ANSTO, PMB1, Menai, NSW 2234[1]
paul.torre@epa.vic.gov.au

## Abstract

An air-monitoring program was conducted from April 2005 to April 2006 to measure the impact of wood smoke in a Melbourne residential suburb where there was extensive use of solid fuel heaters. A number of air pollutants including fine and course particles, benzene, toluene, xylene, polycyclic aromatic hydrocarbons, formaldehyde, carbon monoxide and oxides of nitrogen were monitored to determine the impact on air quality. Air quality was assessed by comparing the monitoring results to state air quality policy objectives and national advisory reporting standards. Multi-elemental analysis by ion beam analysis was also undertaken to characterise the fine particles collected. The study found the main impact on air quality was caused by coarse particles from surrounding local soil and fine particles most likely from a combination of wood smoke and a build up of general motor vehicle emissions in the urban area. Elevated fine particle levels were measured on nine days during June. The highest fine particle concentration measured was 43 µg/m$^3$.

*Keywords*: PM $_{2.5}$, $PM_{10}$ aerosols, wood smoke, fine particle characterisation, benzo(α)pyrene, benzene, toluene, xylene, formaldehyde,.

## 1. Introduction

The Victorian Emissions Inventory 2002 estimates that the most significant source of $PM_{10}$ (particles less than 10 µm) pollutants for the metropolitan area of Melbourne in winter is solid fuel combustion (EPA Victoria 2000a). Smoke from solid fuel heaters such as wood heaters and wood stoves produces odour and reduces visibility. Inhalation of smoke pollutants also has the potential to cause health-related problems, particularly for sensitive groups such as the very young or old, and people with conditions such as cardiovascular or respiratory diseases such as asthma (Pope 2000, EPA Victoria 2000b).

Wood smoke contains a number of pollutants including particles with diameters less than 10µm ($PM_{10}$), fine particles with diameters less than 2.5µm ($PM_{2.5}$), carbon monoxide (CO), nitrogen dioxide ($NO_2$), volatile organic compounds (VOCs) such as benzene, toluene, xylene and formaldehyde and polycyclic aromatic hydrocarbons (PAHs) (Environment Australia 2002).

In order to gain a better understanding of the impact of wood smoke in Melbourne, a study was conducted to measure the impact of smoke on air quality in a Melbourne residential area where the use of solid fuel heaters is common.

This study involved a 12-month study in Eltham a suburb in the north east of Melbourne.

## 2. Methodology

### 2.1. Site Selection

The Victorian Emissions Inventory (2002) was used to estimate the areas with the highest particle concentrations due to wood smoke in Melbourne. The areas were selected from spatial emission grid cells with the dimensions of 0.01 x 0.01º, or approximately 1 km × 1 km.

Although emissions Inventory data does not take into account dispersion of pollutants from weather and local topographical features it does give an indication of where the highest $PM_{10}$ concentrations are most likely to occur.

The suburb of Eltham located approximately 25km north east of the Central Business District (CBD) in Melbourne, in the Shire of Nillumbik was chosen for monitoring. This suburb was chosen because the Air Emissions Inventory for the Melbourne metropolitan area indicated that three (including the highest) of the five highest areas of $PM_{10}$ emissions from wood combustion were located in the Nillumbik Shire. The other two areas were located in the Yarra Ranges Shire

approximately 30km to the east of Melbourne's CBD.

The likelihood of Eltham being impacted by wood smoke was also supported by visual observation of the number of chimneys in the area and information from local residents. Further evidence of visible smoke in Eltham was confirmed from observations from local residents and people working in the area.

Air monitoring was conducted in the playground at the East Eltham Primary School. This site is located in the highest grid cell in the Eltham area identified by the Air Emissions Inventory. There is no major industrial or motor vehicle source within 500 metres of the monitoring site. The site was also considered to be representative of the local area and there is potential for significant population exposure to smoke at this location as it is densely populated and children, a sensitive population group, spend significant time there during the day.

## 2.2. Sampling and Analysis

Sampling was conducted from 20 April 2005 to the 19 April 2006.

### *2.2.1. $PM_{10}$ & $PM_{2.5}$*

PM10 was continuously monitored by a Tapered Elemental Oscillating Microbalance (TEOM) by Australian Standard (AS) 35080.98. The 24-hour average concentrations were adjusted according to the National Environment Protection (Ambient Air Quality) Measure Technical Paper No.10. Daily PM2.5 monitoring was undertaken using the Partisol® Sequential Sampler.

### *2.2.2. $PM_{2.5}$ Speciation*

Sampling was conducted from 20 April 2005 to 15 September 2005 (N=100) using the aerosol sampling program fine sampler (ASP) supplied by the Australian Nuclear Science and Technology Organisation (ANSTO), (Cohen et al 1996). The ASP is limited to two automatic sample runs, therefore to maximise the number of samples, a three day cycle was employed. 24-hour samples were collected on each of the first two successive days of the cycle. The filters were collected and new filters installed on the third day of the cycle.

Elemental species (H, Na, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Br, Pb and black carbon (BC)) were measured) using ion beam analysis techniques (Cohen et al 2002a, 2002b).

### *2.2.3. B(α)P, benzene, toluene, xylene and formaldehyde*

Sampling was conducted one in three days from April 2005 to September 2005 and December to the start of March 2006. The sampling regime was designed to meet the sampling requirements in the National Environment Protection Measure (Air Toxics) [Air Toxics NEPM] for seasonal pollutants such as wood smoke.

Benzo(α)pyrene samples (N=64) were collected onto quartz filter papers with a back-up cartridge of polyurethane foam. Samples were analysed according to USEPA Method TO-13A.

Benzene, toluene and xylene samples (N=65) were collected in stainless steel fused silica-coated canisters using a Graseby Automated Volatile Organic Canister Sampler (AVOCS) and analysed according to USEPA method TO-15.

Formaldehyde Samples were collected on DNPH adsorbent tubes and analysed according to USEPA Method TO-11A.

### *2.2.4. CO & $NO_2$*

Monitoring was conducted continuously by Non Dispersive Infrared and Chemiluminescence techniques using AS3580.7.1 and AS3580.5.1 for carbon monoxide and nitrogen dioxide, respectively.

### *2.3 Air Quality Impact Assessment*

Maximum and average concentrations over the 12-month monitoring period were compared against state and national air quality objectives. $PM_{10}$, carbon monoxide and nitrogen dioxide levels were compared against Victoria's environmental quality objectives and goals in the State Environment Protection Policy (SEPP). $PM_{2.5}$ levels were compared against the National Environment Protection Council advisory reporting standard [NEP(AAQ)M].

Benzene, benzo(α)pyrene, formaldehyde, toluene and xylene levels were compared against the Monitoring Investigation Level (MIL) specified in the Air Toxics NEPM.

The objectives, goals and investigation levels are set to protect environmental amenity and human health.

# 3. Results & Discussion

## 3.1 Air Quality Impact Assessment

### *3.1.1 $PM_{10}$ & $PM_{2.5}$*

The 24-hour average $PM_{10}$ and $PM_{2.5}$ levels measured during the study period are shown in Figure 1. $PM_{10}$ did not meet the air quality objective on a total of seven days. Elevated levels occurred on one day in April 2005, five days during May 2005 and one day in February 2006. $PM_{2.5}$ levels were measured above the $PM_{2.5}$ advisory reporting standard on nine occasions during June 2005.

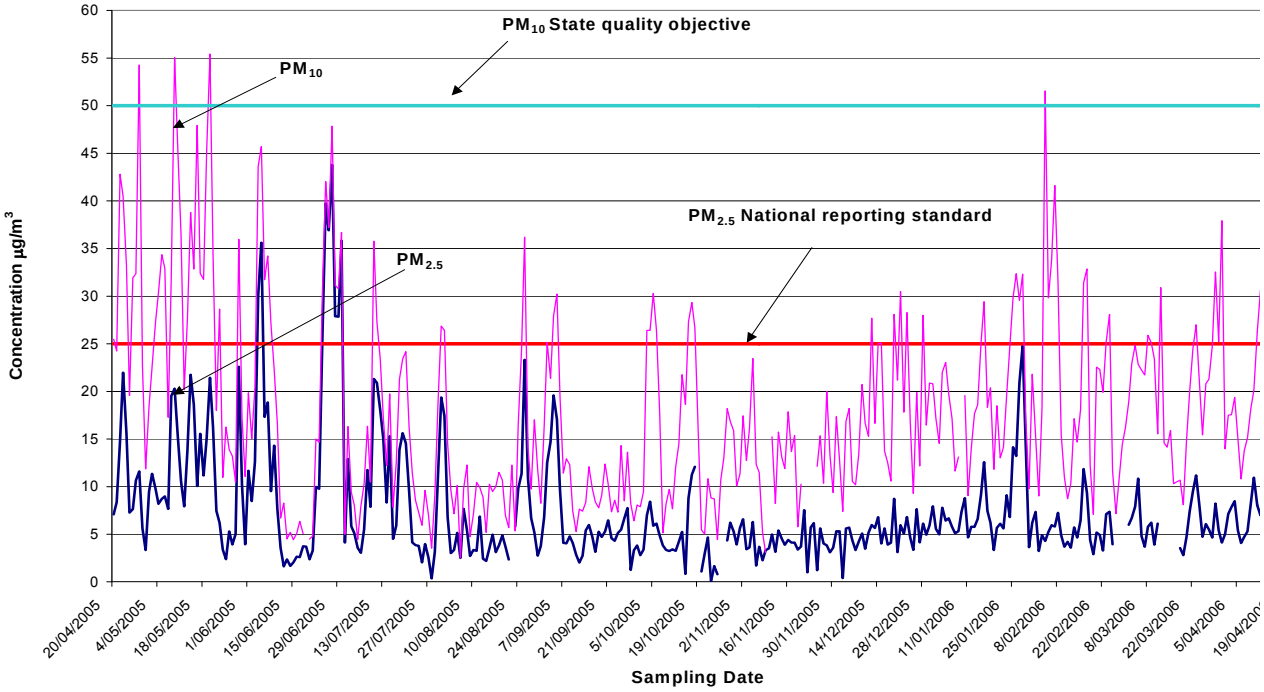


Figure 1. Comparison of 24-hour $PM_{10}$ and $PM_{2.5}$ levels

### *3.1.2 B(α)P, benzene, toluene, xylene and formaldehyde*

The highest 24-hour concentration of B(α)P measured was 2.6 ng/m$^3$. The annual average was 0.2 ng/m$^3$, which was below the Air Toxics NEPM monitoring investigation level (MIL) of 0.3 ng/m$^3$.

The applicable annual average and daily maximum MILs were not exceeded at any time for benzene, toluene, xylene and formaldehyde. A summary of results is listed in Table 1.

| Species | Annual Avg (ppb) | Annual MIL (ppb) | Max 24-Hour Avg (ppb) | 24-hr MIL (ppb) |
|---|---|---|---|---|
| Benzene | 0.5 | 3 | 1.7 | NA |
| Toluene | 19 | 1000 | 49 | 100 |
| Xylene | 7 | 250 | 20 | 200 |
| Formaldehyde | 2.4 | NA | 28 | 40 |

Table 1 Summary of VOC concentrations
NA = Not Applicable

### *3.1.3 CO & $NO_2$*

The highest hourly NO2 concentration (42ppb) and highest eight-hour average concentration measured for CO (2.6ppm) were well below Victoria's policy objectives (SEPP) of 120 ppb for NO2 and 9.0 ppm for CO.

## 3.2 Sources of high $PM_{10}$ & $PM_{2.5}$

### *3.2.1 $PM_{10}$*

The likely cause of the high 24-hour $PM_{10}$ levels was dust from the school playground. Hourly $PM_{10}$ levels measured during the peak events are shown in Figure 2. The high peaks occurred at 11:00 or 13:00 (illustrated by arrows) coinciding with school recess times. This conclusion was also supported by visual observations at the site. These peak events ceased after rain and once mulch was placed over the playground. The elevated level measured in February 2006 was due to soil and dust from excavations being conducted in the playground near the monitoring site.

### *3.2.2 $PM_{2.5}$*

#### *3.2.2.1 $PM_{2.5}$ speciation*

The average mass concentrations of measured elements and elemental carbon commonly referred to as black carbon (BC) are listed in Table 2. The large standard deviations (STD) signify environmental variation rather than experimental errror. Experimental measurement errors ranged from +7% to +15%.

| Species | Average (ng/m$^3$) | STD | Max | Min |
|---|---|---|---|---|
| H | 545 | 593 | 2629 | 41 |
| Na | 226 | 355 | 2054 | 0 |
| Al | 30 | 47 | 284 | 0 |
| Si | 98 | 139 | 869 | 7.6 |
| P | 2 | 2 | 8.1 | 0 |
| S | 274 | 230 | 1147 | 42 |
| Cl | 346 | 390 | 2280 | 0.5 |
| K | 145 | 152 | 722 | 15 |
| Ca | 18 | 14 | 74 | 0 |
| TI | 3.7 | 4.7 | 28 | 0 |
| V | 0.6 | 0.8 | 4.5 | 0 |
| Cr | 0.5 | 0.5 | 2.0 | 0 |
| Mn | 1.4 | 1.3 | 7.7 | 0 |
| Fe | 49 | 52 | 318 | 4.7 |
| Co | 0.4 | 0.6 | 3.8 | 0 |
| Ni | 0.3 | 0.4 | 2.6 | 0 |
| Cu | 1.7 | 1.6 | 7.1 | 0 |
| Zn | 12 | 13 | 78 | 0.5 |
| Br | 4.2 | 3.7 | 17 | 0 |
| Pb | 9.5 | 9.3 | 42 | 0 |
| BC | 1271 | 786 | 3870 | 317 |

Table 2. Average elemental mass concentration

The average composition for the $PM_{2.5}$ particles collected is shown in Figure 2. Soil was estimated from the oxides of Al, Si, Ti, Ca and Fe, salt was assumed to be sea salt comprised mainly of NaCl, sulphate assumed to be fully neutralised and occurring as $(NH_4)_2SO_4$, organics component was estimated from H,C, and O results. The methodology used for estimating the average composition is detailed in Cohen (1998,1999) and Chan (1997). The fine particles were considered to be composed of mainly five components, soil (crustal matter), sea salt, black carbon, ammonium sulphate (sulphate) and organic matter.

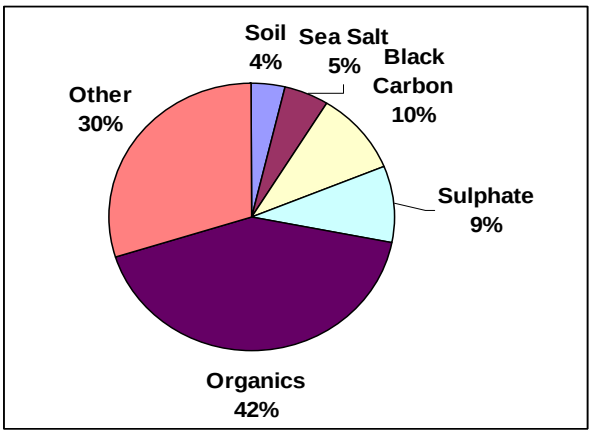


Figure 2. Average Particle Compositions

The comparison of the reconstructed mass (RCM) against the gravimetric mass is shown in Figure 3. There is a strong correlation between the two with 70% of particles being accounted for in the chemical composition estimate. This is excellent mass closure for these types of studies. The mass not accounted for is believed to be from water vapour depending on the humidity, trace elements and nitrates evaporating or not collected on the Teflon filters.

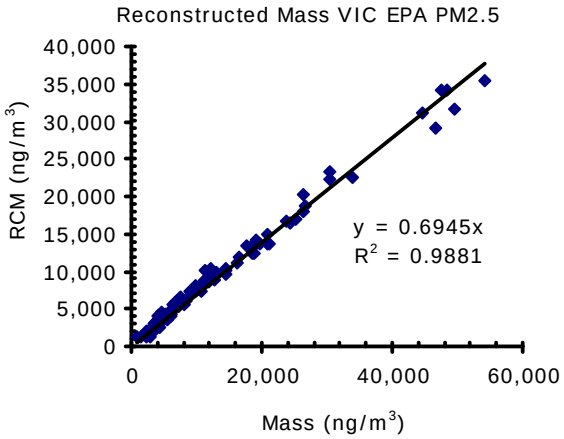


Figure 3. RCM versus gravimetric mass

Soil and black carbon were similar and sea salt slightly lower when compared to monitoring conducted in other similar areas of Australia by ANSTO (ANSTO). While the estimates for ammonium sulphate and organic matter was much lower and much higher (factor of 2) respectively.

The correlation of BC versus K is shown in Figure 4. On average particles from industrial and vehicle combustion sources have lower K and BC proportions. Samples from wood smoke related sources have higher K and BC proportions. Samples that are most likely to be from wood combustion are circled in Figure 4. This indicates wood smoke is one of the sources of the $PM_{2.5}$ levels measured at the site.

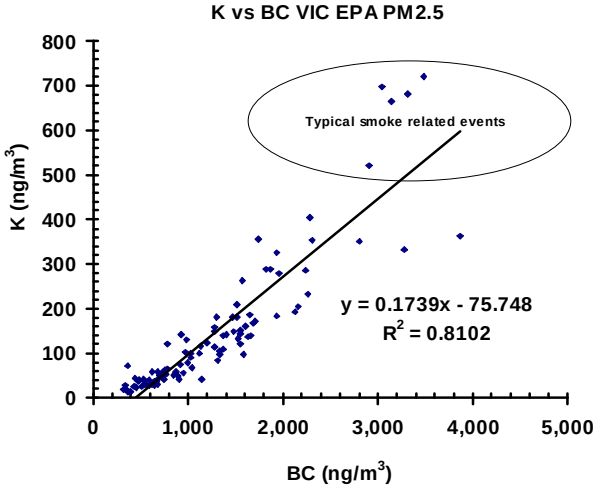


Figure 4. K and BC comparison

In an attempt to estimate the actual source contributions, both Chemical Mass balance (CMB) with principal component analysis and Positive Matrix Factorisation (PMF) receptor modelling was undertaken. Cohen (1998) discusses the details of the CMB technique; the use of PMF in estimating $PM_{2.5}$ sources is discussed by Paatero (1994, 1997). Although CMB and PMF analysis was able to detect six types of sources, soil, sea salt, sulphate and three other black carbon combustion mixed sources. The number of samples and lack of seasonal variability did not enable either analysis to adequately distinguish the composition and relative contribution of motor vehicle emissions and wood smoke. It is recommended for future similar studies to have at least two years, preferably several years of data that includes summer and winter periods to enable the techniques of CMD and PMF to identify source composition and contribution.

*3.2.2.2 Combustion*

The proportion of $PM_{2.5}$ making up $PM_{10}$ on the nine elevated $PM_{2.5}$ days was higher than the average for the monitoring program. On average, the $PM_{10}$ particles consisted of 42% $PM_{2.5}$ compared to between 69% and 99% on the elevated days. The higher proportion of fine particles indicates a predominant combustion source during these days than commonly measured at the site.

The Highest hourly $PM_{10}$ and CO levels on the elevated days were measured at night between 7pm and 11 pm when the average temperature ranged from 6 to 10ºC. This is the most likely time when domestic wood combustion heaters would be used.

Concentrations of B(α)P, $PM_{10}$ and $PM_{2.5}$ are compared in Figure 4. B(α)P was only measured in late autumn and winter 2005 coinciding with a high $PM_{2.5}$ to $PM_{10}$ ratio. These results indicate a seasonal source of combustion products during the cooler months.

*3.2.2.3 Comparison to other sites*

EPA Victoria regularly monitors for $PM_{2.5}$ levels, every three days at fixed Melbourne monitoring sites in an inner north east suburb of Alphington and inner western suburb of Footscray located approximately 10km and 25km, respectively from Eltham. Table 3 lists the elevated levels at each site. Apart from one day (04/06/05) when Eltham levels are markedly higher than the other two sites, levels at Eltham are comparable or lower than the other two sites. The comparative level of $PM_{2.5}$ at sites over such a large area suggests an area wide source such as motor vehicle emissions and bush fires.

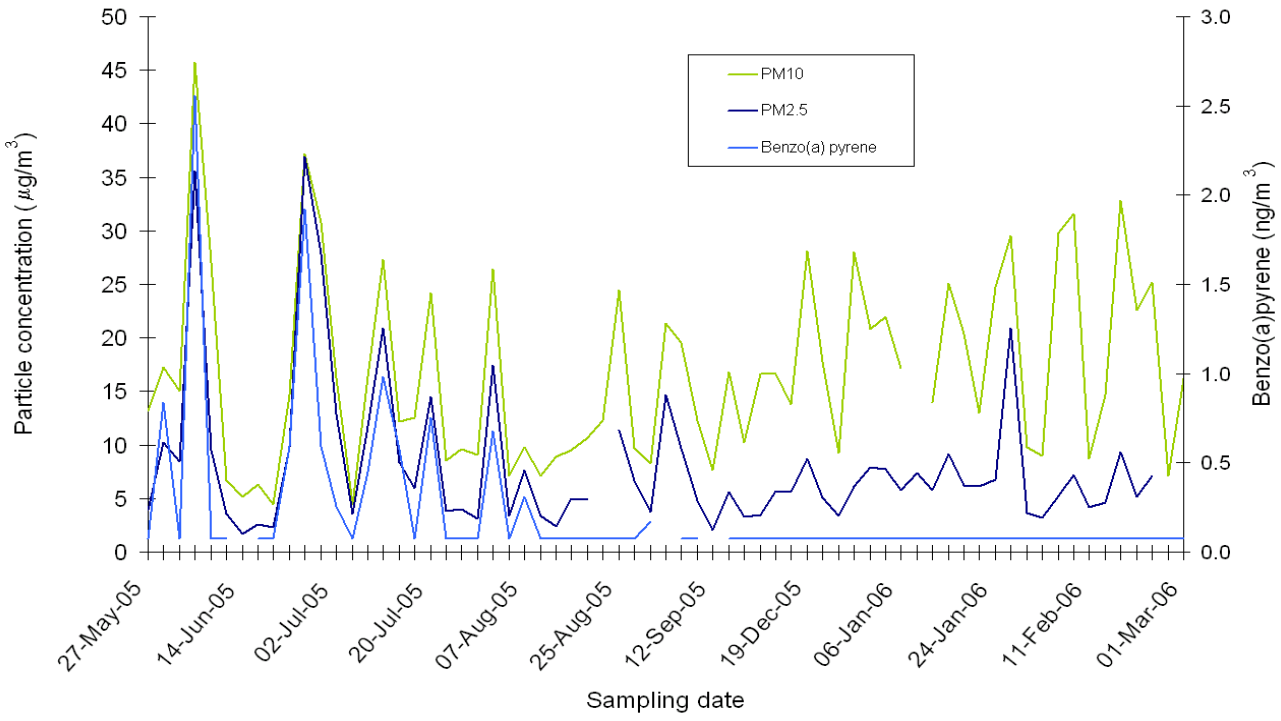


Figure 5. Comparison of 24 hourly B(α)P, $PM_{2.5}$ and $PM_{10}$ levels

| Date | Eltham | Alpington | Footscray |
|---|---|---|---|
| 23/04/05 | 22.0 | 26.8 | 29.4 |
| 4/06/05 | 30.0 | 19.8 | 11.0 |
| 5/06/05 | 35.6 | NS | NS |
| 24/06/05 | 25.3 | NS | NS |
| 25/06/05 | 39.8 | 37.4 | 19.7 |
| 26/06/05 | 36.9 | NS | NS |
| 27/06/05 | 43.8 | NS | NS |
| 28/06/05 | 27.9 | 30.7 | 31.8 |
| 29/06/05 | 27.8 | NS | NS |
| 30/06/05 | 35.6 | NS | NS |
| 27/01/06 | 20.9 | 24.6 | 27.4 |

Table 3. Comparison of elevated 24 hour $PM_{2.5}$ levels NS=No sample

Since there is no major industrial or motor vehicle source within 500 metres of the monitoring site and houses with wood heaters surround the site, the most likely source of combustion products contributing to the elevated levels in Eltham is a combination of wood smoke and a build up of general motor vehicle emissions in the urban area.

## 4. Conclusion

Air quality monitoring at Eltham for one year indicated that $PM_{10}$ did not meet Victoria's state air quality objectives on a total of seven days and fine particles levels did not meet the National daily $PM_{2.5}$ advisory reporting standard on nine occasions during June.

The elevated fine particle $PM_{2.5}$ levels were caused primarily by combustion sources most likely from a combination of wood smoke and motor vehicle emissions while local soil sources contributed to the elevated $PM_{10}$ levels.

Carbon monoxide, nitrogen dioxide, benzene, benzo(α)pyrene, formaldehyde, toluene and xylene met the state air quality objectives and national monitoring investigation level, respectively.

## Acknowledgments

EPA Victoria would like to acknowledge the assistance of Eltham East Primary School for allowing the location of the mobile air monitoring station in the school's playground and D. Cohen and his team at ANSTO for their particle speciation work.

## References

Air Toxics NEPM, National Environment Protection ((Air Toxics) Measure April 2004, Canberra, National Environmental Protection Council publication, www.ephc.gov.au

ANSTO, www.ansto.gov.au/nugeo/iba/, Newsletter & Summary Sheets.

Chan Y.C., Simpson R.W., Mctainsh G.H., Vowles P.D., Cohen D.D., & Baily G.M. 1997, 'Characterisation of chemical species in $PM_{2.5}$ and $PM_{10}$ aerosols in Brisbane, Australia', *Atmospheric Environment* **31,** 3773-3785.

Cohen, D. D., Bailey, G. M., Kondepudi, R. (1996) 'Elemental Analysis by PIXE and other IBA Techniques Fingerprinting of Atmospheric Fine Particle Pollution', *Nucl. Instr. Meth*., B, **109-110**, 218-226.

Cohen, D. D., (1998), 'Characterisation of atmospheric fine particles using IBA Tecnhiques,' *Nucl. Instr. Meth*., B, **136-138**, 14-22.

Cohen, D. D., Stelcer, E., Garton, D. (2002a) Ion beam methods to determine trace heavy metals concentrations and sources in urban airsheds. Nucl. Instr. Meth., B, 190, 446-470.

Cohen, D. D., Siegele, R., Orlic, I., Stelcer, E. (2002b) Long-term accuracy and precision of PIXE and PIGE measurements for thin and thick sample analyses. Nucl. Instr. Meth., B, 189, 81-85.

EPA VIC, (2000a) 'Draft Air Quality Improvement Plan: Port Phillip Region'; Victorian Environment Protection Authority, Melbourne, Victoria. Available at: http://www.epa.vic.gov.au/resource/

EPA Victoria (2000b), '*Melbourne Mortality Study Effects of Ambient Air Pollution in Melbourne 1991-1996'*; Victorian Environment Protection Authority, Melbourne, Victoria, www.epa.vic.gov.au/resource/.

Environment Australia March (2002), Canberra, 'Technical Report No 5 Emissions from domestic appliances,. www.environment.gov.au/atmosphere/airquality/publications/report4/references.html.

NEPM, Variation to the National Environment Protection (Ambient Air Quality) Measure for particles as PM 2.5, June 2003, Canberra, National Environmental Protection Council www.ephc.gov.au.

Paatero P., Tapper U. (1994) Environmetrics, **5,** 111.

Paatero P. (1997) Chemometrics and Intelligent Laboratory systems, **37,**23

Pope III C.A., (2000) 'Review: epidemiological basis for particulate air pollution health standards', *Aerosol Science and Technology*, **32**, 4-14.

SEPP, State Environment Protection Policy (Ambient air quality), Victoria Government Gazette No. S19, 9 Feb 1999 (amended Dec 2001), www.epa.vic.gov.au/resource/.