

## RESEARCH ARTICLE

# Fingerprint of Carcinogenic Semi-Volatile Organic Compounds (SVOCs) during Bonfire Night

Siwatt Pongpiachan

### Abstract

It is well known that increased incidences of lung, skin, and bladder cancers are associated with occupational exposure to PAHs. Animal studies show that certain PAHs also can affect the hematopoietic and immune systems and can produce reproductive, neurologic, and developmental effects. As a consequence, several studies have been attempted to investigate the fate of PAHs in atmospheric environment during the past decades. However, there is still a lack of information in regard to the atmospheric concentration of PAHs during the “Bon Fire Night”. In this study, twenty-three polycyclic aromatic hydrocarbons and twenty-eight aliphatics were identified and quantified in the PM<sub>10</sub> and vapour range in Birmingham (27<sup>th</sup> November 2001-19<sup>th</sup> January 2004). The measured concentrations of total particulate and vapour (P+V) PAHs were consistently higher at the BROS in both winter and summer. Arithmetic mean total (P+V) PAH concentrations were 51.04±47.62 ng m<sup>-3</sup> and 22.30±19.18 ng m<sup>-3</sup> at the Bristol Road Observatory Site (BROS) and Elms Road Observatory Site (EROS) respectively. In addition arithmetic mean total (P+V) B[a]P concentrations at the BROS were 0.47±0.39 ng m<sup>-3</sup> which exceeded the EPAQS air quality standard of 0.25 ng m<sup>-3</sup>. On the other hand, the arithmetic mean total (P+V) aliphatics were 81.80±69.58 ng m<sup>-3</sup> and 48.00±35.38 ng m<sup>-3</sup> at the BROS and EROS in that order. The lowest average of CPI and C<sub>max</sub> measured at the BROS supports the idea of traffic emissions being a principle source of SVOCs in an urban atmosphere. The annual trend of PAHs was investigated by using an independent t-test and one-way independent ANOVA analysis. Generally, there is no evidence of a significant decline of heavier MW PAHs from the two data sets, with only Ac, Fl, Ph, An, 2-MePh, 1+9-MePh, Fluo and B[b+j+k]F showing a statistically significant decline (p<0.05). A further attempt for statistical analysis had been conducted by dividing the data set into three groups (i.e. 2000, 2001-2002 and 2003-2004). For lighter MW compounds a significant level of decline was observed by using one-way independent ANOVA analysis. Since the annual mean of O<sub>3</sub> measured in Birmingham City Centre from 2001 to 2004 increased significantly (p<0.05), it may be possible to attribute the annual reduction of more volatile PAHs to the enhanced level of annual average O<sub>3</sub>. By contrast, the heavier MW PAHs measured at the BROS did not show any significant annual reduction, implying the difficulties of 5- and 6-ring PAHs to be subject to photochemical decomposition. The deviation of SVOCs profile measured at the EROS was visually confirmed during the “Bonfire Night” festival closest to the 6<sup>th</sup> November 2003. In this study, the atmospheric PAH concentrations were generally elevated on this day with concentrations of Fl, Ac, B[a]A, B[b+j+k]F, Ind and B[g,h,i]P being particularly high.

**Keywords:** PAHs - alkanes - cholestanes - hopanes - bonfire night

*Asian Pacific J Cancer Prev*, 14 (5), 3243-3254

### Introduction

PAHs are a class of very stable organic molecules made up of only carbon and hydrogen and contain two to eight fused aromatic rings. PAHs are formed during incomplete combustion of organic materials such as fossil fuels, coke and wood. These molecules were oriented horizontal to the surface, with each carbon having three neighboring atoms much like graphite. Epidemiological evidence suggests that human exposures to PAHs, especially B[a]P are high

risk factors for carcinogenic and mutagenic effects. There are hundreds of PAH compounds in the environment, but only 16 of them are included in the priority pollutants list of US EPA (EPA, 2003). Many PAHs have also been identified as cancer-inducing chemicals for animals and/or humans (IARC, 1983). In 1775, the British surgeon, Percival Pott, was the first to consider PAHs as toxic chemicals with the high incidence of scrotal cancer in chimney sweep apprentices (IARC, 1985). Occupational exposure of workers by inhalation of PAH-both volatile

*NIDA Center for Research and Development of Disaster Prevention and Management, School of Social and Environmental Development, National Institute of Development Administration (NIDA), Bangkok, Thailand \*For correspondence: pongpiajun@gmail.com*

and bound to respirable particulate matter- and by dermal contact with PAH-containing materials, occurs at high levels during coke production, coal gasification, and iron and steel founding. Coke oven workers have a 3- to 7- fold risk increase for developing lung cancer (IARC, 1984; 1987). For this reason, the monitoring of PAHs in environmental media is a reasonable approach to assess the risk for adverse health effects. Since the fate of PAHs in the natural environment is mainly governed by its physiochemical properties, the study of general properties of the compounds is of great concern.

Alkanes are the simplest organic compounds. Alkanes are saturated hydrocarbons containing only two elements, hydrogen and carbon. Each carbon atom forms four bonds and each hydrogen atom forms a single bond to a carbon. The bonding around each carbon atom is tetrahedral, so all bond angles are 109.5°. As a result, the carbon atoms in higher alkanes are arranged in zig-zag rather than linear patterns. Three types of alkanes are common in petroleum: i) *normal-alkane* (n-alkane or paraffin)-saturated hydrocarbons which have an un-branched structure. ii) *isoalkane* (branched alkane or isoparaffin)-differs from n-alkane in the presence of one or more points of branching within the chain. iii) *cycloalkane* (naphthene)-saturated hydrocarbons composed of one or more rings.

On the other hand, the characteristic base structure of a hopane (the degraded and saturated version of a hopanoid) has four cyclohexane rings and one cyclopentane ring, and might have a side chain emerging from C-30. During diagenesis and catagenesis, the biological stereospecificity of hopanoids, particularly at C-17 and C-21 is usually lost, and isomers are generated. The term alpha beta hopane is commonly used as short-hand to denote hopanes with 17 $\alpha$ (H),21 $\beta$ (H) configuration, while alpha alpha hopane would denote 17 $\alpha$ (H), 21 $\alpha$ (H) stereochemistry. The notation 17 $\alpha$ (H) indicates that the hydrogen is located below the plane of the paper, whereas in 17 $\beta$ (H) it is above the plane. The prefix "nor", as for example in 30-norhopane, indicates that the molecule is formally derived for the parent structure by loss of the indicated carbon atom, i.e. C-30 is removed from the hopane skeleton. Additionally, hopanes are very stable and are not degraded under certain conditions. The most stable C30-isomer, 17 $\alpha$ (H),21 $\beta$ (H)-hopane can be used as an internal marker for biodegradation of crude oils (Prince et al., 1994). Another biomarker, cholestane, is a 27-carbon sterane derived by reduction from the steroid alcohol cholesterol. The structure of cholestane is composed of three rings of cyclohexane and one ring of cyclopentane and might have a side chain emerging from C-17. There are four rings in a steroid skeleton and hence there are three fusion points, A/B, B/C and C/D rings share two carbons each (fusion). Every fusion center can either be *cis*- or *trans*-fused. The cholestane structures most likely feasible are: i) *trans-trans-trans* (most natural and synthetic steroids have this skelton, e.g., 5 $\alpha$ -dihydrotestosterone). ii) *cis-trans-trans* (some natural steroids have this skelton, e.g., cholic acids). iii) *cis-trans-cis* (few natural steroids have this skelton, e.g. cardiac glycosides).

Overall, hopanes and cholestanes can be termed as biomarkers, as defined recently by geoscientists, which

are organic compounds that are useful in correlating the biogenic sources of lipid or bituminous matter (Zárate-del et al., 1998; Yamamoto et al., 2006). The original term applied to biomarkers was chemical fossils, which evolved to biological marker compounds and were then contracted to the currently popular term biomarker (Simoneit et al., 2004). The enormous range of organic compounds detected in urban particles may be divided into two major source groups; primary condensates and oxidised hydrocarbons. Primary condensates (alkanes (C<sub>17</sub>-C<sub>36</sub>), alkenes) originate directly from the incomplete combustion of fossil fuels and are sorbed onto the surface of particulate matter. Oxidised hydrocarbons (carboxylic acids, aldehydes, ketones, quinines, esters and phenols) may either be attached to the particulate as a primary condensate or may be produced during atmospheric oxidation reactions (Cautreels, 1978). Bray and Evans (1961) developed the carbon preference index (CPI) as an indicator of the extent of odd or even carbon number homologues within a sample.

The CPI is expressed as a summation of the odd number homologues within a specified range of carbon numbers divided by a summation of the even number homologues within the same range. This inter-sample comparison is useful in identifying sources and establishing dominant sources of aerosol organic matter, as certain biologically produced n-alkanes show a pronounced predominance of odd carbon numbers (Bray and Evans, 1961). For example, organic matter of recent biogenic origin shows a preference for odd carbon numbered n-alkanes with CPI<sub>odd</sub> values of 6-9 and more. Hydrocarbons of abiological origin (e.g. fossil fuels) typically show no carbon number preference or tend towards low CPI values (i.e. CPI<1). To reconcile sources of organic species, CPI was calculated as follows (Tarek et al., 1996):

$$CPI_1 = \frac{\sum(C_{15} - C_{31})}{\sum(C_{14} - C_{32})} \quad \text{Equation 1}$$

CPI<sub>1</sub> represents whole range for n-alkanes

$$CPI_2 = \frac{\sum(C_{15} - C_{25})}{\sum(C_{14} - C_{24})} \quad \text{Equation 2}$$

CPI<sub>2</sub> represents petrogenic n-alkanes

$$CPI_3 = \frac{\sum(C_{25} - C_{31})}{\sum(C_{26} - C_{32})} \quad \text{Equation 3}$$

CPI<sub>3</sub> represents biogenic n-alkanes

The biogenic "wax" concentration of n-alkanes was calculated as follows:

$$Wax-n-Alkane = [C_n] - [(C_{n+1} - C_{n-1})/2] \quad \text{Equation 4}$$

Note that wax\* has traditionally referred to a substance that is secreted by bees (i.e. beeswax) and used them in constructing their honeycombs. Additionally waxes may be natural or artificial. In this context, wax is natural oily substance. Chemically, a wax may be a combination of other fatty alcohols with fatty acids.

Despite of various studies focusing on the fate of several chemical species in atmosphere (Pongpiachan, 2013a; 2013b; Pongpiachan et al., 2009a; 2012; 2013a; 2013b), little is know about the source characteristics

and fingerprints of these organic compounds during “Bonfire Night”. The main objective of this study is to i) investigate the atmospheric concentrations of PAHs, Alkanes, Cholestanes and Hopanes during the “Bonfire Night” event in Birmingham, UK and ii) analyze the annual trend of these congeners.

## Materials and Methods

### Sampling sites

Monitoring of both vapour and particulate phase SVOCs was conducted at two locations and over several time periods (See Figure 1). In all instances, the duration of each sample was 24 h. The air sample collection was carried out at both an urban background site and heavily trafficked area. Monitoring throughout this campaign was conducted at the following two sites, located ~1 km apart from each other. i) Urban background samples were taken at an open field located at the north-western side of the Birmingham University campus close to Elms Road (Elms Road Observatory Site or EROS), and ii) A site based by Bristol Road, located beside South Gate, a main campus entrance, to obtain samples where the main source of pollution was considered to be from road traffic (Bristol Road Observatory Site or BROS)

There were no obstructions in the vicinity of sampling equipment, which was strategically positioned to be accessible to winds from all directions. Monitoring at these two sites was conducted synchronously every month from July 2001-December 2004.

### Sample collection

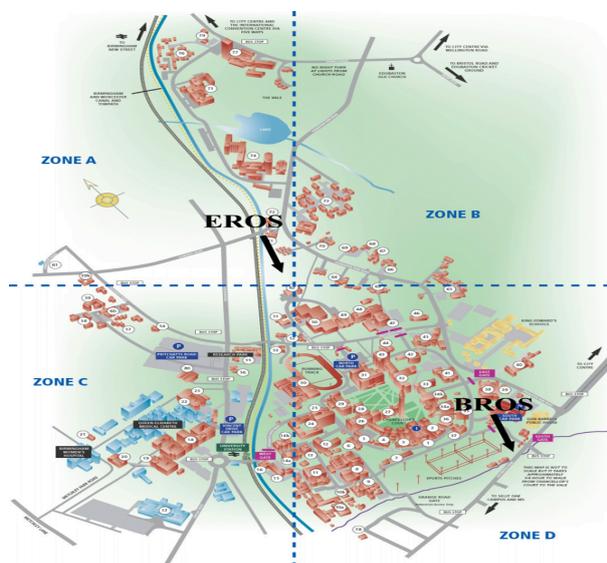
In this research, a  $PM_{10}$  high volume air sampler TE-6001 (Tisch Environmental, Inc) and Variable Resistance Calibration Kit TE-5028 were employed to collect air samples and measure the flow rate. Flow control is accomplished by restricting and thus accelerating the air-flow through the venturi tubes. At some point in the flow stream, the air velocity will equal the acoustic velocity and critical flow will be achieved. As long as downstream

changes are small, all conditions at the venturi tubes (including the flow rate) are determined by upstream conditions. Since critical flow through the tubes are not greatly affected by changes in the filter loading, ambient temperature or barometric pressure, a stable volumetric flow rate is maintained as long as power is provided to the sampler blower motor. In contrast to passive air samplers, high volume air samples are relatively obtrusive, expensive and maintenance-intensive. However, the main advantages of high volume air samplers are their abilities to distinguish between particulate and vapour phase of SVOCs coupled with affording opportunities to study relatively short-term temporal variation in concentrations. Many different methods have been used to collect vapour phase SVOCs in ambient air. The sampling methods are usually combinations of fibre filters, for retaining the particle-bound SVOCs fraction, and adsorbents like polyurethane foam PUF plugs, Tenax-GC and XAD resins to trap the vapour phase of target compounds. (Hart et al., 1992; Harrison and Smith, 1996; Ross et al., 2002). In addition, different kinds of solid traps such as silicagel, florisol and active charcoal have been widely employed in order to retain the gaseous phase of SVOCs (Stein et al., 1987; Garcia et al., 1996).

The PUF plugs have been extensively used in monitoring of air contaminants, and it is recommended in some official methods (US Environmental Protection Agency; EPA TO-10A). This porous polymer allows high sampling flow-rates, making possible the concentration of several hundreds or even thousands of cubic meters of air. Moreover, PUF plugs have been widely employed as a sorbent for gas phase SVOCs trapping material because of its relatively low price, low blank values and ease of cleaning and handling. However, the exchange of SOVCs between the gaseous and particulate phases can cause both positive and negative sampling artifacts (Hart and Pankow, 1994). These artifacts can lead either to underestimation or overestimation of ambient concentrations. The measurement of  $V/P$  (Vapour/Particle distribution or partitioning) has long been estimated on the ratio of adsorbent/filter retained concentrations ( $A/F$ ).

The sorption of gas-phase PAHs to filter surfaces (filter sorption artifact) is known to lead to artificially high measured  $F$  values and low measured  $A$  values, resulting in an artificially high  $F/A$  ratios (Hart and Pankow, 1994), while the PAHs maybe stripped from filter particles (blow-off or volatilisation artifact) and then collected on the gas-sampling adsorbent downstream of the filter to cause artificially low  $F/A$  ratios (Biddleman et al., 1986; Hart and Pankow, 1994; Peters et al., 2000). Therefore, losses of the more volatile compounds due to the high-pressure drop across the collecting filter can cause an underestimation of particle concentration, especially for longer sampling times.

On the other hand, Tenax-GC and XAD-2 exhibit less break-through due to their higher specific surface area (i.e.,  $300\text{ m}^2\text{g}^{-1}$ - $600\text{ m}^2\text{g}^{-1}$  for XAD-2) compared to PUF plug ( $0.007\text{ m}^2\text{g}^{-1}$ - $0.035\text{ m}^2\text{g}^{-1}$ ). Peters et al (2000) also indicated that 2- and 3- ring PAHs having sub-cooled liquid vapour pressure exceeding 0.2 Pa broke through PUF plug sampling media at relatively low sample



**Figure 1. Bristol Road Observatory Sites (BROS) and Elms Road Observatory Sites (EROS)**

volumes (170 m<sup>3</sup>). XAD-2 resin was reported to have higher collection efficiency for naphthalene than PUF plug, and the recoveries of some volatile PAHs on the PUF were improved at lower sampling temperatures (Chuang et al., 1987). However, both Tenax-GC and XAD-2 are less employed in high volume air samplers, mainly due to their relatively high resistance to air flow, and also because the need for a large adsorbent bed makes them expensive for this application.

Bidleman et al. (1984) calculated maximum safe values for sampling collection efficiency of 90% for Fl, Ph, An and Pyr at 20°C were 100 m<sup>3</sup>, 660 m<sup>3</sup>, 920 m<sup>3</sup> and 8200 m<sup>3</sup> respectively when a single plug, 7.8 cm diameter × 7.5 cm thick is used. In this study, the breakthrough of SVOCs from filter was investigated by spiking sampling efficiency standard (SES) prior to air sampling. Furthermore, the loss of volatile SVOCs (i.e. LMW PAHs and LMW aliphatics) was assessed by taking duplicate outdoor air samples at the same site (EROS), using two identical PUF adapters located adjacent to each other. This exercise was repeated four times and it was found that the breakthrough to the second half of the PUF plug was low accounting on average for only 9±5% (n=4) for Ph and much less for the heavier PAHs. Although many sampling strategies do exist in collecting both vapour and particulate phase of SVOCs, only those samples collected using PUF were selected for vapour phase and quartz fibre filter or glass fibre filter were adopted for particulate phase. These sampling media are the standard for collecting atmospheric persistent organic pollutants, including PAHs and aliphatics. Passive sampling data were not used because of difficulties in determining a sampled volume, and hence concentrations. Questionable and novel means of sampling were also not employed.

#### Analysis of SVOCs

The extraction of SVOCs (i.e. Acenaphthylene (Ac), Acenaphthene (Ace), Fluorene (Fl), Phenanthrene (Ph), Anthracene (An), 3-Methyl Phenanthrene (3-MePh), 9-Methyl Phenanthrene (9-MePh), 1-Methyl Phenanthrene (1-MePh), 2-Methyl Phenanthrene (2-MePh), 1-methyl-7-isopropyl phenanthrene or Retene (Ret), Fluoranthene (Fluo), Pyrene (Py), Benz[a]anthracene (B[a]A), Chrysene (Chry), Benzo[b]fluoranthene (B[b]F), Benzo[j]fluoranthene (B[j]F), Benzo[k]fluoranthene (B[k]F), Benzo[e]pyrene (B[e]P), Benzo[a]pyrene (B[a]P), Perylene (Per), Indeno[1,2,3-cd]pyrene (Ind), Benzo[g,h,i]perylene (B[g,h,i]P), Anthanthrene (Ant), Dibenzo[a,h]anthracene (D[a,h]A), Coronene (Cor), Tetradecane (C14), Pentadecane (C15), Hexadecane (C16), Heptadecane (C17), Octadecane (C18), Nonadecane (C19), Eicosane (C20), Henicosane (C21), Docosane (C22), Tricosane (C23), Tetracosane (C24), Pentacosane (C25), Hexacosane (C26), Heptacosane (C27), Octacosane (C28), Nonacosane (C29), Triacontane (C30), Hentriacontane (C31), Dotriacontane (C32), Pristane (PC19), Phytane (PC20), 17 $\alpha$ (H)-22,29,30-Trisnorhopane (th), 17 $\alpha$ (H),21 $\beta$ (H)-30-Norhopane (nh), 17 $\alpha$ (H),21 $\beta$ (H)-Hopane (hop), 17 $\alpha$ (H),21 $\beta$ (H)-22R-Homohopane (homo),  $\alpha\beta\beta$  20R-Cholestane (abbC),  $\alpha\alpha\alpha$

20R-Cholestane (aaaC),  $\alpha\beta\beta$  20R 24S-Methylcholestane (MC),  $\alpha\beta\beta$  20R 24R-Ethylcholestane (EC)) was conducted using two different sizes of Soxhlet extractors (i.e. 250 ml for GFFs/QMFs and 1-litre for PUF plug). After PM<sub>10</sub> determination, the GFFs/QMFs were divided into two parts using stainless scissors. After that, the Soxhlet extraction of PM<sub>10</sub> filter samples, PM<sub>10</sub> filter blanks, PUF samples and PUF blanks were placed inside the Soxhlets, spiked with a known amount of internal standard (deuterated-PAHs and deuterated-Aliphatics), and extracted with DCM for 24 h. The fractionation/cleanup process followed the method reported by Gogou et al. (1996). After the extraction, the DCM solvent was concentrated to dryness by a combination of rotary evaporation and blowing under a gentle nitrogen stream. The concentrated extract is then diluted in 10 ml of *n*-hexane before application to the top of a disposable silica gel column. The extract was then fractionated into individual compound classes by flash chromatography on silica gel as follows: The concentrate was applied to the top of a 30×0.7 cm diameter column, containing 1.5 g of silica gel (activated at 150°C for 3 h). Nitrogen pressure was used in order to obtain a flow of 1.4 ml min<sup>-1</sup> at the bottom of the column. The following solvents were used to elute the different compound classes: (i) 15 ml *n*-hexane (fraction 1, aliphatic and light molecular weight PAHs); (ii) 15 ml toluene-*n*-hexane (5.6:9.4) (fraction 2, middle and heavy molecular weight PAHs). In consideration of the toxicity of the solvent and the solubility of PAHs, toluene was selected for the study. After the fractionation, the eluates were concentrated by using rotary evaporator followed by the evaporation under a gentle nitrogen stream (set flow rate at 1.0 mbar). Because of the low dissipation capability of toluene, a percentage (5-25%) of acetone was added to increase the volatility. The sample was further reduced to incipient prior to being made up to volume with cyclohexane (exactly 100  $\mu$ l in a GC/MS vial insert for both GFF/QMF and PUF samples) prior to GC/MS analysis.

In this research, analyses of all samples were carried out on a Fisons GC800 interfaced with a Fisons MD800 gas chromatograph-mass spectrometry (GC/MS) using a DB-5 (60 m × 0.25 mm, i.d. × 0.25  $\mu$ m film thickness). A DB-5 (SPB-5; OV-5; HP-5) column is coated with 5% phenyl, 95% dimethylpolysiloxane and is a general-purpose column and most suitable for non-polar analytes with a high temperature limit. The ion source temperature, interface temperature and injector port temperature are set at 200°C, 250°C and 300°C respectively. The carrier gas was helium with a column head pressure of 25 psi. The GC oven temperature was programmed at 40°C for 1 min; 8°C min<sup>-1</sup> to 300°C; 300°C for 37 min for PAHs; and 70-150°C at 10°C min<sup>-1</sup>, 150-280°C at 5°C min<sup>-1</sup>, 280°C (30 min) for aliphatics. The MD800 mass spectrometer operated in selected ion, electron ionization mode for both PAHs and aliphatics. Ions monitored were: *n*-alkanes (*m/z*=99), hopanes (*m/z*=191), steranes (*m/z*=218) and PAH (molecular ion). SVOC congeners were quantified by using relative response factors (RRFs) as previously described in Pongpiachan et al. (2009b).

## Results

### PAHs at BROS

All atmospheric PAH were identified successfully in both vapour and particulate-phases from 27<sup>th</sup> November 2001 to 19<sup>th</sup> January 2004 (n=29). Table 1 summarises the concentrations of selected 26 PAHs measured in the 29 samples taken at the Bristol Road Observatory Site (BROS). Bristol road is a section of the A38, a road that passes from north to south through Birmingham city, and therefore forms a main artery for traffic into and out of the city centre on a daily basis. Laurie et al. (2002) conducted a traffic count during their study on this section of road passing by the monitoring site that typically displays mean daytime traffic flows of 800-1000 vehicles per hour, 20-30 per cent of which are diesel-fuelled. This agreed with further traffic count data at the same site that was provided by Birmingham City Council.

The vapour phase PAH concentrations are much higher than those of the particulate fraction- for  $\Sigma$ PAH, the vapour and particulate percentage concentrations are 84.8% and 15.2% respectively. These values agreed with the results reported by Lim et al. (1999), which are 89% and 11% for vapour and particulate phase PAH concentrations in that order. Vapour-phase distributions of PAHs are dominated by MMW PAHs such as Ph, Fl and their methylated species with a mean concentrations of 13.42 ng m<sup>-3</sup>, 5.33 ng m<sup>-3</sup> and 10.81 ng m<sup>-3</sup> in that order, followed by relatively high contributions of Fluo and Py also making a significant contribution of 4.48 ng m<sup>-3</sup> and 4.11 ng m<sup>-3</sup> respectively. It is important to mention that for the vapour phase, Ph alone, with the mean concentration

of 13.42 ng m<sup>-3</sup> comprises 31% of the total.

On the other hand, the HMW PAHs are found mainly in the particulate phase at mean concentrations, for instance, B[a]A (0.69 ng m<sup>-3</sup>), Chry+Tri (0.74 ng m<sup>-3</sup>), B[b+j+k]F (0.44 ng m<sup>-3</sup>), B[e]P (0.44 ng m<sup>-3</sup>), B[a]P (0.45 ng m<sup>-3</sup>), Ind (0.55 ng m<sup>-3</sup>), B[g,h,i]P (0.79 ng m<sup>-3</sup>) and Cor (0.42 ng m<sup>-3</sup>). B[a]P concentrations in both phases (particle + vapour) ranged from <0.01 ng m<sup>-3</sup> to 1.57 ng m<sup>-3</sup> and with an average of 0.47 ng m<sup>-3</sup>, this value is lower than the guideline limits of annual B[a]P concentration of 10 ng m<sup>-3</sup> and 1.0 ng m<sup>-3</sup> proposed by the German Federal Environmental Agency (Baek et al., 1992) and the European Union respectively. However, this value of 0.47 ng m<sup>-3</sup> is two times higher than the proposed value of 0.25 ng m<sup>-3</sup> by the UK Expert Panel of Air Quality Standard (UK EPAQS, 1998). This indicates that even with the variable standard across Europe the results are still outside acceptable limits. In addition, this value is comparable to the concentrations reported in North America (0.20 ng m<sup>-3</sup>-1.60 ng m<sup>-3</sup>), Australia (<0.01 ng m<sup>-3</sup>-2.0 ng m<sup>-3</sup>) and even in Rio de Janeiro et al. (1999) (0.02 ng m<sup>-3</sup>-0.70 ng m<sup>-3</sup>, 1998/1999), but a lot lower than the concentrations reported in temperate and subtropical cities in Asia (<0.01-70 ng m<sup>-3</sup>).

### PAHs at EROS

Elms Road Observatory Site (EROS) represents an urban background site situated on the NW side of the Birmingham University campus. Table 2 shows the mean particulate and vapour phase concentrations of 26 PAHs at the EROS between 27<sup>th</sup> November 2001 and 19<sup>th</sup> January 2004. The vapour and particulate distribution of the mean

**Table 1. Summary of Selected PAH Concentrations from 29 Samples Measured at the BROS (27/11/01-19/1/04)**

	Particulate Phase				Vapour Phase				(V+P) Phase			
	Mean [ng m <sup>-3</sup> ]	STDEV	Min [ng m <sup>-3</sup> ]	Max [ng m <sup>-3</sup> ]	Mean [ng m <sup>-3</sup> ]	STDEV	Min [ng m <sup>-3</sup> ]	Max [ng m <sup>-3</sup> ]	Mean [ng m <sup>-3</sup> ]	STDEV	Min [ng m <sup>-3</sup> ]	Max [ng m <sup>-3</sup> ]
Ac	<b>0.07</b>	0.17	0.01	0.69	<b>2.14</b>	1.95	0.13	8.94	<b>2.20</b>	1.95	0.16	9.01
Ace	<b>0.05</b>	0.19	<MDLs*	0.87	<b>1.04</b>	1.11	0.15	4.35	<b>1.09</b>	1.12	0.16	5.23
Fl	<b>0.14</b>	0.42	0.01	2.23	<b>5.33</b>	2.64	0.69	14.49	<b>5.47</b>	2.67	0.74	14.58
Ph	<b>0.53</b>	0.67	0.12	3.62	<b>13.42</b>	11.81	0.51	41.40	<b>13.95</b>	11.83	0.77	42.21
An	<b>0.18</b>	0.56	0.01	2.98	<b>1.44</b>	2.83	0.04	5.14	<b>1.62</b>	2.88	0.11	7.49
3-MePh	<b>0.19</b>	0.31	0.03	1.60	<b>3.12</b>	3.58	0.45	12.57	<b>3.31</b>	3.60	0.61	12.75
9-MePh	<b>0.24</b>	0.38	0.04	2.00	<b>3.41</b>	3.65	0.43	12.03	<b>3.65</b>	3.67	0.70	12.29
1-MePh	<b>0.20</b>	0.37	0.02	1.64	<b>2.52</b>	2.76	0.28	10.44	<b>2.72</b>	2.78	0.48	10.59
2-MePh	<b>0.12</b>	0.20	0.02	0.96	<b>1.76</b>	1.79	0.35	6.44	<b>1.88</b>	1.80	0.37	6.57
Fluo	<b>0.64</b>	0.41	0.12	1.70	<b>4.48</b>	5.25	0.25	17.45	<b>5.10</b>	5.27	0.70	17.87
Py	<b>0.64</b>	0.47	0.09	2.12	<b>4.11</b>	4.95	0.25	14.74	<b>4.75</b>	4.97	0.53	15.53
Ret	<b>0.05</b>	0.06	0.01	0.14	<b>0.03</b>	0.06	<MDLs	0.24	<b>0.08</b>	0.08	<MDLs	0.34
B[a]A	<b>0.69</b>	0.64	0.03	2.56	<b>0.11</b>	0.13	0.01	1.26	<b>0.81</b>	0.66	0.04	2.62
Chry+Tri	<b>0.74</b>	1.31	0.04	6.26	<b>0.09</b>	0.11	<MDLs	0.50	<b>0.83</b>	1.31	0.07	6.33
B[b+j+k]F	<b>0.44</b>	0.39	0.09	1.40	<b>0.05</b>	0.10	<MDLs	0.50	<b>0.48</b>	0.40	0.01	1.52
B[e]P	<b>0.44</b>	0.33	0.09	1.33	<b>0.04</b>	0.08	<MDLs	0.37	<b>0.48</b>	0.34	0.11	1.45
B[a]P	<b>0.45</b>	0.38	0.07	1.50	<b>0.04</b>	0.10	<MDLs	0.48	<b>0.47</b>	0.39	<MDLs	1.57
Per	<b>0.09</b>	0.11	0.01	0.30	<b>0.01</b>	0.04	<MDLs	0.09	<b>0.10</b>	0.12	0.02	0.31
Ind	<b>0.55</b>	0.50	0.08	2.21	<b>0.04</b>	0.05	<MDLs	0.15	<b>0.56</b>	0.51	<MDLs	2.24
B[g,h,i]P	<b>0.79</b>	0.59	0.12	2.78	<b>0.05</b>	0.08	<MDLs	0.30	<b>0.81</b>	0.59	0.01	2.95
Ant	<b>0.13</b>	0.13	<MDLs	0.65	<b>0.01</b>	0.05	<MDLs	0.15	<b>0.14</b>	0.14	<MDLs	0.65
D[a,h]A	<b>0.08</b>	0.12	<MDLs	0.41	<b>0.02</b>	0.06	<MDLs	0.14	<b>0.10</b>	0.14	<MDLs	0.46
Cor	<b>0.42</b>	0.39	<MDLs	1.92	<b>0.03</b>	0.05	<MDLs	0.17	<b>0.43</b>	0.40	N.D.	2.06
$\Sigma$ PAHs	<b>7.85</b>	9.10	1.01	41.87	<b>43.31</b>	43.23	3.54	152.34	<b>51.04</b>	47.62	5.59	176.62

\*MDLs: Method Detection Limits

**Table 2. Summary of Selected PAH Concentrations from 29 Samples Measured at the EROS (27/11/01-19/1/04)**

	Particulate Phase				Vapour Phase				(V+P) Phase			
	Mean [ng m <sup>-3</sup> ]	STDEV	Min [ng m <sup>-3</sup> ]	Max [ng m <sup>-3</sup> ]	Mean [ng m <sup>-3</sup> ]	STDEV	Min [ng m <sup>-3</sup> ]	Max [ng m <sup>-3</sup> ]	Mean [ng m <sup>-3</sup> ]	STDEV	Min [ng m <sup>-3</sup> ]	Max [ng m <sup>-3</sup> ]
Ac	<b>0.06</b>	0.12	<MDLs*	0.60	<b>0.83</b>	1.04	0.11	3.53	<b>0.89</b>	1.05	0.12	3.65
Ace	<b>0.05</b>	0.13	<MDLs	0.44	<b>0.69</b>	0.49	0.15	2.24	<b>0.73</b>	0.51	0.15	2.26
Fl	<b>0.15</b>	0.33	<MDLs	1.42	<b>4.03</b>	2.99	0.94	12.31	<b>4.18</b>	3.01	0.97	12.44
Ph	<b>0.33</b>	0.42	0.04	1.45	<b>5.76</b>	5.91	0.65	18.15	<b>6.09</b>	5.93	0.90	18.23
An	<b>0.04</b>	0.06	<MDLs	0.28	<b>0.37</b>	0.47	0.07	1.48	<b>0.41</b>	0.48	0.08	1.49
3-MePh	<b>0.12</b>	0.19	0.01	0.66	<b>0.97</b>	1.44	0.26	3.02	<b>1.09</b>	1.46	0.29	3.05
9-MePh	<b>0.15</b>	0.24	0.01	0.78	<b>1.12</b>	0.64	0.31	3.22	<b>1.27</b>	0.68	0.34	3.26
1-MePh	<b>0.11</b>	0.20	0.01	0.61	<b>0.98</b>	0.60	0.25	2.78	<b>1.10</b>	0.64	0.28	2.81
2-MePh	<b>0.09</b>	0.15	<MDLs	0.53	<b>0.69</b>	0.42	0.20	2.27	<b>0.78</b>	0.44	0.21	2.29
Fluo	<b>0.43</b>	0.50	0.04	1.48	<b>1.42</b>	1.29	0.47	6.66	<b>1.85</b>	1.38	0.65	7.15
Py	<b>0.35</b>	0.34	0.03	1.21	<b>0.96</b>	0.72	0.39	2.03	<b>1.31</b>	0.80	0.56	2.86
Ret	<b>0.06</b>	0.19	<MDLs	1.11	<b>0.02</b>	0.03	<MDLs	0.13	<b>0.08</b>	0.19	<MDLs	1.12
B[a]A	<b>0.30</b>	0.45	0.01	1.98	<b>0.05</b>	0.05	<MDLs	0.43	<b>0.35</b>	0.45	0.01	1.98
Chry+Tri	<b>0.25</b>	0.37	0.02	1.52	<b>0.07</b>	0.06	<MDLs	0.25	<b>0.32</b>	0.37	0.03	1.72
B[b+j+k]F	<b>0.29</b>	0.40	0.01	2.08	<b>0.05</b>	0.09	<MDLs	0.51	<b>0.34</b>	0.41	0.03	2.11
B[e]P	<b>0.24</b>	0.20	<MDLs	0.83	<b>0.05</b>	0.10	<MDLs	0.61	<b>0.29</b>	0.22	0.03	0.84
B[a]P	<b>0.20</b>	0.20	<MDLs	0.75	<b>0.06</b>	0.13	<MDLs	0.75	<b>0.25</b>	0.24	0.03	0.86
Per	<b>0.03</b>	0.03	<MDLs	0.13	<b>0.01</b>	0.02	<MDLs	0.12	<b>0.05</b>	0.04	0.01	0.17
Ind	<b>0.23</b>	0.24	0.01	1.02	<b>0.07</b>	0.15	<MDLs	0.72	<b>0.30</b>	0.28	0.04	1.26
B[g,h,i]P	<b>0.28</b>	0.26	0.01	1.09	<b>0.10</b>	0.21	<MDLs	1.04	<b>0.38</b>	0.34	0.06	1.81
Ant	<b>0.02</b>	0.05	<MDLs	0.10	<b>0.02</b>	0.05	<MDLs	0.24	<b>0.04</b>	0.07	<MDLs	0.34
D[a,h]A	<b>0.04</b>	0.04	<MDLs	0.22	<b>0.01</b>	0.01	<MDLs	0.06	<b>0.04</b>	0.05	<MDLs	0.23
Cor	<b>0.12</b>	0.10	<MDLs	0.38	<b>0.04</b>	0.10	<MDLs	0.45	<b>0.16</b>	0.14	0.03	0.77
ΣPAHs	<b>3.93</b>	5.21	0.20	20.67	<b>18.37</b>	17.01	3.80	63	<b>22.30</b>	19.18	4.82	72.7

\*MDLs: Method Detection Limits

**Table 3. Summary of Selected PAH Concentrations from 29 Samples Measured at the BROS (27/11/01-19/1/04)**

	Particulate Phase				Vapour Phase				(V+P) Phase			
	Mean [ng m <sup>-3</sup> ]	STDEV	Min [ng m <sup>-3</sup> ]	Max [ng m <sup>-3</sup> ]	Mean [ng m <sup>-3</sup> ]	STDEV	Min [ng m <sup>-3</sup> ]	Max [ng m <sup>-3</sup> ]	Mean [ng m <sup>-3</sup> ]	STDEV	Min [ng m <sup>-3</sup> ]	Max [ng m <sup>-3</sup> ]
C <sub>14</sub>	<b>0.10</b>	0.12	<MDLs*	0.48	<b>0.41</b>	0.55	<MDLs	1.65	<b>0.51</b>	0.57	0.01	1.92
C <sub>15</sub>	<b>0.16</b>	0.34	<MDLs	1.71	<b>1.21</b>	1.28	<MDLs	4.42	<b>1.37</b>	1.45	0.01	5.36
C <sub>16</sub>	<b>0.38</b>	0.60	<MDLs	2.46	<b>3.68</b>	3.20	0.01	10.56	<b>4.04</b>	3.18	0.02	10.77
PC <sub>19</sub>	<b>0.53</b>	1.21	<MDLs	5.45	<b>4.10</b>	3.89	0.01	12.67	<b>4.64</b>	4.04	0.01	14.57
C <sub>18</sub>	<b>0.42</b>	0.79	<MDLs	3.82	<b>7.49</b>	3.78	0.22	14.73	<b>7.92</b>	4.24	0.23	15.75
PC <sub>20</sub>	<b>0.19</b>	0.39	<MDLs	1.99	<b>3.75</b>	3.72	0.11	13.26	<b>3.94</b>	3.77	0.12	13.65
C <sub>19</sub>	<b>0.92</b>	2.16	0.01	10.99	<b>7.18</b>	4.82	1.19	17.55	<b>8.12</b>	5.22	1.21	18.05
C <sub>20</sub>	<b>1.74</b>	3.29	0.02	15.24	<b>5.80</b>	4.79	0.63	19.08	<b>7.58</b>	5.57	1.37	21.57
C <sub>21</sub>	<b>2.16</b>	2.75	0.03	11.19	<b>2.84</b>	3.09	0.07	14.06	<b>5.02</b>	4.40	0.64	16.18
C <sub>22</sub>	<b>3.36</b>	2.60	0.06	9.78	<b>1.45</b>	2.59	0.01	9.56	<b>4.76</b>	3.45	0.27	12.24
C <sub>23</sub>	<b>4.28</b>	3.04	0.19	12.12	<b>1.09</b>	1.97	<MDLs	7.38	<b>5.30</b>	3.77	0.96	14.38
C <sub>24</sub>	<b>3.03</b>	2.41	0.39	12.34	<b>0.70</b>	1.37	<MDLs	5.24	<b>3.65</b>	3.08	0.47	13.98
C <sub>25</sub>	<b>3.15</b>	2.79	0.39	12.26	<b>0.61</b>	1.46	<MDLs	6.06	<b>3.70</b>	3.14	0.39	12.27
C <sub>26</sub>	<b>2.25</b>	1.82	0.33	8.46	<b>0.77</b>	1.90	<MDLs	8.31	<b>2.92</b>	2.70	0.34	10.87
C <sub>27</sub>	<b>2.68</b>	2.20	0.25	9.45	<b>0.85</b>	2.30	<MDLs	10.91	<b>3.53</b>	3.24	0.25	14.21
C <sub>28</sub>	<b>1.88</b>	2.10	0.05	7.43	<b>0.85</b>	2.81	<MDLs	13.91	<b>2.67</b>	3.34	0.05	15.02
C <sub>29</sub>	<b>3.07</b>	3.04	0.08	13.42	<b>0.91</b>	3.02	<MDLs	15.09	<b>3.88</b>	4.39	0.08	18.84
C <sub>30</sub>	<b>1.42</b>	1.65	0.03	6.89	<b>0.71</b>	2.32	<MDLs	11.64	<b>2.05</b>	2.81	0.03	12.50
C <sub>31</sub>	<b>2.06</b>	1.90	0.04	6.58	<b>0.68</b>	1.85	<MDLs	8.17	<b>2.62</b>	2.73	0.04	10.20
C <sub>32</sub>	<b>0.80</b>	0.83	0.01	3.46	<b>0.49</b>	1.37	<MDLs	6.47	<b>1.24</b>	1.57	0.01	7.10
th	<b>0.30</b>	0.47	<MDLs	2.19	<b>0.10</b>	0.35	<MDLs	1.66	<b>0.37</b>	0.67	<MDLs	2.72
nh	<b>0.45</b>	0.39	<MDLs	1.55	<b>0.09</b>	0.31	<MDLs	1.53	<b>0.49</b>	0.58	<MDLs	2.56
hop	<b>0.47</b>	0.43	<MDLs	1.86	<b>0.05</b>	0.10	<MDLs	0.36	<b>0.47</b>	0.45	<MDLs	0.96
homo	<b>0.26</b>	0.28	<MDLs	1.09	<b>0.04</b>	0.15	<MDLs	0.73	<b>0.27</b>	0.37	<MDLs	1.66
abbC	<b>0.16</b>	0.20	<MDLs	0.90	<b>0.03</b>	0.09	<MDLs	0.47	<b>0.17</b>	0.28	<MDLs	1.37
aaaC	<b>0.23</b>	0.16	<MDLs	0.51	<b>0.03</b>	0.09	<MDLs	0.39	<b>0.25</b>	0.19	<MDLs	0.66
MC	<b>0.11</b>	0.16	<MDLs	0.78	<b>0.01</b>	0.03	<MDLs	0.12	<b>0.12</b>	0.18	<MDLs	0.91
EC	<b>0.17</b>	0.13	<MDLs	0.47	<b>0.03</b>	0.11	<MDLs	0.55	<b>0.19</b>	0.20	<MDLs	0.87

\*MDLs: Method Detection Limits

**Table 4. Summary of Selected Aliphatic Concentrations from 29 Samples Measured at the EROS (27/11/01-19/1/04)**

	Particulate Phase				Vapour Phase				(V+P) Phase			
	Mean [ng m <sup>-3</sup> ]	STDEV	Min [ng m <sup>-3</sup> ]	Max [ng m <sup>-3</sup> ]	Mean [ng m <sup>-3</sup> ]	STDEV	Min [ng m <sup>-3</sup> ]	Max [ng m <sup>-3</sup> ]	Mean [ng m <sup>-3</sup> ]	STDEV	Min [ng m <sup>-3</sup> ]	Max [ng m <sup>-3</sup> ]
C <sub>14</sub>	<b>0.16</b>	0.19	<MDLs*	0.63	<b>0.37</b>	0.74	<MDLs	3.70	<b>0.53</b>	0.74	0.02	3.71
C <sub>15</sub>	<b>0.19</b>	0.37	<MDLs	1.85	<b>0.70</b>	1.10	<MDLs	5.16	<b>0.89</b>	1.12	0.03	5.77
C <sub>16</sub>	<b>0.24</b>	0.28	<MDLs	1.31	<b>1.30</b>	1.48	0.01	5.20	<b>1.54</b>	1.49	0.13	5.21
PC <sub>19</sub>	<b>0.26</b>	0.44	<MDLs	2.04	<b>1.41</b>	1.44	0.01	4.66	<b>1.68</b>	1.58	0.13	6.63
C <sub>18</sub>	<b>0.32</b>	0.45	0.01	2.06	<b>2.30</b>	1.84	0.13	8.57	<b>2.62</b>	1.82	0.25	8.61
PC <sub>20</sub>	<b>0.17</b>	0.18	0.01	0.70	<b>1.98</b>	1.58	0.11	5.64	<b>2.14</b>	1.58	0.19	5.67
C <sub>19</sub>	<b>0.35</b>	0.43	0.01	1.73	<b>2.16</b>	1.54	0.04	5.67	<b>2.51</b>	1.45	0.30	5.72
C <sub>20</sub>	<b>0.48</b>	0.58	N.D.	2.42	<b>2.20</b>	2.41	0.01	10.98	<b>2.68</b>	2.32	0.23	10.98
C <sub>21</sub>	<b>0.86</b>	0.65	0.03	2.21	<b>1.37</b>	1.26	<MDLs	4.21	<b>2.23</b>	1.17	0.18	4.86
C <sub>22</sub>	<b>1.31</b>	1.20	0.04	5.55	<b>0.84</b>	1.03	<MDLs	3.78	<b>2.15</b>	1.35	0.14	7.86
C <sub>23</sub>	<b>1.82</b>	1.37	0.14	5.15	<b>0.92</b>	1.34	<MDLs	4.52	<b>2.73</b>	1.89	0.22	6.67
C <sub>24</sub>	<b>1.74</b>	1.47	0.14	5.88	<b>0.58</b>	0.95	<MDLs	3.57	<b>2.32</b>	1.59	0.15	6.26
C <sub>25</sub>	<b>2.48</b>	2.29	0.56	9.64	<b>0.51</b>	0.82	<MDLs	2.94	<b>2.99</b>	2.35	0.56	12.58
C <sub>26</sub>	<b>1.98</b>	1.71	0.23	7.66	<b>0.53</b>	0.80	<MDLs	4.00	<b>2.52</b>	1.76	0.23	11.66
C <sub>27</sub>	<b>2.76</b>	2.38	0.50	8.02	<b>0.52</b>	0.72	<MDLs	4.45	<b>3.28</b>	2.41	0.66	10.09
C <sub>28</sub>	<b>1.92</b>	1.42	0.20	5.30	<b>0.52</b>	0.73	<MDLs	4.87	<b>2.44</b>	1.44	0.22	8.44
C <sub>29</sub>	<b>3.59</b>	3.21	0.24	10.33	<b>0.57</b>	0.79	<MDLs	5.31	<b>4.16</b>	3.15	0.51	15.65
C <sub>30</sub>	<b>1.56</b>	1.14	0.15	5.47	<b>0.59</b>	0.74	<MDLs	5.72	<b>2.15</b>	1.15	0.15	9.52
C <sub>31</sub>	<b>2.71</b>	2.42	0.26	8.60	<b>0.45</b>	0.63	<MDLs	5.01	<b>3.16</b>	2.37	0.27	10.67
C <sub>32</sub>	<b>1.17</b>	0.79	<MDLs	6.86	<b>0.33</b>	0.39	<MDLs	4.31	<b>1.50</b>	0.78	0.16	6.88
th	<b>0.20</b>	0.23	<MDLs	0.86	<b>0.08</b>	0.28	<MDLs	1.40	<b>0.28</b>	0.36	<MDLs	1.58
nh	<b>0.31</b>	0.31	<MDLs	1.24	<b>0.07</b>	0.22	<MDLs	1.10	<b>0.38</b>	0.35	<MDLs	1.24
hop	<b>0.42</b>	0.43	<MDLs	1.82	<b>0.05</b>	0.08	<MDLs	0.29	<b>0.46</b>	0.43	<MDLs	1.82
homo	<b>0.18</b>	0.26	<MDLs	1.23	<b>0.04</b>	0.14	<MDLs	0.68	<b>0.21</b>	0.28	<MDLs	1.23
abbC	<b>0.08</b>	0.09	<MDLs	0.37	<b>0.01</b>	0.02	<MDLs	0.09	<b>0.09</b>	0.09	<MDLs	0.37
aaaC	<b>0.13</b>	0.14	<MDLs	0.49	<b>0.01</b>	0.02	<MDLs	0.08	<b>0.15</b>	0.13	<MDLs	0.49
MC	<b>0.08</b>	0.10	<MDLs	0.37	<b>0.01</b>	0.01	<MDLs	0.04	<b>0.08</b>	0.11	<MDLs	0.39
EC	<b>0.11</b>	0.12	<MDLs	0.45	<b>0.01</b>	0.03	<MDLs	0.15	<b>0.12</b>	0.12	<MDLs	0.45

\*MDLs: Method Detection Limits

values in Table 2 are clearly illustrated that the more abundant LMW PAHs mainly exist in the vapour phase, whilst the HMW PAHs are predominantly present in the particulate phase. These results agree with those measured at the EROS by Laurie et al. (2002). At the EROS the vapour and particulate concentrations of the  $\Sigma$ PAH were 82.4% and 17.6% respectively. These values are very similar to the results of 86% and 14% of the vapour and particulate concentrations of the  $\Sigma$ PAH reported by Laurie et al. (2002). The most abundant compounds in the vapour phase were Ph (5.76 ng m<sup>-3</sup>), Fl (4.03 ng m<sup>-3</sup>), Fluo (1.42 ng m<sup>-3</sup>), MePh groups (3.76 ng m<sup>-3</sup>), Ac (0.83 ng m<sup>-3</sup>), Ace (0.69 ng m<sup>-3</sup>) and Py (0.96 ng m<sup>-3</sup>), and contributing 28%, 19%, 7%, 18%, 4%, 3% and 5% in that order. Conversely the HMW PAHs were almost entirely associated with the particulate phase. In accordance with the results measured at the BROS, the high MW compounds such as B[a]A (0.30 ng m<sup>-3</sup>), Chry+Tri (0.25 ng m<sup>-3</sup>), B[b+j+k]F (0.29 ng m<sup>-3</sup>), B[e]P (0.24 ng m<sup>-3</sup>), B[a]P (0.20 ng m<sup>-3</sup>), Ind (0.23 ng m<sup>-3</sup>), B[g,h,i]P (0.28 ng m<sup>-3</sup>) and Cor (0.12 ng m<sup>-3</sup>) were found in particulate phase, and contributing 8%, 6%, 7%, 6%, 5%, 6%, 7% and 3% in that order.

#### Aliphatics at BROS

As described previously in section 2, BROS represents for more traffic-influenced site. Table 3 shows the mean, min and max values of both particulate and vapour phase concentrations of 29 aliphatics (i.e. 21 species of alkanes,

4 species of hopanes and cholestanes) recorded at the BROS between 27<sup>th</sup> November 2001 and 19<sup>th</sup> January 2004. Table 3 shows that vapour phase aliphatics are much higher than those of the particulate fraction—for total aliphatics, the vapour and particulate percentage contributions are 56% and 44% respectively. The more volatile lower MW alkanes (C<sub>14</sub>-C<sub>21</sub>) are present mainly in vapour phase whereas the higher MW alkanes, C<sub>23</sub> (4.28 ng m<sup>-3</sup>), C<sub>22</sub> (3.36 ng m<sup>-3</sup>), C<sub>25</sub> (3.15 ng m<sup>-3</sup>), C<sub>29</sub> (3.07 ng m<sup>-3</sup>) and C<sub>24</sub> (3.03 ng m<sup>-3</sup>), are found mainly in particulate phase, and making a significant contribution to a mean particulate phase total alkanes level of 34.57 ng m<sup>-3</sup>. On the other hand, C<sub>18</sub> (7.49 ng m<sup>-3</sup>), C<sub>19</sub> (7.18 ng m<sup>-3</sup>), C<sub>20</sub> (5.80 ng m<sup>-3</sup>) and Pristane C<sub>19</sub>+C<sub>17</sub> (4.10 ng m<sup>-3</sup>) are the main vapour alkane species, and constituting about 16%, 16%, 13% and 9% respectively. The characteristic of relatively low C<sub>max</sub> (20.48) observed at the BROS suggesting the strong influence of vehicle exhausts (Azevedo et al., 1999; Cecinato et al., 1999) followed by a *saw-tooth distribution* with maxima centred around C<sub>29</sub>-C<sub>31</sub> indicating biogenic emissions (Kalaitzoglou et al., 2004). Four hopane and cholestane homologues were identified in both vapour and particulate samples of BROS, including 17 $\alpha$ (H) series for hopanes and  $\alpha\beta$ -20R series for cholestanes.

Summarised mean concentration ranges of individual hopane and cholestane homologues identified in the samples are listed in Table 3 in term of each phase. The mean hopane homologues levels (n=4) is up to 0.37 ng m<sup>-3</sup>

**Table 5. Mean Total (P+V) PAH Concentrations for the BROS in 2000-2001 and 2001-2004, and Independent t-test Significance Levels**

Compound	Mean			Mean			[%] Change	t-test p-Value	Significance Level
	2000-2001	Min	Max	2001-2004	Min	Max			
Ac	4.18	1.33	12.04	2.20	0.16	9.01	-47	0.007	S
Ace	1.41	0.55	5.98	1.09	0.16	5.23	-23	0.423	NS
Fl	9.14	4.28	36.56	5.47	0.74	14.58	-40	0.023	S
Ph	21.91	9.09	58.48	13.95	0.77	42.21	-36	0.011	S
An	4.66	1.59	12.79	1.62	0.11	7.49	-65	0.000	S
3-MePh	3.94	1.50	7.74	3.31	0.61	12.75	-16	0.455	NS
9-MePh	5.65	1.74	11.31	1.88	0.37	6.57	-67	0.000	S
1-MePh	4.33	1.26	8.28	6.37	1.18	22.88	+47	0.033	S
2-MePh	8.29	2.44	18.55	5.10	0.70	17.87	-38	0.041	S
Fluo	7.66	1.58	19.40	4.75	0.53	15.53	-38	0.064	NS
Py	1.03	0.27	3.83	0.08	<MDLs	0.34	-92	0.000	S
Ret	0.73	0.13	4.05	0.81	0.04	2.62	+11	0.573	NS
B[a]A	1.24	0.30	5.84	0.83	0.07	6.33	-33	0.353	NS
Chry+Tri	1.09	0.33	4.43	0.48	0.01	1.52	-56	0.004	S
B[b+j+k]F	0.57	<MDLs	2.17	0.48	0.11	1.45	-15	0.685	NS
B[e]P	0.44	0.07	2.37	0.47	<MDLs	1.57	+8	0.577	NS
B[a]P	0.69	0.08	3.55	0.56	<MDLs	2.24	-19	0.641	NS
Per	1.42	0.33	5.97	0.81	0.01	2.95	-43	0.056	NS
Ind	0.12	<MDLs	0.70	0.10	<MDLs	0.46	-19	0.744	NS
B[g,h,i]P	0.47	<MDLs	1.68	0.43	<MDLs	2.06	-8	0.986	NS
ΣPAHs	78.95	34.31	195.48	50.80	12.39	140.92	-36	0.005	S

\*Note that “-” for decline, “+” for increase, “NS” for Not significant (p>0.05), “S” for Significant (p<0.05) and “MDLs” for Method Detection Limits

**Table 6. Annual Variation of Mean Total (P+V) PAH Concentrations for the BROS from 2000-2004 and One Way Independent ANOVA Analysis**

Compound	2000	2001-2002	2003-2004	2000-2002	2001-2004	p-Value	S.L.***	
	Mean [ng m <sup>-3</sup> ]	Mean [ng m <sup>-3</sup> ]	Mean [ng m <sup>-3</sup> ]	Change* [%]	Change* [%]			F**
Ac	3.38	3.74	1.72	+11	-54	5.83	0.01	S
Ace	1.24	2.20	0.73	+77	-67	9.73	0.00	S
Fl	6.72	8.25	4.59	+23	-44	6.13	0.00	S
Ph	16.79	23.23	11.00	+38	-53	5.85	0.01	S
An	3.89	2.07	1.47	-47	-29	10.82	0.00	S
3-MePh	3.84	3.77	3.16	-2	-16	0.43	0.65	NS
2-MePh	5.76	1.78	1.91	-69	+8	22.84	0.00	S
1+9-MePh	4.47	7.00	6.17	+57	-12	1.03	0.37	NS
Fluo	9.45	9.93	3.57	+5	-64	9.31	0.00	S
Py	8.65	7.86	3.75	-9	-52	4.93	0.01	S
Ret	1.08	0.06	0.09	-94	+44	19.29	0.00	S
B[a]A	0.54	0.45	0.92	-17	+103	2.03	0.14	NS
Chry	0.96	0.41	0.96	-58	+137	0.72	0.49	NS
B[b+j+k]F	0.88	0.43	0.49	-52	+16	4.12	0.02	S
B[e]P	0.49	0.47	0.49	-3	+3	0.01	0.99	NS
B[a]P	0.33	0.39	0.50	+18	+30	0.87	0.43	NS
Ind	0.46	0.61	0.55	+33	-10	0.28	0.76	NS
B[g,h,i]P	1.00	0.89	0.79	-11	-11	0.38	0.68	NS
D[a,h]A	0.11	0.06	0.11	-41	+74	0.46	0.63	NS
Cor	0.60	0.67	0.36	+12	-46	1.62	0.21	NS
ΣPAH	73.66	74.27	43.33	+1	-42	7.47	0.00	S

\*- = decrease and + = increase. \*\*F (2, 40)=3.23, p < 0.05). \*\*\*“NS” for Not Significant when F<3.23, “S” for Significant when F>3.23 (Sampling period of 2N.D.=26/1N.D.-23/11/00, n=14; Sampling period of 2001-2002=27/11/01-7/5/02, n=7) (Sampling period of 2003-2004=29/4/03-19/1/04, n=22)

in particulate phase, which is higher than that in vapour phase with the value of 0.07 ng m<sup>-3</sup> by a factor of 5.3. A similar pattern was observed in cholestane homologues where the mean levels (n=4) in particulate phase is 0.17 ng m<sup>-3</sup>, which is higher than that in vapour phase with the value of 0.03 by a factor of 5.7. Overall, for both hopanes and cholestanes, the majority of chemical species exists mainly in particulate phase with the particulate and vapour

percentage concentrations of 85% and 15% respectively.

#### Aliphatics at EROS

The monitoring of aliphatics was conducted at the EROS 800 m west of the BROS within the “Green Space” of the University of Birmingham campus between 27<sup>th</sup> November 2001 and 19<sup>th</sup> January 2004. The mean, min and max values of both particulate and vapour phase

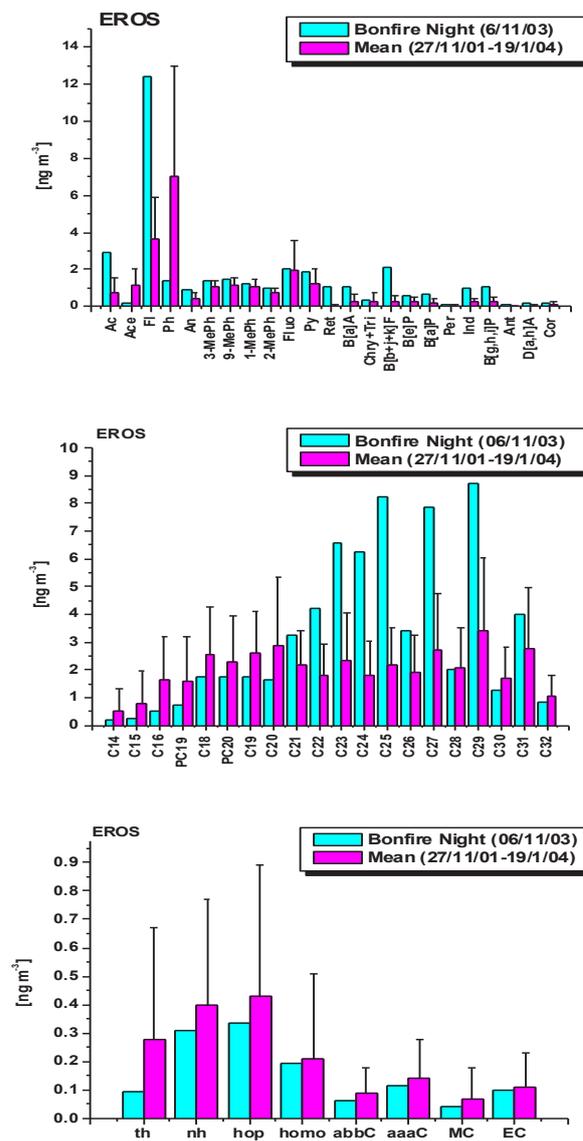
**Table 7. Monthly Level of Ozone ( $\mu\text{g m}^{-3}$ ) Observed at the DEFRA Monitoring Site in Birmingham City Centre (2001-2004)**

Year	2001	2002	2003	2004
Jan	24	32	35	36
Feb	30	51	27	34
Mar	37	41	45	44
Apr	53	52	54	N/A
May	45	56	68	49
Jun	52	52	63	51
Jul	46	39	52	44
Aug	38	36	N/A	47
Sep	32	32	N/A	40
Oct	33	25	27	N/A
Nov	22	23	24	N/A
Dec	22	21	23	26
Average	36	38	42	41
STDEV	11	12	17	8

\*Source: (<http://www.airquality.co.uk/archive>)

concentrations of 29 aliphatics measured at the EROS between 27<sup>th</sup> November 2001 and 19<sup>th</sup> January 2004 were illustrated at Table 4. According to the results obtained from Table 4, the majority of cholestanes and hopanes exist in particulate rather than vapour phase and the particulate and vapour percentage concentrations are 84% and 16% respectively. For alkanes, the more volatile lower MW alkanes ( $C_{14}$ - $C_{21}$ ) are present mainly in vapour phase whereas the higher MW ( $C_{22}$ - $C_{32}$ ) is found mainly in particulate phase, which agreed with the results measured at the BROS. The percentage contribution of vapour to total vapour phase of  $C_{20}$ ,  $C_{19}$ ,  $C_{18}$  and Phytane  $C_{20}$  are 12%, 11%, 12% and 11% respectively whereas the percentage contribution of particulate to total particulate phase of  $C_{27}$ ,  $C_{29}$ ,  $C_{25}$ ,  $C_{26}$  and  $C_{28}$  are 10%, 13%, 9%, 7% and 7% in that order. The biogenic hydrocarbons  $C_{27}$ ,  $C_{29}$  and  $C_{31}$  followed by a *saw-tooth distribution* with maxima centred around  $C_{29}$ - $C_{31}$  were the most abundant compounds representing typical *n*-alkanes attributable to natural plant waxes introduced into aerosols mainly by direct emissions from higher plants (Simoneit and Elias, 2000). Thus it appears reasonable to assume that the air masses at the EROS might have been subject to important mixing of air masses from the BROS (i.e. traffic emission with high abundant of LMW alkanes, pristane and phytane) and green space inside the campus (i.e. biogenic emission with high abundant of HMW alkanes coupled with a chain saw distribution of *odd-to-even* number).

In addition, the mean concentrations of vapour phase are  $C_{20}$  ( $0.37 \text{ ng m}^{-3}$ ),  $C_{19}$  ( $0.70 \text{ ng m}^{-3}$ ),  $C_{18}$  ( $1.30 \text{ ng m}^{-3}$ ) and PC20 ( $1.98 \text{ ng m}^{-3}$ ) whereas the mean concentrations of particulate phase are  $C_{27}$  ( $2.76 \text{ ng m}^{-3}$ ),  $C_{29}$  ( $3.59 \text{ ng m}^{-3}$ ),  $C_{25}$  ( $2.48 \text{ ng m}^{-3}$ ),  $C_{26}$  ( $1.98 \text{ ng m}^{-3}$ ) and  $C_{28}$  ( $1.92 \text{ ng m}^{-3}$ ). For both urban monitoring sites, the predominant sum (P+V) of hopane homologue is always  $17\alpha(\text{H}),21\beta(\text{H})$ -Hopane with the concentration of  $0.47 \text{ ng m}^{-3}$  and  $0.46 \text{ ng m}^{-3}$  in the BROS and EROS respectively. Since  $17\alpha(\text{H}),21\beta(\text{H})$ -Hopane is the product of biogenic organic matter transformed in sedimentary deposits by diagenesis and catagenesis, it is possible to use this triterpane hydrocarbon as an indicator to assess the annual/seasonal variation of asphalt particles, bitumens and lubricating

**Figure 2. Source profiles of SVOCs at the EROS during the Bonfire Night**

oils in urban air. In contrast,  $17\alpha(\text{H}),21\beta(\text{H})$ -22R-Homohopane is the least abundant in the sum (P+V) of hopane homologues of the BROS and EROS, suggesting their relatively low content in asphalt and lubricating oil.

## Discussion

SVOCs During Bonfire Night, Figure 2 illustrates the source profiles of SVOCs observed at the EROS during the bonfire night. Throughout the monitoring period from 27<sup>th</sup> November 2001 to 19<sup>th</sup> January 2004, the highest PAH concentration (P+V) was  $\text{Ph}>\text{Fl}>\text{Fluo}>\text{Ace}$ , whereas alkane concentrations (P+V) was following the decrease order of  $C_{29}>C_{20}>C_{27}>C_{18}$ . During the bonfire night episode, the highest contributions of individual PAH (P+V) came from Fl, Ac, Ret, B[b+j+k]F, Ind, B[g,h,i]P, while alkane concentrations (P+V) was following the decrease order of  $C_{29}>C_{24}>C_{27}>C_{22}$  (see Figure 2). It is interesting to note that "a chain-saw-distribution" of alkanes was evident at the range of  $C_{23}$  to  $C_{31}$  during the bonfire night episode, suggesting a strong signal of biomass burnings. These results are in good agreement

with the fact that bonfire night is strongly related with fireworks and wood combustion. As expected, the distribution of cholestanes and hopanes observed at the bonfire night were in consistent with those of the annual mean. This result indicates that biomass burning has less impact on the deviation of cholestanes and hopanes, and thus providing a good validation of using these two compounds as petroleum biomarkers.

Annual Trend of PAHs, Atmospheric PAH have been monitored at the BROS and EROS in last few years, including 2000-2001 sampling campaign (Harrad et al., 2003) for the BROS and 1997 (Lim, 1999), 1999-2001 (Laurie, 2002) for the EROS respectively. The annual mean sum (P+V) of individual PAH measured at the BROS in 2000-2001 and 2001-2004 was illustrated in Table 5. The observed annual sum (P+V) decrease of  $\Sigma$ PAHs from 79 ng m<sup>-3</sup> (average of 2000-2001) to 51 ng m<sup>-3</sup> (average of 2001-2004) is probably caused by the impact of emission control legislation (European Community Directive, 91/441/EEC). To determine whether the observed reduction of  $\Sigma$ PAHs is indeed due to significant emission control legislation or merely caused by coincidental effects of emissions, atmospheric transportation and chemical degradation, the statistical analysis was performed and will be discussed below.

The PAH concentrations were subjected to both independent *t*-test and one-way independent ANOVA analysis to investigate a significant decline at the BROS and EROS (see Table 6). Generally, there is no evidence of a significant decline of heavier MW PAH from the two data sets, with only Ac, Fl, Ph, An, 2-MePh, 1+9-MePh, Fluo and B[b+j+k]F showing a statistically significant decline ( $p < 0.05$ ). Further attempt for statistical analysis had been done by separating data set into three groups (i.e. group1: 2000, group2: 2001-2002 and group3: 2003-2004). For lighter MW compounds such as Ac, Ace, Fl, Ph, An, 2-MePh, Fluo, Py and Ret, a significant level of decline [ $F(2, 40) = 3.23, p < 0.05$ ] was observed by using one-way independent ANOVA analysis. Overall, these statistical results reveal the significant decrease of LMW PAHs at the BROS. It is worth mentioning that confounding factors such as "revolatilisation", "fluctuation of mixing layer depth", "variation of long range atmospheric transportation (LRAT)", "change of source fingerprint" and "chemical degradation" can have a huge impact on the variation of LMW PAH concentrations. Therefore, the data analysis must be performed with great caution. Since there is no significant difference in ambient temperature during the monitoring period, the revolatilisation effect is probably not the major factor responsible for this decline. The strong positive correlation ( $R = 0.95$ ) between annual mean sum (P+V) of individual PAH (2000-2001) vs PAH (2001-2004) observed at the BROS suggests that the overall PAHs distribution is constant at the traffic site. This finding is in consistent with the high value of  $R = 0.99$  reported by Laurie (2002) at the same site, indicating that "change of source fingerprint" might have minor importance for the reduction of LMW PAHs. Furthermore, the more volatile PAHs such as Ac, Fl and Ph, in general, are not efficiently trapped by catalytic converter (Kado et al., 1996). By contrast, the trapping efficiency would be

greater for PAHs containing five or more rings.

The fluctuation of mixing layer depth will affect the change of individual PAHs concentration equally, and thus this phenomenon cannot be attributed to the decrease of volatile PAHs. In addition it should be emphasised that the BROS is adjacent to the ongoing primary emission sources of PAHs, suggesting that LRAT would have little impact on the reduction of LMW PAHs. The most convincing explanation, therefore, was plausibly attributed to the increase of ozone level observed at the DEFRA monitoring site in Birmingham City Centre. As illustrated in Table 7, the atmospheric content of ozone in 2003 ( $42 \pm 17 \mu\text{g m}^{-3}$ ) was 1.16 time higher than those of 2001 ( $36 \pm 11 \mu\text{g m}^{-3}$ ). It is well known that the volatile PAHs interact with several atmospheric photo-oxidants such as O<sub>3</sub>, NO<sub>2</sub>, NO<sub>3</sub> and OH (Gigliotti et al., 2000; Ho et al., 2002), whereas the 5- and 6-ring PAHs are hardly influenced by gas-particle partitioning effects and thus more appropriate to be specifically assessed the impacts of chemical degradation on particle-bound PAHs. It is therefore reasonable to assume that the reduction of more volatile PAHs at the BROS is mainly caused by chemical reaction with photo-oxidants such as O<sub>3</sub>.

In conclusion, the variations of retene during the Bonfire night were investigated by conducting air monitoring from 5<sup>th</sup> November 2003 to 7<sup>th</sup> November 2003. The "Bonfire Night" festival is an annual British event that involves setting off fireworks and lighting bonfire and its anniversary is centred on the 5<sup>th</sup> November and spills over to adjacent dates. The highest concentrations of sum (P+V) retene were detected on 6<sup>th</sup> November 2003 with the concentration of 1.115 ng m<sup>-3</sup>, which exceeded the value of the BROS (0.094 ng m<sup>-3</sup>) and annual mean of the EROS (0.075 ng m<sup>-3</sup>) for 12 and 15 times respectively. This result supported the idea that wood combustion during the bonfire night festival is the major source of retene (Fang et al., 1999). The latest results from Johansson et al. (2001), however, reported that retene has also been detected in traffic emissions and thus its use as a unique tracer for coniferous wood combustion may be questioned.

## Acknowledgements

This work was performed with the approval of National Institute of Development Administration (NIDA). The author acknowledges Prof. Dr. Roy M Harrison for his contributions to the project's guidance.

## References

- Azevedo D, Moreira LS, Siqueira DS (1999). Composition of extractable organic matter in aerosols from urban areas of Rio de Janeiro city, Brazil. *Atmos Environ*, **33**, 4987-5001.
- Baek SO, Goldstone ME, Kirk PW, Lester JN, Perry R (1992). Concentrations of particulate and gaseous polycyclic aromatic hydrocarbons in London air following a reduction in the lead content of petrol in the UK. *Sci Tot Environ*, **111**, 169-99.
- Bidleman TF, Billings WN, Foreman WT (1986). Vapour-particle partitioning of semi-volatile organic compounds estimates from Field Collections. *Environ Sci Technol*, **20**, 1038-43.
- Bray EE, Evans ED (1961). Distribution of n-paraffins as a

- clue to recognition of source beds. *Geochim Cosmochim Acta*, **22**, 2-15.
- Cecinato A, Marino F, Filippo P, Lepore L, Possanzini M (1999). Distribution of n-alkanes, polynuclear aromatic hydrocarbons and nitrated aromatic hydrocarbons between the fine and coarse fractions of inhalable atmospheric particulates. *J Chromatogr A*, **846**, 255-64.
- Chuang JC, Hannan SW, Wilson NK (1987). Field comparison of polyurethane foam and XAD-2 resin for air sampling for polynuclear aromatic hydrocarbons. *Environ Sci Technol*, **21**, 798-804.
- EPA Appendix A to 40 CFR, Part 423-126 Priority Pollutants Available from: <http://www.epa.gov/region01/npdes/permits/generic/prioritypollutants.pdf>, (2003).
- Fernades MB, Brickus LSR, Moreira JC, Cardoso JN (1999). Atmospheric carcinogens in Rio de Janeiro during the summer of 1998/99: benzo[a]pyrene and benzene. *Rev Environ Health*, **14**, 145-57.
- García L, Boer D (1996). Determination of non-and mono-ortho-polychlorinated biphenyls in background ambient air. *Environ Sci Technol*, **30**, 1032-7.
- Giglioti CL, Dachs J, Nelson ED, Brunciak PA, Eisenreich SJ (2000). Polycyclic aromatic hydrocarbons in New Jersey coastal atmosphere. *Environ Sci Technol*, **34**, 3547-54.
- Gogou A, Stratigakis N, Kanakidou M, Stephanou E (1996). Organic aerosol in Eastern Mediterranean: component source reconciliation by using molecular markers and atmospheric back trajectories. *Org Geochem*, **25**, 79-96.
- Harrad S, Hassoun S, Romero CSM, Harrison MR (2003). Characterisation and source attribution of the semi-volatile organic content of atmospheric particles and associated vapour phase in Birmingham, UK. *Atmos Environ*, **37**, 4985-91.
- Harrison RM, Smith DJT, Luhana L (1996). Source apportionment of atmospheric polycyclic aromatic hydrocarbons collected from an Urban Location in Birmingham, UK. *Environ Sci Technol*, **30**, 825-32
- Hart KM, Isabelle LM, Pankow JF (1992). High-volume air sampler for particle and gas sampling. 1. Design and gas sampling performances. *Environ Sci Technol*, **26**, 1048-52.
- Hart KM, Pankow JF (1994). High-volume air sampler for particle and gas sampling. 2. Use of backup filters to correct for the adsorption of gas-phase polycyclic aromatic hydrocarbons to the front filter. *Environ Sci Technol*, **28**, 655-61.
- Ho KF, Lee SC, Ciu GMY (2002). Characterization of selected volatile organic compounds, polycyclic aromatic hydrocarbons and carbonyl compounds at a roadside monitoring station. *Atmos Environ*, **36**, 57-65.
- International Agency for Research on Cancer (1983). IARC Monographs on the evaluation of the carcinogenic risk of chemicals to man, Vol.32: Polycyclic aromatic hydrocarbons, Part 1: Chemical, environmental and experimental data. IARC, Lyon, France.
- International Agency for Research on Cancer (1984). IARC Monographs on the evaluation of the carcinogenic risk of chemicals to man, Vol.34: Polycyclic aromatic hydrocarbons, Part 3: Industrial exposures in aluminium production, coal gasification, coke production, and iron and steel founding. IARC, Lyon, France.
- International Agency for Research on Cancer (1985). IARC Monographs on the evaluation of the carcinogenic risk of chemicals to man, Bitumens, coal-tars and derived products, shale-oils and soots. Monograph No 35, IARC, Lyon, France.
- International Agency for Research on Cancer (1987). IARC Monographs on the evaluation of the carcinogenic risk of chemicals to man, Supplement, IARC, Lyon, France.
- Kado YN, Okamoto AR, Kuzmicky AP (1996). Chemical and bioassay analyses of diesel and biodiesel particulate matter: Pilot Study, Final Report. Department of Environmental Toxicology, University of California, Davis, California.
- Kalaitzoglou M, Terzi E, Samara C (2004). Patterns and sources of particle-phase aliphatic and polycyclic aromatic hydrocarbons in urban and rural sites of western Greece. *Atmos Environ*, **38**, 2545-60.
- Laurie HE (2002). Source apportionment of urban atmospheric polycyclic aromatic hydrocarbons, A PhD thesis submitted to the University of Birmingham for the degree of Doctor of Philosophy.
- Lim HL, Harrison MR, Harrad S (1999). The contribution of traffic to atmospheric concentrations of polycyclic aromatic hydrocarbons. *Environ Sci Technol*, **33**, 3538-42.
- Peters AJ, Lane DA, Gundel LA, Northcott GL, Jones KC (2000). A comparison of high volume and diffusion denuder samplers for measuring semi-volatile organic compounds in the atmosphere. *Environ Sci Technol*, **34**, 5001-6.
- Pongpiachan S, Thamanu K, Ho KF, Lee SC, Sompongchaiyakul P (2009a). Predictions of gas-particle partitioning coefficients ( $K_p$ ) of polycyclic aromatic hydrocarbons at various occupational environments of Songkhla province, Thailand. *Southeast Asian J Trop Med Public Health*, **40**, 1377-94.
- Pongpiachan S, Bualert S, Sompongchaiyakul P, Kositanont C (2009b). Factors affecting sensitivity and stability of polycyclic aromatic hydrocarbons. *Anal Lett*, **42**, 2106-30.
- Pongpiachan S, Thumanu K, Kositanont C, et al (2012). Parameters Influencing Sulfur Speciation in Environmental Samples Using Sulfur K-Edge X-Ray Absorption Near-Edge Structure (XANES). *J Anal Methods Chem*, **2012**, 659858.
- Pongpiachan S, Choochuay C, Hattayanone M, Kositanont C (2013a). Temporal and spatial distribution of particulate carcinogens and mutagens in Bangkok, Thailand. *Asian Pac J Cancer Prev*, **14**, 1879-87.
- Pongpiachan S (2013b). Vertical distribution and potential risk of particulate polycyclic aromatic hydrocarbons in high buildings of Bangkok, Thailand. *Asian Pac J Cancer Prev*, **14**, 1865-77.
- Pongpiachan S (2013c). Diurnal variation, vertical distribution and source apportionment of carcinogenic polycyclic aromatic hydrocarbons (PAHs) in Chiang-Mai, Thailand. *Asian Pac J Cancer Prev*, **14**, 1851-63.
- Pongpiachan S, Ho KF, Cao J (2013d). Estimation of gas-particle partitioning coefficients ( $K_p$ ) of carcinogenic polycyclic aromatic hydrocarbons by carbonaceous aerosols collected at Chiang-Mai, Bangkok and Hat-Yai, Thailand. *Asian Pac J Cancer Prev*, **14**, 3369-84.
- Prince RC, Elmendoft DL, Lute RJ, Hsu CE (1994).  $17\alpha(H), 21\beta(H)$ -hopanes as a conserved internal marker for estimating the biodegradation of crude oil. *Environ Sci Technol*, **28**, 142-5.
- Ross BA, Jones MJ, Chaiklangmuang S, et al (2002). Measurement and prediction of the emission of pollutants from the combustion of coal and biomass in a fixed bed furnace. *Fuel*, **81**, 571-82.
- Simoneit BRT, Elias VO (2000). Organic tracers from biomass burning in atmospheric particulate matter over the ocean. *Mar Chem*, **69**, 301-12.
- Simoneit TRB (2004). Biomarkers (molecular fossils) as geochemical indicators of life. *Adv Space Res*, **33**, 1255-61.
- Stein AT, Angus L, Borrero E, Auguste JL, Wise L (1987). High-performance liquid-chromatographic assay for prostaglandins with the use of p-(9-anthroyloxy)phenacyl bromide. *J Chromatogr A*, **395**, 591-5.
- Tarek AT, Aboul-Kassim, Bernd RT Simoneit (1996). Lipid

*Siwatt Pongpiachan*

geochemistry of surficial sediments from the coastal environment of Egypt I. Aliphatic hydrocarbons — characterization and sources. *Mar Chem*, **54**, 135-58.

Yamamoto S, Otto A, Krumbiegel G, Simoneit TRB (2006). The natural product biomarkers in succinite, glessite and stantienite ambers from Bitterfeld, Germany. *Rev Palaeobot Palyno*, **140**, 27-49.

Zárate-del Valle FP, Simoneit TRB (2005). Hydrothermal bitumen generated from sedimentary organic matter of rift lakes-Lake Chapala, Citala Rift, western Mexico. *Appl Geochem*, **20**, 2343-50.