

# Evidence

## Landfill air quality monitoring: a supplementary survey

Report: P1-396/R2

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Miranda Kavanagh

**Director of Evidence**

# Executive summary

Surveys of air quality were carried out at two landfill sites. Enviro Consulting Ltd were commissioned to carry out one survey and the Environment Agency's National Laboratory Service conducted a survey at a second landfill.

The landfill sites were selected to be typical of sites accepting municipal solid waste and similar wastes. The surveys were a follow-up to an earlier, more detailed study of emissions from two landfill sites. Because this was a supplementary study, the two landfill sites are referred to as Site C and Site D. The surveys were designed to provide additional data on levels of specific air pollutants of potential concern to human health.

The substances where further data was sought were:

- arsine (also known as arsenic trihydride)
- chromium VI
- 1,2-dichloroethane
- dimethyl disulphide
- dimethyl sulphide
- formaldehyde (also known as methanal)
- methyl mercaptan (also known as methane thiol or thiomethane)
- polycyclic aromatic hydrocarbons (PAHs)
- stibine (also known as antimony trihydride)
- chloroethene (also known as vinyl chloride).

The levels of possible concern for the substances (health criteria values developed in the earlier study) are at very low concentrations and this presents difficulties in measuring the substances at the necessary limits of detection.

For Site C, preliminary tests were carried out to identify the highest sample volumes that could be taken for the substances. For eight of the ten substances/ groups under consideration, it was possible to measure concentrations at sufficiently low levels to enable an assessment of potential risks to health. For two substances, this was not possible. For these, the survey at Site C was carried out on the understanding that it would not be possible to detect levels of the substances if they were close to or below the 'health criteria values' developed in the previous project.

This study provided a snapshot of measurements at locations close to the two landfill sites in June 2009. Samples were taken over periods of a few hours for some substances, and from three days to a week for other substances. Measurements were taken at two locations at Site C and at three locations at Site D. Background measurements were taken at locations away from the landfill sites.

Measured levels of the following substances were within the project-specific health criteria values developed during the previous project:

- 1,2-dichloroethane
- dimethyl disulphide

- dimethyl sulphide
- methyl mercaptan
- PAHs, based on benzo(a)pyrene (however, care is needed in the interpretation of PAH concentrations)
- chloroethene.

Arsine and chromium VI were not detected during the survey. However, because of restrictions imposed by the methods used, it is not possible to say whether levels were above or below health criteria values for these substances, the exception being arsine at Site D, where the reporting limit was lower than the project-specific health criteria value.

Measurements for formaldehyde at Site C were below the project-specific health criteria value but at Site D measured values exceeded health criteria value at each of the three monitoring locations. A comparison of the formaldehyde measurements against World Health Organisation (WHO) air quality guidelines showed that all measured values were below the guideline level.

Thus, measured levels of these substances at the time and location of this survey did not give cause for concern.

Dioxins and furans were assessed in a different way. Comparing the levels measured in this study to those measured in the previous survey showed that the measured levels would not be expected to give cause for concern. Dioxins and furans were not measured at Site D.

Stibine was not measured at Site C or Site D, because of an inability to obtain the necessary sample tubes which could not be sourced in the UK at that time.

We recommend that further work be carried out to develop environmental measurement techniques able to detect arsine, chromium VI and stibine at sufficiently low levels to enable the potential health risks to be established with more confidence.

# Acknowledgements

We would like to express our thanks to the two landfill operators for their cooperation with this study.

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# 1 Introduction

## 1.1 Background

The Environment Agency carried out a research project on the exposure assessment of landfill sites (Environment Agency 2010). The project measured the concentrations of substances in air around two landfill sites and developed project-specific health criteria values. Measured concentrations were then compared against the project-specific health criteria values.

The Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT)<sup>1</sup> reviewed this work and identified some substances of potential concern to human health. This survey was designed to provide additional data on levels of these specific air pollutants.

The substances where further data were sought were:

- arsine (also known as arsenic trihydride)
- chromium VI
- 1,2-dichloroethane
- dimethyl disulphide
- dimethyl sulphide
- formaldehyde (also known as methanal)
- methyl mercaptan (also known as methane thiol or thiomethane)
- polycyclic aromatic hydrocarbons (PAHs)
- stibine (also known as antimony trihydride)
- chloroethene (also known as vinyl chloride).

The identities of the landfill sites at which measurements were carried out are confidential, continuing the approach adopted for the two landfills in the initial project.

The Committee on Toxicity released a Second Statement on Landfill Sites (COT 2010). To provide continuity with the terminology in that statement, the landfills in this study are referred to as Site C and Site D.

## 1.2 The study at Site C

### 1.2.1 Outline

Enviros Consulting Ltd was commissioned by the Environment Agency to carry out a survey of air quality at a landfill site (Site C).

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<sup>1</sup> <http://cot.food.gov.uk/>

The ambient air monitoring study was carried out with regard to the methods recommended in Environment Agency Technical Guidance Note M9 (Environment Agency 2000).

Two survey locations were identified at Site C. These are shown in the schematic plan in Appendix 1. Survey location 1 was south of the landfill site, and was used when the wind had a northerly component, and for all three-day samples. Survey location 2 was to the north-west of the site, and was used when the wind had a southerly component.

A mains powered high rate sampler was used for the three-day samples. Battery-operated samplers were used for the shorter duration samples.

### **1.2.2 Preliminary testing**

A preliminary evaluation indicated that measurement techniques for some substances might not be sufficiently sensitive to confirm substances of concern at levels as low as the proposed health criteria values.

Preliminary testing was carried out in the laboratory to explore the possibility of increasing sample times/flow rates above the values set out in the established methods. Preliminary testing was carried out for the following substances:

- 1,2-dichloroethane
- methyl mercaptan
- chloroethene.

This was also a concern over limits of detection for chromium VI, but it was not possible to carry out preliminary testing for this substance due to health and safety concerns.

The results of the preliminary testing are set out in Section 3.1.1.

### **1.2.3 Substances measured**

For the following substances, six samples, each over a period of up to six hours, were taken at the two survey locations and one sample, over approximately four hours, was taken at a background location away from any landfill sites:

- arsine
- chromium VI
- 1,2-dichloroethane
- dimethyl disulphide
- dimethyl sulphide
- formaldehyde
- methyl mercaptan
- chloroethene.

Two samples over a two-day period were taken at the southern survey location for the following substances:

- polycyclic aromatic hydrocarbons (PAHs)

- dioxins and furans and dioxin-like polychlorinated biphenyls (PCBs).

We intended to measure stibine, but the specialist sample medium required for this measurement was no longer available.

## 1.2.4 Programme

The study programme is set out in Table 1.1

**Table 1.1 Site C - Study programme**

<b>Date</b>	<b>Activity</b>	<b>Location</b>
Wednesday 10 June 2009	Commence first two-day sample	South
	Carry out four- to six-hour sample	South
Thursday 11 June 2009	Carry out four- to six-hour sample	South
Friday 12 June 2009	End first two-day sample	South
	Carry out four- to six-hour sample	North-west
Monday 15 June 2009	Commence second two-day sample	South
	Carry out four- to six-hour sample	South
Tuesday 16 June 2009	Carry out four- to six-hour sample	North-west
Wednesday 17 June 2009	End second two-day sample	South
	Carry out four- to six-hour sample	North-west
Thursday 18 June 2009	Carry out four- to six-hour sample	Background

## 1.3 The study at Site D

### 1.3.1 Outline

The Environment Agency's National Laboratory Service was commissioned to carry out an air quality survey at a landfill site (Site D).

Three survey locations were identified at Site D. These are shown in the schematic plan in Appendix 1. The locations were:

- on the south side away from tipping area relatively close to a moderately busy road;
- north west of landfill at perimeter away from tipping area alongside a quiet road;
- north east of landfill at perimeter closest to tipping area alongside a quiet road.

The background measurements were taken at the Environment Agency's Nottingham laboratory, an urban environment.

NIOSH (US National Institute for Occupational Safety and Health) sampling methods were used. Sampling rates complied with the methods; however, sample volumes were

increased to achieve the minimum reporting limits. The exception to this was arsine, where a higher capacity absorbent tube was used and the flow rate was increased.

Three sampling pumps were used at each location for a period of one week.

One pump was connected to an automatic sampling unit which exposed two thermal desorption tubes consecutively for 36 hours each, followed by sorbent tubes for formaldehyde for the remaining four days.

The other two pumps were independent, one used to sample for PAHs as particulate and vapour, the other for chromium on a filter and arsine on charcoal.

Battery-powered sampling pumps were used.

### 1.3.2 Substances measured

- arsine
- chromium VI
- formaldehyde
- polycyclic aromatic hydrocarbons (PAHs)
- a wide range of volatile organic compounds (VOCs), as listed in Table 1.2, including 40 substances listed as “air toxics” by the USEPA, and a further 34 commonly encountered substances.

**Table 1.2 Volatile organic compounds measured at Site C**

USEPA “air toxics”		Other commonly encountered compounds	
Dichlorodifluoromethane	1,2 dichloropropane	Pentane	Methyl isobutyl ketone
Chlorodifluoromethane	cis 1,3 dichloropropylene	Acetone	Butyl acetate
Dichlorotetrafluoroethane	Toluene	Dimethyl sulfide	2-Hexanol
Chloromethane	trans 1,3 dichloropropylene	Isopropyl Alcohol	n,n-dimethylformamide
Chloroethene	1,1,2 trichloroethane	Carbon disulphide	1-Methoxy-2-propyl acetate
Bromomethane	Tetrachloroethene	Isohexane	2-Ethoxyethyl acetate
Chloroethane	1,2 dibromoethane	Cyclopentane	Amyl acetate
Trichlorofluoromethane	Chlorobenzene	Methyl tertiarybutyl ether	2-Heptanol
1,1 dichloroethene	Ethyl benzene	n hexane (estimate)	2-butoxyethanol
Trichlorotrifluoroethane	Xylene (meta & para)	2-Butanone	Cyclohexanone
Dichloromethane	ortho xylene	Ethyl Acetate	2-ethylhexanol
trans 1,2 dichloroethene	Styrene	Tetrahydrofuran	1-methyl-2-pyrrolidinone
1,1 dichloroethane	1,1,2,2 tetrachloroethane	Isopropyl acetate	Dodecane
cis 1,2 dichloroethene	1,3,5 trimethylbenzene	2,2,4-trimethylpentane	Naphthalene
Chloroform	1,2,4 trimethylbenzene	Heptane	
1,1,1 trichloroethane	1,3 dichlorobenzene	1-Butanol	
Carbon tetrachloride	1,4 dichlorobenzene	1-methoxy-2-propanol	
Benzene	1,2 dichlorobenzene	n-Propyl acetate	
1,2 dichloroethane	1,2,4 trichlorobenzene	2-ethoxyethanol	
Trichloroethene	Hexachlorobutadiene	Dimethyldisulphide	

To achieve concentrations as low as the project-specific health criteria values, all determinations exceeded the recommended safe sampling volumes specified in the respective methods. Methods are designed for occupational situations where the concentrations of potential concern are typically much higher than the health criteria values developed in the landfill exposure assessment research (Environment Agency 2010).

Because stibine is unstable and readily oxidised, the sampling method for stibine requires the use of treated silica gel tubes. These are specific for this substance, the silica gel being treated with mercuric chloride. The two suppliers of this type of product, SKC and Sulpelco, were unable to supply the tubes. It might be possible to carry out in-house dosing of readily available silica gel tubes, but it would be necessary to validate the adsorption efficiency of stibine for any tubes produced in-house.

### **1.3.3 Programme**

Three monitors were set up around Site D in the locations described in Section 1.2.1. The monitors ran over a period of seven days from 2 June 2009.

## 2 Survey methods

### 2.1 Survey methods at Site C

#### 2.1.1 Site identification

The aim was to identify a site at which the survey could be carried out, which would be typical of sites accepting municipal solid waste and similar wastes.

The site at which the survey was carried out had the following characteristics:

- Capacity Approximately 3,000,000 tonnes
- Throughput Approximately 200,000 tonnes per year in the past, but recently reduced to around 100,000 tonnes per year
- Type of waste accepted Municipal solid waste and similar industrial/commercial waste; bagged asbestos-containing waste
- Quantity of waste in place Approximately 1,000,000 tonnes
- Local land use Urban fringe location; surrounding land uses mainly farm/rural, with scattered industrial and residential premises

#### 2.1.2 Limits of detection

It was important to ensure that the measurements would provide useful data in the context of the project-specific health criteria values (HCVs). Ideally, the technique should have a limit of detection significantly below the HCV. Proposed measurements were checked against the HCVs to identify any substances for which this criterion would not be achieved. These substances were considered in more detail.

Table 2.1 sets out achievable environmental limits of detection based on expected laboratory detection limits and published sample methods.

**Table 2.1 Site C - Detection limits based on published sample methods**

Substance	Desirable detection limit ( $\mu\text{g}/\text{m}^3$ ) (A)	Achievable laboratory detection limit ( $\mu\text{g}/\text{sample}$ ) (B)	Required sample volume ( $\text{m}^3/\text{sample}$ ) (C=B/A)	Method reference	Notes
Chromium VI	0.00025	0.05	200	NIOSH 7600	Membrane, colorimetric determination. Some possible interferences from Fe, Cu, Ni, V. Max vol 400 l
Arsine	0.0007	0.01	14	NIOSH 6001 modified	Carbon, nitric acid, ICP/MS (filter to stop aerosols, total As reported as $\text{AsH}_3$ ), max sample 10 l
1,2-Dichloroethane	0.036	0.005	0.14	MDHS 72 modified	Multitube tube, GC/MS (SIM), max volume around 10 l
Dimethyl disulphide	0.5	0.01	0.020	MDHS 89 modified	Multitube tube, GC/MS (SIM), max volume around 10 l
Dimethyl sulphide	0.5	0.01	0.020	MDHS 89 modified	Multitube tube, GC/MS (SIM), max volume around 10 l
Formaldehyde	1	0.01	0.010	OSHA 1007	Special Supelco Diffusive Sampler, LC/UV detection, up to 240 min, equivalent samp. rate 70 l/min ( $17 \text{ m}^3$ )
Methyl mercaptan	0.4	0.03	0.075	TO-17	Multitube tube, GC/MS (SIM), max volume around 10 l
PAHs, based on relative potencies including dibenzo [a,l] pyrene. benzo[a]anthracene chrysene benzo[b/k]fluoranthene benzo[a]pyrene Indeno[123-cd]pyrene dibenz[a,h]anthracene	0.00025 0.00075 0.00025 0.000025 0.00025 0.000015 0.000025	0.01	667	EPA TO13A	Filter/PUF, HR GC/MS, suggested volume $1,000 \text{ m}^3$
dioxins and furans (and their WHO PCB equivalents)	As per previous work, 10 fgTEQ/ $\text{m}^3$ or better	5 pg	500	EPA TO9A	Filter/PUF, HR GC/MS, suggested volume $1,000 \text{ m}^3$
Chloroethene	0.1	0.01	0.1	MDHS 72 etc modified	Multitube tube, GC/MS (SIM), max volume around 10 l

We found that published methods would give satisfactory limits of detection for the following substances:

- dimethyl disulphide
- dimethyl sulphide
- formaldehyde
- polycyclic aromatic hydrocarbons
- dioxins and furans

Survey methods would need to be adapted and tested for the following substances to ensure a satisfactory limit of detection:

- chromium VI
- arsine
- 1,2-dichloroethane
- methyl mercaptan
- chloroethene

Preliminary tests were carried out for 1,2-dichloroethane, methyl mercaptan and chloroethene to establish whether the sample volume for these substances could be increased. Dimethyl sulphide and dimethyl disulphide were included in these tests.

It was not possible to carry out preliminary tests for arsine or chromium VI because of health and safety concerns regarding the handling of hazardous materials. For these substances, the survey was carried out on the understanding that it would not be possible to detect levels of the substances close to or below the HCVs.

### 2.1.3 Sampling and analytical methodology

The sampling and analytical methodology is set out in the technical survey report in Appendix 2.

A health and safety plan was prepared, discussed with the landfill site manager and implemented during the survey.

## 2.2 Survey methods at Site D

### 2.2.1 Site identification

The landfill was selected as a typical landfill for non-hazardous waste accepting municipal solid waste and similar wastes.

The site at which the survey was carried out had the following characteristics:

- |                          |  |
|--------------------------|--|
| • Size of site           | One hundred hectares   |
| • Throughput             | Approximately 500,000 tonnes per year  |
| • Type of waste accepted | Municipal solid waste and similar industrial/commercial waste                                      |
| • Other activities       | Site incorporates stone-processing plant for concrete and road-surfacing material                  |
| • Local land use         | Rural location; surrounding land uses mainly agricultural/rural; industrial site on eastern border |

### 2.2.2 Minimum reporting values

The sampling methods used were taken from the NIOSH methods. These stipulate the flow rate for sampling. They also give maximum sampling volumes based on the method validation work at the appropriate concentrations of the substance in question.

To achieve limits of detection comparable to the health criteria values, the sampling volumes specified in the measurement methods were exceeded.

The minimum reporting values were as follows:

- Arsine - the minimum reporting value equates to 0.002  $\mu\text{g}/\text{m}^3$ .
- Formaldehyde – the minimum reporting value equates to 4  $\mu\text{g}/\text{m}^3$ .
- Chromium VI – the end-determination minimum reporting value equates to 6  $\text{ng}/\text{m}^3$ . As no results exceeded this figure, the measured concentrations were reported for information.
- PAHs – a guide to the minimum reporting value is three times the blank equivalent concentration, as set out in the final column of Table 3.6.
- VOCs – the arbitrary reporting limit is 20 nanogrammes for any substance on the tube which equates to 0.06 micrograms per cubic metre.

### 2.2.3 Sampling and analytical methodology

Three pumps were used to collect air samples at each of the three locations.

One pump, running at approximately 200 millilitres per minute, was connected to an auto-sampler and was used to collect VOCs on thermal desorption tubes for two consecutive 36-hour periods, and then for the remaining four days, formaldehyde onto a dedicated adsorbent tube.

Two pumps, running at approximately two litres per minute, were used to sample polycyclic aromatic hydrocarbons (PAHs) as particulate and vapour, and chromium on a filter/ arsine on charcoal.

For arsine, NIOSH Method 6008 was used. The air was drawn through a filter to remove arsenic compounds present in particulate matter. The arsenic vapour was then trapped on a charcoal adsorbent. Sampling was for one week at approximately two litres per minute.

For formaldehyde, NIOSH Method 2016 was used. The air was drawn through a dedicated adsorbent, silica gel coated with 2,4-dinitrophenylhydrazine, for four days at 200 ml per minute.

NIOSH Method 7600 was used for chromium, where all forms were trapped on a PVC membrane. The membrane was digested according to NIOSH 7600, to bring into solution both soluble and insoluble chromium VI compounds whilst preserving the oxidation state. The concentration of chromium VI was determined colourimetrically. Subsequent analysis determined the chromium VI present. The air was sampled at a rate of approximately two litres per minute for one week.

For PAHs, NIOSH Method 5506 was used. Air was drawn through a PTFE membrane and onto a dedicated adsorbent tube (XAD-2 resin) at a rate of two litres per minute for one week. Analysis of the filter and adsorbent tube was carried out separately to distinguish between PAHs as vapour and PAHs adsorbed onto particulate matter.

VOCs were sampled at approximately 200 millilitres per minute for 36 hours. Two 'air toxic' tubes were site-sampled consecutively at each location.

# 3 Results

## 3.1 Results for Site C

### 3.1.1 Preliminary testing

The results of preliminary testing are shown in Table 3.1. This table shows the proportion of material recovered from a sample medium 'spiked' with a known quantity of each determinand, after a known volume of air was passed through the medium.

**Table 3.1 Site C results of preliminary tests**

Substance	Proportion of determinand remaining after purging (%)		
	12 litres air	36 litres air	100 litres air
Chloroethene	92	73	0
Methyl mercaptan	56	67	0
Dimethyl sulphide	82	84	38
1,2-Dichloroethane	104	116	37
Dimethyl disulphide	40	46	75

The results in Table 3.6 show that sample volumes for substances listed in Table 3.1 should not exceed approximately 50 litres. At higher volumes, there is a risk that the substances may be stripped from the sample medium, and consequently that airborne concentrations of the substances could be under-reported. Anomalous results were obtained for dimethyl disulphide. In view of the consistent results obtained for the other substances, the results for dimethyl disulphide were disregarded.

The sample volumes used for these substances were therefore around 50 litres. This was expected to provide satisfactory limits of detection for dimethyl disulphide and dimethyl sulphide, and close to satisfactory limits of detection for chloroethene, methyl mercaptan and 1,2-dichloroethane.

### 3.1.2 Survey results

The survey results are set out in Table 3.2 below.

**Table 3.2 Site C survey results**

Substance	Sample period	HCV ( $\mu\text{g}/\text{m}^3$ )	Measured concentration ( $\mu\text{g}/\text{m}^3$ )						
			10/06	11/06	12/06	15/06	16/06	17/06	18/06
			Loc 1	Loc 1	Loc 2	Loc 1	Loc 2	Loc 2	Back-ground
1,2-Dichloroethane	4 hours	0.36	<0.02	0.13	<0.02	<0.03	<0.02	<0.02	<0.03
Dimethyl disulphide	4 hours	5	<0.02	<0.02	<0.02	<0.03	<0.02	<0.02	<0.03
Dimethyl sulphide	4 hours	5	<0.15	<0.21	<0.22	<0.33	<0.20	<0.21	<0.30
Methane thiol	4 hours	4	<0.15	<0.21	<0.22	<0.33	<0.20	<0.21	<0.30
Chloroethene	4 hours	1	<0.03	<0.04	<0.04	<0.07	<0.04	<0.04	<0.06
Arsine	4 hours	0.007	<0.012	<0.010	<0.010	<0.015	<0.011	<0.010	<0.013
Formaldehyde	4 hours	10	4.6	1.8	1.6	<1.2	1.6	1.6	1.2
Chromium VI	6-8 hours	0.0025	<1	<1	<1	<2	<1	<1	<1
			Location 1			Location 1			
Dioxins and furans	54 hours		4.2-8.6 fg ITEQ/m <sup>3</sup>			11.6-13.2 fg ITEQ/m <sup>3</sup>			NM
Benzo(a)pyrene	54 hours	0.00025	0.00011			<0.00011			NM
Wind direction			North	North/north-west	South/south-east	North-north-west	South	South/south-east	NA

NM: Not Measured, NA: Not Applicable

Measured levels of PAHs and PCBs are given in Table 3.3 and Table 3.4 below.

**Table 3.3 Site C measured levels of PAHs**

Substance	Measured concentration ( $\mu\text{g}/\text{m}^3$ )	
	10-12 June 2009	15-18 June 2009
Acenaphthene	0.00011	0.00045
Acenaphthylene	<0.00011	0.00011
Anthracene	0.00022	0.00022
Benzo(a)anthracene	0.00022	0.00011
Benzo(a)pyrene	0.00011	0.00011
Benzo(b/k)fluoranthene	0.00022	0.00022
Benzo(ghi)perylene	0.00011	0.00022
Chrysene	0.00101	0.00011
Dibenzo(ah)anthracene	<0.00011	0.00011
Fluoranthene	0.00213	0.00258
Fluorene	0.00157	0.00123
Indeno(123-cd)pyrene	0.00011	0.00011
Naphthalene	0.00022	0.00011
Phenanthrene	0.00931	0.00976
Pyrene	0.0009	0.00112
Dibenzo(al)pyrene	Not measured	Not measured

**Table 3.4 Site C measured levels of PCBs**

Substance	Measured concentration (pg/m <sup>3</sup> )	
	10-12 June 2009	15-18 June 2009
PCB BZ#105	0.6	<0.6
PCB BZ#114	<0.6	<0.6
PCB BZ#118	1.8	1.3
PCB BZ#123	<0.6	<0.6
PCB BZ#126	<0.6	<0.6
PCB BZ#156	<0.6	<0.6
PCB BZ#157	<0.6	<0.6
PCB BZ#167	<0.6	<0.6
PCB BZ#169	<0.6	<0.6
PCB BZ#189	<0.6	<0.6
PCB BZ#77	<0.6	<0.6
PCB BZ#81	<0.6	<0.6

## 3.2 Results for Site D

The survey results are set out in Table 3.5 to Table 3.8.

**Table 3.5 Site D results**

Substance	HCV(µg/m <sup>3</sup> )	Measure concentration (µg/m <sup>3</sup> )			
		Background	South	NE	NW
Arsine	0.007	<0.002	<0.002	<0.002	<0.002
Formaldehyde	10	<4	46	38	35
Chromium VI	0.0025	<0.006 (0.0041)	<0.006 (0.0017)	<0.006 (0.0026)	<0.006 (0.0017)

Laboratory results for chromium are reported in brackets. All were below the reporting limit.

**Table 3.6 Site D PAH measurements**

	Background filter ng/m <sup>3</sup>	Background absorption tube ng/m <sup>3</sup>	South filter ng/m <sup>3</sup>	South absorption tube ng/m <sup>3</sup>	NE filter ng/m <sup>3</sup>	NE absorption tube ng/m <sup>3</sup>	NW filter ng/m <sup>3</sup>	NW absorption tube ng/m <sup>3</sup>	Crude MRV: 3x proc blank ng/m <sup>3</sup>
Naphthalene	0.11 (ND)	4.66	0.01 (ND)	87.03	<0.01 (ND)	21.01	<0.01 (ND)	26.52	1.94
Acenaphthylene	0.01 (ND)	0.39	<0.01 (ND)	0.30	0.01 (ND)	0.06 (ND)	0.02 (ND)	0.12	0.10
Acenaphthene	<0.01 (ND)	4.62	<0.01 (ND)	1.59	0.02 (ND)	0.56	0.01 (ND)	0.99	0.51
Fluorene	0.01 (ND)	4.41	<0.01 (ND)	1.51	<0.01 (ND)	0.54 (ND)	<0.01 (ND)	1.33	0.57
Phenanthrene	0.07 (ND)	6.09	0.03 (ND)	1.26	0.02 (ND)	0.68	0.04 (ND)	1.53	0.62
Anthracene	0.03 (ND)	0.17	0.01 (ND)	0.12	<0.01 (ND)	0.06 (ND)	0.03 (ND)	0.10	0.09
Fluoranthene	0.08 (ND)	0.39	<0.01 (ND)	0.14 (ND)	<0.01 (ND)	0.10 (ND)	0.06 (ND)	0.15 (ND)	0.31
Pyrene	0.06 (ND)	0.27 (ND)	<0.01 (ND)	0.08 (ND)	<0.01 (ND)	0.07 (ND)	0.05 (ND)	0.08 (ND)	0.33
Benzo(a)anthracene	0.03 (ND)	0.04 (ND)	<0.01 (ND)	0.08 (ND)	<0.01 (ND)	0.08 (ND)	0.02 (ND)	0.06 (ND)	0.11
Chrysene	0.06 (ND)	0.05 (ND)	0.01 (ND)	0.06 (ND)	0.01 (ND)	0.05 (ND)	0.05 (ND)	0.04 (ND)	0.14
Benzo(b)fluoranthene	0.14	0.06 (ND)	0.02 (ND)	0.07	0.03 (ND)	0.06 (ND)	0.09	0.06 (ND)	0.07
Benzo(k)fluoranthene	0.04 (ND)	0.05 (ND)	<0.01 (ND)	0.05 (ND)	<0.01 (ND)	0.04 (ND)	0.04 (ND)	0.05 (ND)	0.06
Benzo(a)pyrene	0.03 (ND)	0.05 (ND)	<0.01 (ND)	0.06	<0.01 (ND)	<0.01 (ND)	0.05 (ND)	<0.01 (ND)	0.06
Inden(1,2,3,cd)pyrene	0.12	0.04 (ND)	<0.01 (ND)	0.08	<0.01 (ND)	<0.01 (ND)	<0.01 (ND)	<0.01 (ND)	0.08
Dibenzo(ah)anthracene	0.07	0.07	<0.01 (ND)	0.07	0.01 (ND)	<0.01 (ND)	<0.01 (ND)	0.03 (ND)	0.06
Benzo(ghi)perylene	0.08 (ND)	<0.01 (ND)	<0.01 (ND)	<0.01 (ND)	<0.01 (ND)	<0.01 (ND)	<0.01 (ND)	<0.01 (ND)	0.31
Dibenzo(a,l)pyrene	0.01 (ND)	0.07	<0.01 (ND)	0.06 (ND)	0.03 (ND)	0.01 (ND)	<0.01 (ND)	0.02 (ND)	0.07

Figures given are net of procedure blank. Some of the figures given as <0.01 were below the procedural blank concentrations. The last column is three times the procedure blank; figures below these should strictly be discounted, that is, considered to be below the detection limit. These are shown as non detects 'ND'.

Table 3.7 Site D VOC results, USEPA “air toxics” compounds

	Background $\mu\text{g}/\text{m}^3$		South $\mu\text{g}/\text{m}^3$		NE $\mu\text{g}/\text{m}^3$		NW $\mu\text{g}/\text{m}^3$	
	Tube 1	Tube 2	Tube 1	Tube 2	Tube 1	Tube 2	Tube 1	Tube 2
Dichlorodifluoromethane	0.06	0.06	<0.06	<0.06	0.01	<0.06	<0.06	<0.06
Chlorodifluoromethane (estimated)	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Dichlorotetrafluoroethane	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Chloromethane	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Chloroethene	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Bromomethane	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Chloroethane	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Trichlorofluoromethane	0.16	0.15	<0.06	<0.06	0.36	<0.06	<0.06	<0.06
1,1-dichloroethylene	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Trichlorotrifluoroethane	0.04	<0.06	<0.06	<0.06	0.05	<0.06	<0.06	<0.06
Dichloromethane	0.09	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Trans 1,2-dichloroethylene	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
1,1-dichloroethane	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Cis 1,2-dichloroethylene	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Chloroform	0.01	0.01	<0.06	<0.06	0.02	<0.06	<0.06	<0.06
1,1,1-trichloroethane	<0.06	<0.06	<0.06	<0.06	0.01	<0.06	<0.06	<0.06
Carbon tetrachloride	0.02	0.02	<0.06	<0.06	0.07	<0.06	<0.06	<0.06
Benzene	0.06	0.05	0.06	0.13	0.07	0.04	0.01	0.03
1,2-dichloroethane	<0.06	0.01	<0.06	<0.06	0.02	<0.06	<0.06	<0.06
Trichloroethylene	<0.06	<0.06	<0.06	<0.06	0.01	<0.06	<0.06	<0.06
1,2-dichloropropane	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Cis 1,3-dichloropropylene	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Toluene	0.35	0.43	0.10	0.23	0.19	0.10	0.14	0.07
Trans 1,3-dichloropropylene	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
1,1,2-trichloroethane	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Tetrachloroethylene	<0.06	<0.06	<0.06	<0.06	0.01	0.01	<0.06	<0.06
1,2-dibromoethane	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Chlorobenzene	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Ethyl benzene	0.10	0.08	0.02	0.06	0.06	0.02	0.03	0.02
Xylene (meta & para)	0.32	0.24	0.06	0.19	0.14	0.08	0.09	0.11
Ortho xylene	0.14	0.10	0.02	0.06	0.06	0.02	0.03	0.03
Styrene	0.02	<0.06	<0.06	<0.06	0.01	<0.06	<0.06	<0.06
1,1,1,2-tetrachloroethane	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
1,3,5-trimethylbenzene	0.05	0.04	<0.06	0.01	0.01	<0.06	<0.06	<0.06
1,2,4-trimethylbenzene	0.24	0.19	0.02	0.05	0.05	0.02	0.03	0.05
1,3-dichlorobenzene	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
1,4-dichlorobenzene	0.02	0.03	<0.06	<0.06	<0.06	0.01	<0.06	<0.06
1,2-dichlorobenzene	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
1,2,4-trichlorobenzene	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Hexachlorobutadiene	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06

**Table 3.8 Site D VOC results for other commonly encountered compounds**

	Background $\mu\text{g}/\text{m}^3$		South $\mu\text{g}/\text{m}^3$		NE $\mu\text{g}/\text{m}^3$		NW $\mu\text{g}/\text{m}^3$	
	Tube 1	Tube 2	Tube 1	Tube 2	Tube 1	Tube 2	Tube 1	Tube 2
Pentane (estimate)	0.09	0.06	<0.06	0.01	0.06	0.17	<0.06	0.26
Acetone	0.29	0.19	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Dimethyl sulphide	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Isopropyl alcohol	0.01	0.01	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Carbon disulphide	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Isohexane	<0.06	0.04	<0.06	<0.06	0.01	<0.06	<0.06	<0.06
Cyclopentane	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Methyl tertiarybutyl ether	0.01	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
n hexane (estimate)	0.02	0.01	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
2-Butanone	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Ethyl acetate	0.02	0.04	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Tetrahydrofuran	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Isopropyl acetate	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
2,2,4-trimethylpentane	0.02	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Heptane	0.03	0.04	<0.06	<0.06	0.01	<0.06	<0.06	<0.06
1-Butanol	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
1-methoxy-2-propanol	<0.06	<0.06	<0.06	0.01	<0.06	<0.06	<0.06	<0.06
n-Propyl acetate	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
2-ethoxyethanol	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Dimethyldisulphide	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Methyl isobutyl ketone	0.01	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Butyl acetate	0.05	0.09	0.01	0.01	<0.06	<0.06	<0.06	<0.06
2-Hexanol	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
n,n-dimethylformamide	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
1-Methoxy-2-propyl acetate	0.01	0.02	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
2-Ethoxyethyl acetate	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Amyl acetate	<0.06	<0.06	0.01	0.02	0.02	<0.06	<0.06	<0.06
2-Heptanol	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
2-butoxyethanol	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Cyclohexanone	<0.06	<0.06	<0.06	<0.06	0.01	<0.06	<0.06	<0.06
2-ethylhexanol	0.03	0.01	<0.06	0.03	<0.06	0.01	0.02	0.02
1-methyl-2-pyrrolidinone	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Dodecane	0.11	0.06	0.04	0.08	0.06	0.05	0.05	0.05
Naphthalene	0.04	0.02	0.01	0.02	0.03	0.02	0.02	0.02

Highlighted rows are the specific substances of interest

# 4 Conclusions and recommendations

## 4.1 Introduction

This survey provided a snapshot of measurements at locations close to the two landfill sites. It must be remembered when drawing conclusions that the airborne levels of these substances would be different:

- at different locations around the site;
- at different landfill sites;
- at different times;
- under different weather conditions.

## 4.2 Comparison with health criteria values

The study on the exposure assessment of landfills (Environment Agency 2010) developed project-specific health criteria values. Measured concentrations from this survey were assessed against the health criteria values for those substances where further data was sought by the Committee on Toxicity. Table 4.1 sets out the project-specific health criteria values.

**Table 4.1 Health criteria values from Environment Agency 2010**

Substance	Health criteria values ( $\mu\text{g}/\text{m}^3$ )
Arsine	0.007
Chromium VI	0.0025
1,2-Dichloroethane	0.36
Dimethyl disulphide	5
Dimethyl sulphide	5
Formaldehyde	10
Methyl mercaptan	4
PAHs (as benzo(a)pyrene)	0.00025
Stibine	5
Chloroethene	1

Measured levels of the following substances were lower than health criteria values:

- 1,2-dichloroethane
- dimethyl disulphide
- dimethyl sulphide
- methyl mercaptan (methane thiol)
- PAHs, based on benzo(a)pyrene (see Section 4.3 below)

Arsine and chromium VI were not detected in the survey. However, because of restrictions imposed by the instruments used, it is not possible to say whether levels

were above or below the health criteria values for these substances. The exception was arsine at Site D, where the reporting limit of  $0.002 \mu\text{g}/\text{m}^3$  was within the project-specific health criteria value of  $0.007 \mu\text{g}/\text{m}^3$ .

Measurements for formaldehyde at Site C were within the health criteria value but at Site D measured values exceeded the health criteria value at each of the three monitoring locations. An investigation of the area around Site D revealed, on the eastern boundary of the site, a manufacturer of bespoke packaging and cases using wood. Wood particle board commonly uses a formaldehyde-based resin. Heat moulding of such material can release formaldehyde vapours. This possible source for formaldehyde has not been confirmed.

The COT Second Statement on Landfill (COT 2010) considered formaldehyde measurements against the World Health Organisation air quality (30-minute average) guideline of  $100 \mu\text{g}/\text{m}^3$ . All measured values were below this guideline level.

Thus, measured levels of these substances at the time and location of this survey did not give cause for concern.

Stibine was not measured at Site C or Site D and so no comparison can be made with the health criteria value.

Dioxins and furans need to be assessed in a different way because indirect exposure is likely to be more significant than direct exposure via inhalation. Measured levels of dioxins and furans were within the range of levels measured in the main project (Environment Agency 2010), and would not be expected to give cause for concern.

### 4.3 Polycyclic aromatic hydrocarbons

The health criteria value used in this study for benz(a)pyrene is specified on the basis that benz(a)pyrene accounts for around half the carcinogenic burden of six PAHs with known or suspected carcinogenic activity (Expert Panel on Air Quality Standards, 1999). Since publication of that report, a seventh PAH (dibenzo(al)pyrene) has been identified as having carcinogenic potential 10 to 100 times higher than benz(a)pyrene.

The carcinogenic burden of the suite of PAHs was calculated on the basis of published relative potency values for six PAHs (Environment Agency 2010), as set out in Table 4.2 below.

This calculation indicates that benz(a)pyrene accounted for 28 to 62 per cent of the carcinogenic activity of the sample taken on 10-12 June 2009 (Site C); up to 31 per cent for the sample taken on 13-16 June 2009 (Site C); and 30 per cent using the combined filter and absorption tube measurements for the samples taken on 2-9 June 2009 (Site D).

Including consideration of dibenzo(al)pyrene at Site D suggests that benzo(a)pyrene could account for one to seven per cent of the carcinogenic activity of this sample.

The health criteria value for benz(a)pyrene is specified on the basis that benz(a)pyrene accounts for approximately half of the carcinogenic activity of PAHs, not including dibenzo(al)pyrene. This condition was fulfilled for the three measurements of PAHs at Sites C and D. Measured levels of benzo(a)pyrene complied with the health criteria value. However, given the potential significance of levels of dibenzo(al)pyrene, care is needed in the interpretation of measured levels of PAHs.

## 4.4 Limits of Detection

We recommend that further work be carried out to develop environmental measurement techniques able to detect arsine, chromium VI and stibine at levels comparable with health criteria values used in the main research project (Environment Agency 2010).

This should be relatively straightforward for arsine, for which the technique used at Site C provided a detection limit which is approximately twice the HCV. At Site D the reporting limit was lower than the HCV, although the technique was not validated for the sample volume used at this site.

In the case of chromium VI, the technique used at Site C provided a detection limit which is several hundred times the HCV. At Site D a minimum reporting value close to the HCV was reached by extending the sample volume and optimising the digestion/ analytical procedure, although the technique was not validated for the sample volume used at this site.

One approach to establishing a higher sample volume for ambient air where concentrations are low would be to undertake simultaneous and consecutive sampling. The simplest way to achieve this would be to have two or more consecutive samples and one simultaneous sample covering the consecutive periods. As long as the concentration in each of the consecutive periods was above the detection limit, the result from the simultaneous sample could be used to validate a larger safe sampling volume.

**Table 4.2 Relative potency of potentially carcinogenic PAHs**

Substance	RP	Measured concentrations Site C 10 – 12 June 2009 (µg/m <sup>3</sup> )		Measured concentrations Site C 15 – 18 June 2009 (µg/m <sup>3</sup> )			Average measured concentrations Site D (µg/m <sup>3</sup> )	
		Measured	Relative to BaP (ND at DL)	Relative to BaP (ND at 0)	Measured	Relative to BaP (ND at DL)	Relative to BaP (ND at 0)	Measured
Benzo(a)anthracene	0.1	0.00022	0.000022	0.000022	< 0.00011	0.000011	0.00008	0.000008
Benzo(a)pyrene	1	0.00011	0.00011	0.00011	< 0.00011	0.00011	0.00004	0.00004
Benzo(b/k)fluoranthene	0.03	0.00022	0.0000066	0.0000066	0.00022	0.0000067	0.00017	0.0000051
Chrysene	0.03	0.00101	0.000030	0.0000303	< 0.00011	0.0000034	0.00007	0.0000022
Dibenzo(ah)anthracene	1.91	< 0.00011	< 0.00021		< 0.00011	< 0.00021	0.00004	0.00007
Indeno(123-cd)pyrene	0.08	0.00011	0.0000088	0.0000088	< 0.00011	0.0000090	0.00003	0.0000021
Dibenzo(a)pyrene	10 to 100	Not measured			Not measured		0.00004	0.0004 to 0.004
<b>Total carcinogenic PAHs excluding dibenzo(a)pyrene</b>			<b>0.00039</b>	<b>0.0001777</b>		<b>0.00036</b>	<b>0.0000067</b>	<b>0.000124</b>
<b>Proportion attributable to B(a)P</b>			<b>28%</b>	<b>62%</b>		<b>31%</b>	<b>0%</b>	<b>30%</b>
<b>Proportion attributable to B(a)P including dibenzo(a)pyrene</b>								<b>1-7%</b>

RP: Relative potency ND: Non-detected values DL: Detection limit B(a)P: benz(a)pyrene

# References

Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (2010) *Second Statement on Landfill Sites*.

Environment Agency (2000) *Technical Guidance Note M9 - Monitoring Methods for Ambient Air*.

Environment Agency (2010) *Exposure Assessment of Landfill Sites*.

Expert Panel on Air Quality Standards, Polycyclic Aromatic Hydrocarbons (1999) The Stationery Office London.

World Health Organisation (2000) *Air quality guidelines for Europe*. WHO Regional Publications, European Series, No. 91. Second edition. WHO Regional Office for Europe: Copenhagen.

# List of abbreviations

COT	Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment
HCV	Health criteria value
NIOSH	US National Institute for Occupational Safety and Health
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyls
USEPA	United States Environmental Protection Agency
VOC	Volatile organic compounds

# Appendix 1 – Monitoring point locations

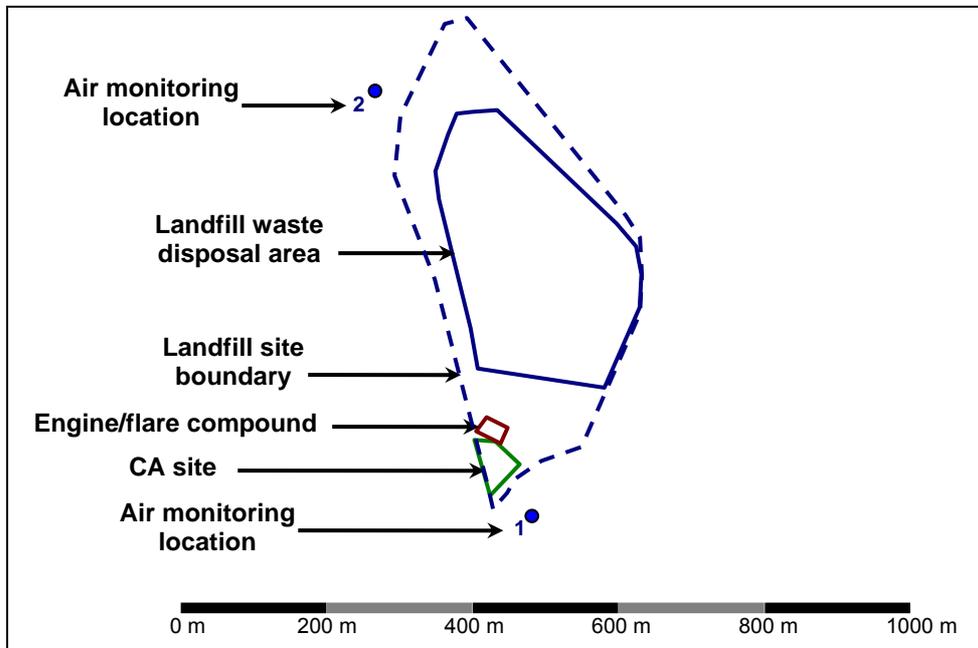
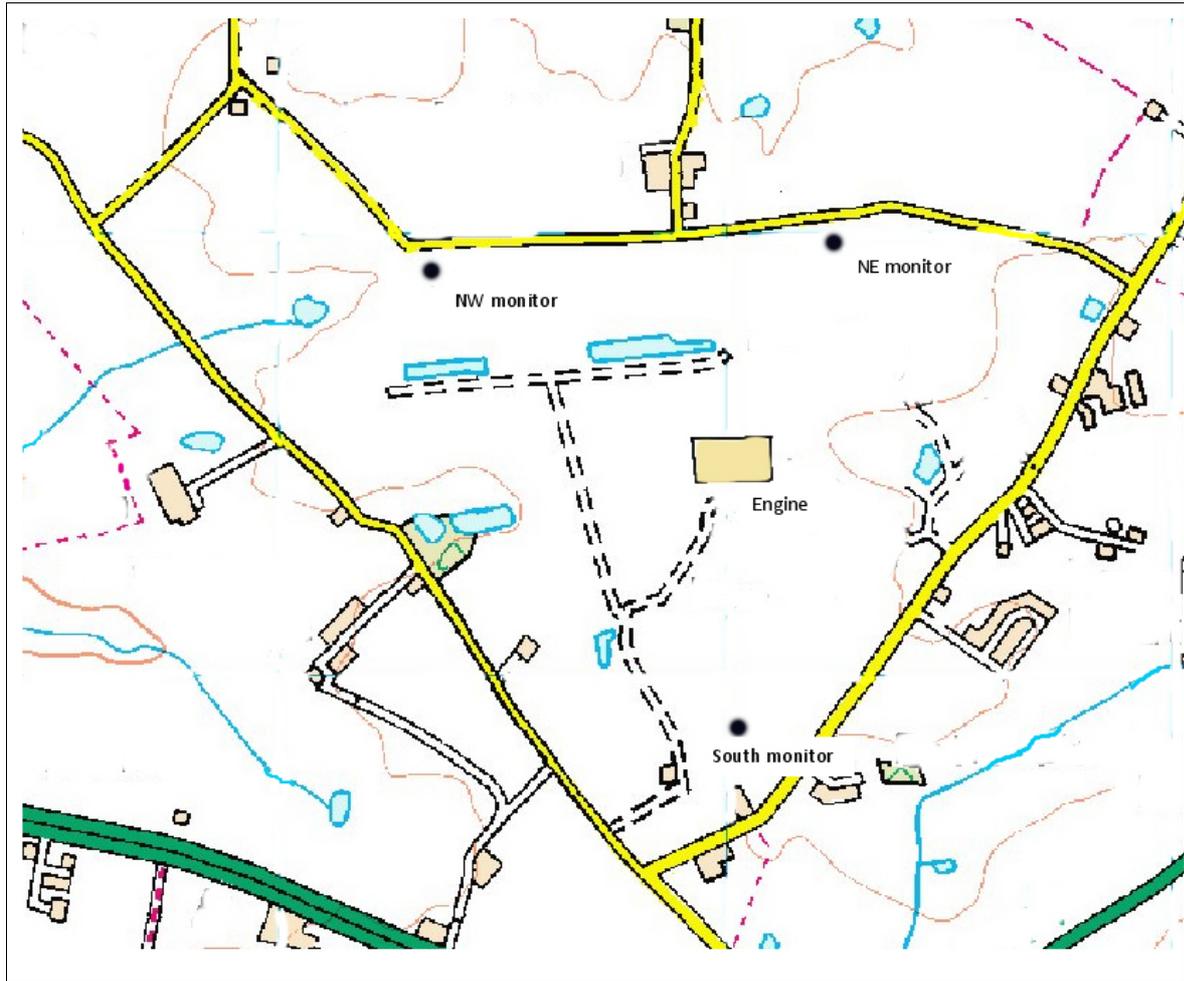


Figure A.1 Schematic of monitoring locations - Landfill C



**Figure A.2 Monitoring locations - Landfill D**

# Appendix 2 – Sampling and laboratory report for Site C

## MONITORING OF AMBIENT POLLUTANTS IN PROXIMITY TO LANDFILL OPERATIONS

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June, 2009

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## EXECUTIVE SUMMARY

Resource & Environmental Consultants (REC) Ltd was commissioned by Enviros Consulting Ltd to carry out an ambient air monitoring project to assess ambient air concentrations of various pollutants in proximity to landfill operations.

The monitoring programme included the collection and subsequent laboratory analysis of samples to determine ambient concentrations of the following volatile organic compounds (VOCs):

1,2 - Dichloroethane  
Dimethyl disulphide  
Dimethyl sulphide  
Formaldehyde  
Methane thiol  
Vinyl chloride  
Chromium (VI)

Samples were also collected to determine ambient concentrations of the following

Polychlorinated dibenzodioxins (PCDDs) and Polychlorinated dibenzofurans (PCDFs)  
Polyaromatic hydrocarbons (PAHs) in particular; benzo[a]anthracene, chrysene, benzo[b/k]fluoranthene, benzo[a]pyrene, Indeno[123-cd]pyrene, dibenz[a,h]anthracene, dibenzo [a,l] pyrene.

Samples were collected over the period 10 – 12 June, 2009 and 15-17 June, 2009.

An additional set of VOC samples were also collected on 18 June, 2009 at the offices of Enviros in Shrewsbury. These were to be used as method backgrounds/blanks .

Section 2 of this report describes the sampling and analytical methodology employed to determine ambient concentrations of the above pollutants.

Section 3 of the report describes the sampling details and Section 4 summarises the results of the sampling undertaken.

## **1.0 INTRODUCTION**

### **1.1 Background**

Resource & Environmental Consultants (REC) Ltd was commissioned by Enviro Consulting Ltd to carry out an ambient air monitoring project to assess potential emissions from a landfill site (site confidential).

### **1.2 Scope of the Survey**

Enviro required information on concentrations of polychlorinated dibenzodioxins (PCDDs or "dioxins") and polyaromatic hydrocarbons (PAHs) and a suite of volatile organic compounds (VOCs) in the ambient air in proximity to landfill operations.

The VOC suite included 1,2-Dichloroethane, Dimethyl disulphide, Dimethyl sulphide, Formaldehyde, Methane thiol, Vinyl Chloride.

Concentrations of Chromium (VI) in the ambient air were also to be measured.

Samples were to be collected from a single, secure location over 2 x 3-day periods in proximity to the landfill.

Baseline/background concentrations of VOCs were also to be measured at a location remote from the landfill operations.

The results of this study were to be included in an environmental assessment examining the potential health impact of emissions from landfill operations.

## **2.0 SAMPLING & ANALYTICAL PROCEDURES**

### **2.1 Sampling Methodology & Equipment**

The ambient air monitoring to assess concentrations of the pollutants required was undertaken as far as reasonably practicable, using methodology recommended in EA Technical Guidance Note M9:

#### **Dioxins & Furans, PCBs and PAHs**

Sampling was carried out in accordance with the requirements of United States Environmental Protection Agency (US EPA) methodology. The method was taken from the Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air (TO series).

Method TO-9 describes a method for the sampling of PCDDs and PCDFs in ambient air using high resolution gas chromatography/mass spectrometry and a high volume sampler.

Sampling of the ambient air was achieved using high volume air samplers based upon General Metal Works Model PS-1 and manufactured by Graseby Anderson. Air is drawn through a fine porosity quartz filter and adsorbent cartridge containing polyurethane foam (PUF) to trap the particulate and volatile fractions respectively.

The samplers are capable of operating at a flowrate of up to 200 litres/minute. The sampler was calibrated prior to the tests using a standard orifice and manometer.

In order to achieve the required detection limits the sample was not to be split i.e. an aliquot taken for PAH analysis.

Instead two PUF samplers were utilised and each test carried out over a three day period to ensure a reasonable sample volume is collected. The two PUF samplers were used to collect a dioxin/PCB and PAH sample over the same sample period at the same location.

A copy of the calibration curves for the PUF samplers are enclosed in Appendix 1.

### **Adsorption Tube Sampling for VOCs**

In order to sample for the additional compounds various adsorption tubes were employed and Table 1 below summarises the substances, methods and sampling details.

For Cr(VI) sampling PTFE filters were used to capture mist/aerosol as opposed to the use of adsorption tubes for the more volatile compounds.

## **ADSORPTION TUBE SAMPLING METHODOLOGY**

<b>Substance</b>	<b>Method Ref.</b>	<b>Sampling Details</b>
Chromium VI	NIOSH 7600	Membrane filter, Colorimetric determination. Some possible interferences from Fe, Cu, Ni, V. Max Vol 400 litres
Arsine	NIOSH 6001 modified	Carbon, Nitric Acid, ICP/MS (filter to stop aerosols). Total As (reported as AsH <sub>3</sub> )
1,2-Dichloroethane	MDHS 72 etc modified	Multibed tube, GC/MS (SIM)
Dimethyl disulphide	MDHS 89 modified	Multibed tube, GC/MS (SIM)
Dimethyl sulphide	MDHS 89 modified	Multibed tube, GC/MS (SIM)
Formaldehyde	NIOSH 2541	Silica gel tubes treated with 2,4 Dinitrophenylhydrazine (2,4 DNPH) which forms stable derivative on tube. HPLC analysis
Methane thiol	TO-17	Multibed tube, GC/MS (SIM)
Vinyl chloride	MDHS 72 etc modified	Multibed tube, GC/MS (SIM)

To ensure that breakthrough volumes were not exceeded on the adsorption tubes for the compounds concerned initial validation work was undertaken by spiking tubes with known amounts of the compounds concerned. A measured volume was then pulled through the tubes and the mass of each analyte determined.

In the Table below the results in terms of % recovery from pulling 12, 36 and 100 litre volumes through the adsorption tubes are summarised. Based upon these results it was decided to limit the sampling volume to 50 litres to minimize potential sampling losses.

## **ADSORPTION TUBE VOC RECOVERY VALIDATION WORKS**

<b>Analyte</b>	<b>Volume Purged</b>		
	<b>12 (litres)</b>	<b>36 (litres)</b>	<b>100 (litres)</b>
VCM	92%	73%	0%
Methyl mercaptan	56%	67%	0%
Dimethyl sulphide	82%	84%	38%
1,2-Dichloroethane	104%	116%	37%
Dimethyl disulphide	40%	46%	75%

## 2.2 Sampling Protocol

### Dioxins & Furans, PCBs & PAHs

The sampler was assembled with a pre-cleaned glass fibre filter and PUF trap. The filter used in the tests had a pore size of 0.45 microns, capable of attaining a > 99.5 percent efficiency of capture of 0.3 micron particles. The filter composite comprised a PUF plug retained in a glass sampling cartridge. The foam was spiked with <sup>13</sup>C labelled isomers in order to allow a recovery experiment to be performed.

In order to obtain a detection limit in ambient air of approximately one femtogram (fg) a sample volume of approximately 1000m<sup>3</sup> is required i.e. sampling over a minimum period of 2 to 3 days.

The flow through the system was monitored using a Venturi/Magnehelic assembly. From the calibration graph the gauge reading was then used to calculate a flowrate in cubic feet per minute (cfm) and from this a flowrate in l/min. An average flowrate over the whole sampling period was then calculated.

On completion of sampling the filters and PUF cartridges were sealed with the original aluminium foil and transferred to a hexane rinsed amber glass jars. The sample was then labelled and sampling information logged onto a Laboratory Submission Sheet prior to transport from the site to ensure a chain of custody from sample collection to laboratory receipt.

### Adsorption Tube Sampling

Sampling was undertaken using portable battery operated, low flow (20-250 ml/min) sampling pumps connected to the adsorption tubes. The flowrate through the tubes and pumps was checked using a UKAS calibrated bubble flowmeter.

Samples were collected over periods ensuring breakthrough volumes would not be reached for the compounds concerned.

### Cr (VI) Sampling

Sampling was undertaken using PTFE filters held in PTFE filter holders. The filters were connected to battery operated sampling pumps operating at a flowrate of 2 litre/min. The flowrate through the filters was calibrated using a rotameter.

## 2.3 Data Recording

Copies of REC Worksheets detailing the actual sampling periods are enclosed in Appendix 2.

Copies of Laboratory Certificates of Analysis are enclosed in Appendix 2 (including selected pages from PCDD & PCDF certificates).

## **2.4 Sample Analysis**

### **Dioxins & Furans, PCBs and PAHs**

Samples were submitted to Scientific Analysis Laboratories (SAL) Ltd for subsequent analysis. SAL are UKAS accredited for the analysis of dioxins and furans, PCBs and PAHs.

Analysis for dioxins and furans was undertaken on a composite sample consisting of the filter and PUF cartridge. High resolution gas chromatography/mass spectrometry (GC/MS) was employed to accurately identify and quantify the PCDD and PCDF isomers.

Extraction, clean-up and analysis procedures followed USEPA protocols and the full quality assurance and quality control regime set out in EPA Method 1613 was followed. The full laboratory methodology for the determination of PCDDs and PCDFs is described in the SAL Certificate of Analysis.

An aliquot of the extracted sample was also analysed by GC/MS for PCBs (WHO 12)

PAHs were determined on a separate filter/PUF cartridge again by solvent extraction, clean up and HR GC/MS.

### **VOC Sampling**

The Multibed tubes were thermally desorbed and analysed by a high resolution GC/MS operating in the target mode to identify and quantify the compounds of interest against prepared standards.

The charcoal tubes for arsine determination were acid extracted and analysed by ICP/MS.

The formaldehyde tube on which a stable 2,4 DNPH derivative was formed was solvent extracted and analysed by HPLC.

### **Cr (VI) Sampling**

The PTFE filters were extracted and analysed by a colorimetric procedure.

## **3.0 SAMPLING & OPERATIONAL DETAILS**

### **3.1 Sampling Point**

Sampling was carried out in proximity to a landfill site (site confidential).

Background samples were collected from Enviros offices in Shrewsbury.

### **3.2 Sampling Survey Details**

The tests were carried out over 2x 3 day periods, 10-12 June and 15-17 June, 2009. VOC samples were collected on each day from a single location and dioxins/PCBs and PAHs each collected over the 2 x 3 day periods at the same location.

Baseline/background VOC sampling was undertaken at Enviros, Shrewsbury on 18 June, 2009

## **4.0 RESULTS**

### **4.1 Dioxin & Furan, PCB and PAH Concentrations**

The results of the PCDD and PCDF sampling are summarised in Table 1 below. From the analytical data and sample volume expressed in cubic metres, ambient air concentrations were calculated. The PCDD and PCDF concentrations are expressed in terms of femtogram per cubic metre (fg/m<sup>3</sup>).

PCDDs and PCDFs are chlorinated tricyclic aromatic compounds with similar chemical properties. The chlorine content is indicated by a prefix thus: tetra (T), penta (Pe), hexa (Hx), hepta (Hp) and octa (O). The position at which the chlorine atoms are substituted is indicated by the preceding numerals. Thus, 2,3,7,8 - tetrachlorodibenzo-para-dioxin is abbreviated to 2,3,7,8 -TCDD.

A large number of positions of substitution and number of chlorine atoms are possible and, as a result there are 75 different PCDDs and 135 PCDFs. The groups of compounds having the same basic structure and the same number of chlorine atoms (regardless of the position of substitution) are referred to as homologues or as homologue groups.

The OCDD and OCDF homologues consist of only one compound each, but all other homologues are made up of a number of different compounds which are referred to as isomers. For example, 1,2,3,4-TCDD and 2,3,7,8-TCDD are isomers in the TCDD homologue.

Most toxicological studies on PCDDs and PCDFs have been carried out on the most toxic compound 2,3,7,8-TCDD. Few studies have been carried out on the other PCDDs and PCDFs, although the available data indicates that only those with chlorine atoms in the 2,3,7 and 8 position are likely to be important toxicologically, with increasing substitution from four (tetra) to eight (octa) atoms, generally resulting in a marked decrease in potency.

As the PCDDs and PCDFs occur as complex mixtures, an assessment of the toxicity of such mixtures is necessary and the concept of Toxic Equivalents was developed. This method uses the available toxicological and in-vitro biological data to generate a set of weighting factors, each of which express the toxicity of a particular PCDD or PCDF isomer, in terms of an equivalent amount of 2,3,7,8-TCDD.

Multiplication of the concentration of the isomer by this toxic equivalent factor (TEF) gives a 2,3,7,8-TCDD toxic equivalence (TEQ). The toxicity of any mixture relative to 2,3,7,8-TCDD is thus taken to be the sum of the individual TEQs.

A number of different weighting schemes are available. The PCDD and PCDF concentrations quoted in the tables are based on European Community (EC)/NATO TEFs. A summary of the TEFs for all PCDD and PCDF isomers is given in the SAL report.

The Individual TEFs of the 17, 2,3,7,8 substituted isomers, also referred to as the 2,3,7,8 congener group are used to produce a total PCDD and PCDF equivalent

amount for all homologues. EC/NATO standards assign no TEFs to the 193 non-2,3,7,8 substituted isomers.

Details of the surrogate recovery experiment are enclosed in the SAL report. Good recoveries were obtained for the 3  $^{13}\text{C}_{12}$  labelled surrogate standards added to the PUF cartridges.

Copies of the calculation spreadsheets are enclosed in Appendix 3.

The minimum values quoted assume that a "none detect" for any compound is treated as zero rather than a calculated detection limit for each compound. The maximum values include for a calculated detection limit for each compound.

The results of the PCB and PAH sampling are summarised in Tables 2 and 3.

From the mass of PCBs in ng/sample and volume sampled PCB concentrations expressed in picogram per cubic metre ( $\text{pg}/\text{m}^3$ ) have been calculated.

From the mass of PAHs in microgram per sample ( $\mu\text{g}/\text{sample}$ ) and volume sampled PAH concentrations in nanogram per cubic metre ( $\text{ng}/\text{m}^3$ ) have been calculated.

## 4.2 VOC Concentrations

Tables 4 to 6 summarise the results of the VOC testing undertaken over the 6 days at the landfill (Day 1 to 6) and the background samples obtained at Enviros offices (Day 7).

Table 4 summarises the results from the mixed bed tube sampling for various target VOCs. From the mass of each target VOC detected on the tube in nanogram per tube ( $\text{ng}/\text{tube}$ ) and volume sampled, an ambient concentration in microgram per cubic metre ( $\mu\text{g}/\text{m}^3$ ) was calculated.

Table 5 summarises the results from the charcoal tube sampling for arsine. From the mass of arsenic detected on the tube in microgram per tube ( $\mu\text{g}/\text{tube}$ ) and volume sampled, an ambient concentration in milligram per cubic metre ( $\text{mg}/\text{m}^3$ ) was calculated.

Table 6 summarises the results from the treated silica gel tube sampling for formaldehyde. From the mass of formaldehyde detected on the tube in microgram per tube ( $\mu\text{g}/\text{tube}$ ) and volume sampled, an ambient concentration in  $\mu\text{g}/\text{m}^3$  was calculated.

The majority of the measured concentrations were at the limit of detection of the methodology employed. Any values above the limit of detection for any determinand have been highlighted in **bold** type.

### 4.3 Cr (VI) Concentrations

Table 7 summarises the results from the analysis of the PTFE filter sampling for Cr(VI). From the mass of Cr(VI) detected on the filter in microgram per filter ( $\mu\text{g}/\text{filter}$ ) and volume sampled, an ambient concentration in  $\text{mg}/\text{m}^3$  was calculated.

No Cr(VI) sample results were above the limit of detection of the methodology employed.

===== END OF REPORT =====

**TABLE 1**

**AMBIENT PCDD/PCDF DATA SUMMARY**

Sample Ref.	PCDDs/PCDFs (TEQ) (fg/m <sup>3</sup> )	
	Minimum	Maximum
TEST 1 10/6/09 - 12/6/09	4.2	8.6
TEST 2 15/6/09 – 17/6/09	11.6	13.2

**Note:** Minimum LoD = 0, Maximum LoD = calculated LoD

**TABLE 2**

**AMBIENT PCB DATA SUMMARY**

PCBs (WHO12)	TEST 1 10/6/09 - 12/6/09			TEST 2 15/6/09 – 17/6/09		
	ng/sample	Volume (m <sup>3</sup> )	PCB Conc (pg/m <sup>3</sup> )	ng/sample	Volume (m <sup>3</sup> )	PCB Concn (pg/m <sup>3</sup> )
PCB BZ#105	<b>0.5</b>	891.83	<b>0.56</b>	0.5	1301.30	0.56
PCB BZ#114	0.5	891.83	0.56	0.5	1301.30	0.56
PCB BZ#118	<b>1.6</b>	891.83	<b>1.8</b>	<b>1.2</b>	1301.30	<b>1.3</b>
PCB BZ#123	0.5	891.83	0.56	0.5	1301.30	0.56
PCB BZ#126	0.5	891.83	0.56	0.5	1301.30	0.56
PCB BZ#156	0.5	891.83	0.56	0.5	1301.30	0.56
PCB BZ#157	0.5	891.83	0.56	0.5	1301.30	0.56
PCB BZ#167	0.5	891.83	0.56	0.5	1301.30	0.56
PCB BZ#169	0.5	891.83	0.56	0.5	1301.30	0.56
PCB BZ#189	0.5	891.83	0.56	0.5	1301.30	0.56
PCB BZ#77	0.5	891.83	0.56	0.5	1301.30	0.56
PCB BZ#81	0.5	891.83	0.56	0.5	1301.30	0.56

**Note:** Concentrations above the limit of detection are highlighted in **bold**

**TABLE 3**

**AMBIENT PAH DATA SUMMARY**

PAHs EPA16	TEST 1 10/6/09 - 12/6/09			TEST 2 15/6/09 – 17/6/09		
	ug/sample	Volume (m <sup>3</sup> )	PAH Conc (ng/m <sup>3</sup> )	ug/sample	Volume (m <sup>3</sup> )	PAH Concn (ng/m <sup>3</sup> )
Acenaphthene	<b>0.1</b>	891.83	<b>0.11</b>	<b>0.4</b>	1301.30	<b>0.45</b>
Acenaphthylene	0.1	891.83	0.11	0.1	1301.30	0.11
Anthracene	<b>0.2</b>	891.83	<b>0.22</b>	<b>0.2</b>	1301.30	<b>0.22</b>
Benzo(a)Anthracene	<b>0.2</b>	891.83	<b>0.22</b>	0.1	1301.30	0.11
Benzo(a)Pyrene	<b>0.1</b>	891.83	<b>0.11</b>	0.1	1301.30	0.11
Benzo(b/k)Fluoranthene	<b>0.2</b>	891.83	<b>0.22</b>	<b>0.2</b>	1301.30	<b>0.22</b>
Benzo(ghi)Perylene	<b>0.1</b>	891.83	<b>0.11</b>	<b>0.2</b>	1301.30	<b>0.22</b>
Chrysene	<b>0.9</b>	891.83	<b>1.0</b>	0.1	1301.30	0.11
Dibenzo(ah)Anthracene	0.1	891.83	0.11	0.1	1301.30	0.11
Fluoranthene	<b>1.9</b>	891.83	<b>2.1</b>	<b>2.3</b>	1301.30	<b>2.6</b>
Fluorene	<b>1.4</b>	891.83	<b>1.6</b>	<b>1.1</b>	1301.30	<b>1.2</b>
Indeno(123-cd)Pyrene	<b>0.1</b>	891.83	<b>0.11</b>	0.1	1301.30	0.11
Naphthalene	<b>0.2</b>	891.83	<b>0.22</b>	0.1	1301.30	0.11
Phenanthrene	<b>8.3</b>	891.83	<b>9.31</b>	<b>8.7</b>	1301.30	<b>9.8</b>
Pyrene	<b>0.8</b>	891.83	<b>0.90</b>	<b>1.0</b>	1301.30	<b>1.1</b>

**Note:** concentrations above the limit of detection are highlighted in **bold**

TABLE 4

**AMBIENT TARGET VOC DATA SUMMARY – MULTIBED TUBES**

Sampling Data	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7 -
	10/06/09	11/06/09	12/06/09	15/06/09	16/06/09	17/06/09	18/06/09
	Multibed Tube	Multibed Tube	Multibed Tube	Multibed Tube	Multibed Tube	Multibed Tube	Multibed Tube
Counter Start	226078	311925	712159	783032	831518	912999	993838
Counter End	311160	372554	783011	831406	912800	988260	1047188
Calibration Factor	0.76	0.76	0.62	0.62	0.62	0.62	0.62
Volume Sampled (litres)	64.662	46.078	43.928	29.992	50.395	46.662	33.077
Ambient Temp (°C)	13	14	16	16	16	17	17
Ambient Press (kPa)	101.4	101.7	101.6	101.5	101.5	101.8	101.5
Volume Sampled (Litres) at STP	66.310	47.227	44.668	30.467	51.193	47.377	33.485
Analytical Data (ng/tube)	Tube Ref. 32457/4	Tube Ref. 32457/8	Tube Ref. 32457/12	Tube Ref. 32457/16	Tube Ref. 32457/32	Tube Ref. 32457/36	Tube Ref. 32457/40
1,2-Dichloroethane	1	<b>6</b>	1	1	1	1	1
Dimethyl disulphide	1	1	1	1	1	1	1
Dimethyl sulphide	10	10	10	10	10	10	10
Methane thiol	10	10	10	10	10	10	10
Vinyl chloride	2	2	2	2	2	2	2
Concentration Data (µg/m <sup>3</sup> )							
1,2-Dichloroethane	0.02	<b>0.13</b>	0.02	0.03	0.02	0.02	0.03
Dimethyl disulphide	0.02	0.02	0.02	0.03	0.02	0.02	0.03
Dimethyl sulphide	0.15	0.21	0.22	0.33	0.20	0.21	0.30
Methane thiol	0.15	0.21	0.22	0.33	0.20	0.21	0.30
Vinyl chloride	0.03	0.04	0.04	0.07	0.04	0.04	0.06

Note: **Bold** figure = Result >LOD

**TABLE 5**

**AMBIENT ARSINE DATA SUMMARY – CHARCOAL TUBES**

Sampling Data	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
	10/06/09	11/06/09	12/06/09	15/06/09	16/06/09	17/06/09	18/06/09
	Charcoal Tube	Charcoal Tube	Charcoal Tube	Charcoal Tube	Charcoal Tube	Charcoal Tube	Charcoal Tube
Counter Start	126667	236641	370184	501778	590549	718442	864613
Counter End	236107	369593	501751	590450	718403	853740	965883
Calibration Factor	0.76	0.76	0.76	0.76	0.76	0.76	0.76
Volume Sampled (litres)	83.174	101.044	99.991	67.391	97.169	102.826	76.965
Ambient Temp (°C)	13	14	16	16	16	17	17
Ambient Press (kPa)	101.4	101.7	101.6	101.5	101.5	101.8	101.5
Volume Sampled (Litres) at STP	85.294	103.563	101.675	68.458	98.708	104.403	77.915
Analytical Data (µg/tube)	Tube Ref. 32457/2	Tube Ref. 32457/6	Tube Ref. 32457/10	Tube Ref. 32457/14	Tube Ref. 32457/30	Tube Ref. 32457/34	Tube Ref. 32457/38
Arsenic on tube	1	1	1	1	1	1	1
Arsine	1.04	1.04	1.04	1.04	1.04	1.04	1.04
Concentration Data (mg/m <sup>3</sup> )							
Arsine	0.012	0.010	0.010	0.015	0.011	0.010	0.013

Note: **Bold** figure = Result >LOD

TABLE 6

**AMBIENT FORMALDEHYDE DATA SUMMARY – TREATED SILICA GEL TUBES**

Sampling Data	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
	10/06/09	11/06/09	12/06/09	15/06/9	16/06/09	17/06/09	18/06/09
	Treated Silica Gel Tube						
Counter Start	396506	535057	473337	635700	743753	902309	79012
Counter End	534370	710657	635657	743652	902187	1065735	189439
Calibration Factor	0.62	0.62	0.76	0.76	0.76	0.76	0.76
Volume Sampled (litres)	85.476	108.872	123.363	82.044	120.410	124.204	83.925
Ambient Temp (°C)	13	14	16	15	16	17	17
Ambient Press (kPa)	101.4	101.7	101.6	101.3	101.5	101.8	101.5
Volume Sampled (Litres) at STP	87.654	111.587	125.441	83.468	122.317	126.108	84.960
Analytical Data (µg/tube)	Tube Ref. 32457/3	Tube Ref. 32457/7	Tube Ref. 32457/11	Tube Ref. 32457/27	Tube Ref. 32457/31	Tube Ref. 32457/35	Tube Ref. 32457/39
Formaldehyde	<b>0.4</b>	<b>0.2</b>	<b>0.2</b>	0.1	<b>0.2</b>	<b>0.2</b>	<b>0.1</b>
Concentration Data (µg/m <sup>3</sup> )							
Formaldehyde	<b>4.6</b>	<b>1.8</b>	<b>1.6</b>	1.2	<b>1.6</b>	<b>1.6</b>	<b>1.2</b>

Note: **Bold** figure = Result >LOD

**TABLE 7**

**AMBIENT CHROMIUM (VI) DATA SUMMARY**

Sampling Data	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
	10/06/09	11/06/09	12/06/09	15/06/9	16/06/09	17/06/09	18/06/09
	PVC Filter	PVC Filter	PVC Filter	PVC Filter	PVC Filter	PVC Filter	PVC Filter
Start time	09:50:00	07:53:00	07:41:00	11:15:00	07:56:00	07:56:00	09:52:00
End time	16:30:00	15:53:00	15:41:00	16:30:00	15:56:00	15:56:00	16:00:00
Total sampling time	06:40:00	08:00:00	08:00:00	05:15:00	08:00:00	08:00:00	06:08:00
Sample rate (l/min)	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Volume Sampled (litres)	800	960	960	630	960	960	736
Ambient Temp (°C)	13	14	16	15	16	17	17
Ambient Press (kPa)	101.4	101.7	101.6	101.3	101.5	101.8	101.5
Volume Sampled (Litres) at STP	820	984	976	641	975	975	745
Analytical Data (µg/filter)	Tube Ref. 32457/1	Tube Ref. 32457/5	Tube Ref. 32457/9	Tube Ref. 32457/25	Tube Ref. 32457/29	Tube Ref. 32457/33	Tube Ref. 32457/37
Chromium VI	1	1	1	1	1	1	1
Concentration Data (mg/m <sup>3</sup> )							
Chromium VI	0.001	0.001	0.001	0.002	0.001	0.001	0.001

Note: **Bold** figure = Result >LOD

## APPENDIX 1: PUF SAMPLER CALIBRATIONS

<b>CALIBRATION OF PUF SAMPLER 1</b>
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DATE            17/07/2008     JT

actual	m= 6.1	b= -0.001116			
standard	m= 9.73	b= -0.000551			
Indicated in H <sub>2</sub> O	Calibrator Reading in H <sub>2</sub> O	Pa mmHg	Ta K	Qa m <sup>3</sup> /min	Qst m <sup>3</sup> /min (Std)
70	7.9	772	273	0.2742	0.318
60	7.3			0.2636	0.306
50	6.0			0.2390	0.277
40	4.8			0.2138	0.248
30	3.6			0.1851	0.215
20	2.1			0.1415	0.164
10	1.1			0.1024	0.119
0				0.0000	0.000

<b>CALIBRATION OF PUF SAMPLER 2</b>
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DATE            04/07/2008     JT

actual	m= 6.1	b= -0.001116			
standard	m= 9.73	b= -0.000551			
Indicated " H <sub>2</sub> O	Calibrator Reading " H <sub>2</sub> O	Pa mmHg	Ta K	Qa m <sup>3</sup> /min	Qst m <sup>3</sup> /min (Std)
70	7.2	772	273	0.2618	0.304
60	6.3			0.2449	0.284
50	5.9			0.2370	0.275
40	4.5			0.2070	0.240
30	3.0			0.1690	0.196
20	2.1			0.1415	0.164
10	1.1			0.1024	0.119
0				0.0000	0.000



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