

# Good control practice for workers' exposure to gases in landfill

Sampling and measurement report

Prepared by the **Health and Safety Laboratory**  
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## Sampling and measurement report

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Gases generated by decomposition of landfill contain, principally, methane and carbon dioxide, but may also contain hazardous concentrations of trace components. This project gathered information on the potential exposure of workers to these trace components during specific types of tasks, to provide evidence to develop guidance on good practice for the control of exposure. The study was conducted at six land fill sites identified as having the potential to generate high concentrations of three representative trace components, vinyl chloride, hydrogen sulphide and benzene. Comparisons of personal exposures were made with the levels found in the collected raw gas. The personal task based exposures (given the environmental conditions prevailing at the time monitoring was conducted) were insignificant for all three components and would not normally pose a health concern.

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# EXECUTIVE SUMMARY

## Objectives

- In co-operation with the waste industry this work gathered information on types of task, pattern of work and potential for exposure of workers to landfill gas. Six landfill sites were visited to monitor the activities carried out by a number of different contractors, and to provide measurement data for both personal exposure, and of the hazard source, for vinyl chloride (VCM), hydrogen sulphide (H<sub>2</sub>S) and benzene.

This work aimed to establish if there was a risk of personal exposure to these substances at levels that may cause concern. The results of the measurements, combined with direct observations, will form the basis for a new guidance document for work in this industry. This guidance will describe the adequate control of risks to health, as defined under the Control of Substances Hazardous to Health Regulations 2002 (COSHH), from trace components in landfill gas. It will apply to all harmful substances in landfill gas, such as those listed by the Environment Agency document LFTGN 04 *Guidance for monitoring trace components in landfill gas*. This guidance will not feature in this report.

## Main Findings

- The maximum personal exposure to VCM measured during bore hole drilling operations was 0.0001ppm (the 8 hour Workplace Exposure Limit (WEL) is 3 ppm). The VCM concentration at the associated bore hole was 2.17ppm which equates to a dilution factor of 1:21,700. The maximum recorded concentration of VCM at the bore holes was 2.6 parts per million (ppm).
- The maximum personal exposure to H<sub>2</sub>S measured during bore hole drilling operations was 0.97 ppm (the WEL for H<sub>2</sub>S is 5 ppm.(8hour) and 10 ppm (15 minute). The H<sub>2</sub>S concentration at the associated bore hole was greater than 320ppm which equates to a dilution factor of at least 1: 320. This bore hole H<sub>2</sub>S concentration was also the maximum recorded concentration.
- The maximum personal exposure to benzene measured during bore hole drilling operations was 0.0002 ppm. (the 8 hour WEL for benzene is 1 ppm). The concentration at the associated bore hole was 1.44ppm which equates to a dilution factor of 1:7200. The maximum recorded concentration of benzene at the bore holes was 5.5 ppm.
- Under the environmental conditions prevailing at the time samples were taken, and the working practices observed at that time, no personal exposure was measured for any of the substances under discussion at concentrations that may cause concern.
- Methane is a major constituent of the landfill gas and workers carry alarms to warn against explosive atmospheres. Measured dilution factors between the hazard source (gas emitted from the bore hole) and the personal exposure were greater than the dilution factor at which a standard issue methane alarm would warn of danger when set to trigger at 10% of the lower explosive limit (LEL) for methane.



# 1 INTRODUCTION

## 1.1 BACKGROUND

Landfill gases contain methane and carbon dioxide, and may also contain toxic gases such as those found on the Environment Agency (EA) priority list of trace components (EA LFTGN 04), including vinyl chloride (VCM) which is a category 1 human carcinogen, and hydrogen sulphide (H<sub>2</sub>S), a known toxic gas. There is insufficient information to be able to make a firm judgement about the potential for worker exposure and adverse health when working on site. In co-operation with the Environmental Services Agency, the aim of this project was to gather information on types of task, patterns of work and potential for exposure of workers to landfill gas in order to develop guidance on good practice for the control of exposure. As well as VCM and H<sub>2</sub>S, benzene was also measured. Sampling surveys took place on landfill sites where there was a potential cause for concern. Personal exposures were monitored, following typical activities on a range of waste sites such as borehole drilling and leachate well sampling. Comparisons of personal exposures were made with the levels of toxic substance found in emissions from the boreholes and with collected gas that feeds to the gas power plants.

Waste for landfill is disposed in active cells on the landfill site. A cell is created on a base layer of geofabric liner and gravel. After filling, a top layer of clay is added forming a closed cell into which oxygen can not enter. Degradation produces gas and uses up oxygen; a typical composition might be ~30% carbon dioxide, ~40% methane, with the balance comprising nitrogen, oxygen and water vapour at a temperature of around 40-50°C. Composition may vary between wells, from cell to cell and from site to site. The cells are normally held at negative pressure by removal of gas. Liquids (leachate) are also formed, and the activities involved in monitoring or extracting both the leachate and the gas form the main focus of the monitoring programme. Boreholes are drilled to allow insertion of a perforated plastic pipe through which the landfill gas is collected and fed up to a valve and cap at the surface. This gas is then integrated into a network of surface pipes that ultimately lead to the site gas powered electricity generators and/or flares. Drilling is carried out by a contractor and overseen by a well supervisor. The rig orientation may be determined by a need for the rig to face downhill for drilling. The rig barrel tapers internally toward the cutting edge and the ram that clears the drill barrel of debris cannot go past the taper point. This is the reason for inserting a billet (often a length of wood) between the ram face and the remaining waste in the barrel, to remove such waste. On completion of the hole the pipe is inserted and the space around this manually filled with large gravel to the level of the top perforation. The non-perforated part of the pipe protrudes up through the upper geofabric layer of the cell and this zone is sealed to prevent gas leakage using bentonite clay and water. Finally the pipe will be capped pending being fitted with a valve, usually done at a later stage and carried out by other contractors. Methane content and other gases such as oxygen, nitrogen carbon dioxide are monitored from each well by passing the gas through a meter.

Leachate well drilling is technically difficult due to the need to drill onto a pre-installed concrete cap. The duration of this task is not known. Gas and leachate wells may become silted and restricted. During this process operators wear personal protective equipment against exposure to leachate, and where necessary, airline breathing apparatus (BA) where there are elevated concentrations of hydrogen sulphide or other known toxic gases. For the removal process the leachate pump is turned off 48 hours before the task, to allow leachate to rise above the perforated part of the pipe and minimise air ingress into the landfill. Surrounding wells are also turned off. Pump removal takes between 5 and 15 minutes. The well is capped between

removal and pump replacement. This involves work close to the well head. Pump replacement takes about 5 minutes. Pump maintenance / cleaning does not involve exposure to gases.

## 2 SAMPLING AND ANALYSIS METHODS

### 2.1.1 Vinylchloride and Benzene

Sampling was by drawing air (100 ml/min) through a sorbent tube containing a dual bed of the weak sorbent Tenax TA (66%) and the strong sorbent Unicarb (34%) using a Gillian GilAir Trimode sampling pump. Personal samplers were set up in pairs with the H<sub>2</sub>S sampler on a single pump and were fixed in the breathing zone of the worker during task activity. Borehole samples were taken using the same basic process (100 to 200 ml/min) but sampling was for 10 minutes or less. Samples of feed gas were collected directly prior to the combustion process at the gas power plant in a Tedlar bag from which was immediately transferred 100ml and 200 ml samples to sorbent tubes using a glass gas tight syringe. Samples from the gas wells were taken using a 50 ml syringe fixed to a sampling valve on the well head. Two syringes full were collected per location and transferred onto sorbent sample tubes. Pressure was equalised within the syringe prior to disengaging from the valve as the well heads are under negative pressure. Leachate was collected into sealed containers using drainage fittings on the well heads. Subsequently, 100 ml headspace samples were collected from the leachate at 50°C.

Samples were analysed by thermal desorption (TD) and gas chromatography (GC) with mass selective detection (MS). A Markes Unity 1 TD system was used with the following settings. dry purge (helium) 30ml/min, desorption 10 minute at 300 C, split ratio 162:1, (inlet 20, desorption 20, outlet 80 ml/min), trap 20°C to 290°C for 3 min. The GCMS separation was on a BP5 MS column 30m x 250 µm , 0.25 µm film, flow 1ml/min, with an oven temperature programme (40°C for 6 min, 2C/min to 50°C, 5°C/min to 150°C. MS detector scan range 25 to 150 mass units. Vinyl chloride was not detected in any of the blanks so no blank corrections were applied. The LoD was estimated as 3 x the signal to noise ratio of a 50 ng VCM standard. Benzene was detected in all samples including blanks and VCM standards. All results are blank corrected. The LoD was estimated as 3 x the standard deviation of the blank values determined from the VCM standards.

### 2.1.2 Hydrogen Sulphide

Sampling was based on the method OSHA 1008. Air was pulled through samplers (100 ml/min) containing silver nitrate coated silica gel using a sampling pump. The hydrogen sulphide reacts to form silver sulphide. Personal samplers were set up in pairs with the VCM/benzene samplers on a single pump as previously described. Bore hole samples were collected as above for VCM. Tedlar bag samples (see Section 2.1.1) were also taken. 100 ml gas samples were withdrawn and passed on to sample tubes using a gas tight syringe. Samples were stored in a freezer until analysis.

Hydrogen sulphide reacted with the silver nitrate to form silver sulphide is extracted using sodium cyanide and sodium hydroxide and converted to sulphate using hydrogen peroxide which is analysed by ion chromatography using a conductivity detector. Results are corrected using site blanks. Limits of detection are dependent on the sample volume. Provided that performance specifications set out in BS EN 1232 and BS EN 13205 for pumps and inhalable samplers were achieved then the overall uncertainty of the method for sampling and analysis should comply with BS EN 482, i.e. < 30% between 0.5 and 2 times the limit value and < 50% between 0.1 and 0.5 times the limit value. (8hr TWA WEL is 5 ppm). These requirements were fully met during this work. Tedlar bag samples were also analysed using a RAE Systems Multirae Gas Detector fitted with an H<sub>2</sub>S sensor and calibrated using a BOC reference cylinder at 52 ppm.

### 3 SITE VISIT AND SAMPLING INFORMATION

#### 3.1 SITE 1

**Site Operator 1**                      **Drilling Contractor 1**  
**Visit Date**      29/09/2009      **Conditions**      Cool, dry, W-NW, 4 to 11 m/s.

Sampling took place on a geofabric sheeted and capped area of the landfill site and monitored the activities associated with the drilling of a new borehole. Within the duration of the sampling period 5 augers full of waste were extracted. Background samples were taken at ground level. The waste being drilled was compacted. Each auger (drill barrel) was withdrawn on completing its full length. Work took place close to the auger to attach hydraulic hoses for a ram to remove compacted waste from the auger, and also to remove residual waste from the auger barrel because the ram did not reach the barrel end; the operator used a metal rod to dislodge these residues, placed manually between the waste blockage and the ram end. The waste material was steaming (Figures 1 and 2). About 2 or 3 auger loads were discharged to an open dumper truck, and taken for disposal elsewhere in the landfill.



**Figure 1**                      **Emptying the auger.**



**Figure 2**                      **Emptying the auger.**

#### 3.2 SITE 2

**Site Operator 1**                      **Drilling Contractor 1**  
**Visit Date**      30/09/2009      **Conditions**      Dry, sunny, wind easterly, 0.8 m/s

Sampling took place in an active tipping area and waste deposition and compaction continued in close proximity to drilling and well installation (Figure 3). The waste type was 'co-disposal' – industrial and domestic waste. For the first borehole drilled (Figure 4) sampling took place for about 90 minutes and monitored work close to the well head which was visibly emitting gases and steam. The second well involved drilling for about 50 minutes. The drillers removed 6 augers full of the poorly-compacted waste from the new well. Further sampling took place during geofabric installation. At a lower level on the site but nearby the drilling, contractors were laying and welding geofabric liners over the clay cap of an old cell, as the liner for a new cell. Two of these workers were also sampled for about 90 minutes. All sampling information is shown in Table 2.



**Figure 3** General environment.



**Figure 4** manual handling of auger.

### 3.3 SITE 3

**Site Operator 2**

**Visit Dates** 15/10/2009, 27/10/09

**Drilling Contractor 1**

**Conditions** 15/10/09 Cool, West 1 - 2.5 m/s  
27/10/09 Mild, wind South 0.5 - 3 m/s

At Site 3 two visits were made. Drilling on the first visit was taking place on a capped cell of mixed (90% domestic, 10% industrial) waste. The well had already been bored prior to arrival and the auger was in position in the well to reduce gas emission and the surface exit point sealed with Bentonite clay. Only background sampling was carried out on this visit, taking two samples from just outside the ‘standoff’ distance of 10 metres. During the second visit three shallow wells were sampled, all emitting visible vapour. Samples were taken from the bore hole (Figure 5) and for gas collector installation, gravel / bentonite backfilling and capping (Figure 6). Separate samplers were used for drilling and for gas collector installation. A single static sample was taken. This was downwind by approximately 20 metres from the rig. Each time the rig was moved to a new position the static was re-positioned without switch off.



**Figure 5** Site 3 – The installed pipe



**Figure 6** Capping the hole

### 3.4 SITE 4

#### Site Operator 2

**Visit Dates** 3/11/2009      **Conditions** Mild, spitting rain, Wind South, 2-3 m/s

At Site 4 leachate monitoring was examined. The volume of leachate discharged was recorded for each gas well in a process known as well dipping (Figure 7). In some cases a dip tube was lowered into leachate pump chamber to remove a small leachate sample for similar testing (Figure 8). 37 wells or chambers were tested over about 3.5 hours.



**Figure 7**      **Checking the well**



**Figure 8**      **Sampling the leachate**

### 3.5 SITE 5

#### Site Operator 2

#### Drilling Contractor 1

**Visit Dates** 4/11/2009      **Conditions** Sunny, cool. Wind SW to S, 5 to 7 m/s

At site 5 the drilling rigs were generally placed across-wind. Sampling was split between the two holes being drilled. Hole 1 involved the continuation from the previous days drilling, then installation of gas collector with gravel and bentonite cap. Hole 2 involved drilling from surface to 20 metres.

### 3.6 SITE 6

#### Site Operator 1

**Visit Dates** 4/12/2009      **Conditions** clear and with almost no breeze.

At Site 6 the opportunity was taken to examine a number of random wells for gas composition, plus the compressed feed gas for the generators. Each well produces a different composition of gas at a different rate. A number of wells feed to manifolds where flows are balanced for ducting to the power plant. Sampling took place on the “old site” (closed for 5 years) and on Cells 13 and 11. Gas output is in decline on the old site, whereas for Cell 13 gas production is increasing. Samples of 0.1 litre volume were collected from 11 randomly selected wellheads or at well manifolds. Two further samples were taken from the main feed line to the power plant. No hydrogen sulphide samples were collected from the gas wells, two samples only being collected from the feed line at the plant.

### 3.7 SAMPLING DETAILS

**Table 1 VCM and H<sub>2</sub>S Sampling Information for Site 1**

HSL Ref	Pump No.	Sampler Number	On	Off	Tube Reference Number	Exposure Time (min)	Flow Rate (ml/min)	Sample Volume (litres)	Location
<b>Samplers for Vinylchloride</b>									
113	n/a	100	n/a	n/a	103585	n/a	n/a	0.1	Engine Feed
114	n/a	200	n/a	n/a	097089	n/a	n/a	0.2	Engine Feed
115	n/a	PBH	N/A	N/A	103565	10	100	1.0	Bore Hole
116	18	5	0856	1200	103586	184	100	18.4	Rig Static - SE
117	20	9	0952	1156	103543	124	100	12.4	Assistant Driller
118	3	6	0950	1156	103579	126	100	12.6	Foreman Driller
<b>Samplers for Hydrogen Sulphide</b>									
119	18	5	0856	1200	n/a	184	100	18.4	Rig Static - SE
120	20	9	0952	1156	n/a	124	100	12.4	Assistant Driller
121	3	6	0950	1156	n/a	126	100	12.6	Foreman Driller
122	n/a	n/a	n/a	n/a	n/a	10	100	1.0	Bore Hole
<b>Landfill Gas Sample</b>									
123	Tedlar Bag Sample								

**Table 2 VCM and H<sub>2</sub>S Sampling Information for Site 2**

HSL Ref	Pump No.	Sampler Number	On	Off	Tube Reference Number	Exposure Time (min)	Flow Rate (ml/min)	Sample Volume (litres)	Location
<b>Samplers for Vinylchloride</b>									
213	3	#	n/a	n/a	097004	10	78	0.78	Bore Hole ONE
214	3	#	n/a	n/a	097030	10	70	0.70	Bore Hole TWO
215	n/a	100	n/a	n/a	103531	n/a	n/a	0.10	Feed Gas – Engine
216	n/a	200	n/a	n/a	103585	n/a	n/a	0.20	Feed Gas – Engine
217	10	1	1013	1237	097010	144	100	14.4	Static -Liner Edge
218	15	3	0944	1055	103507	71	110	7.8	Static – W. of Drill 1
219	12	4	0913	1035	103552	82	100	8.2	Foreman Driller
220	13	8	0913	1045	097043	92	100	9.2	Assistant Driller
221	18	18	1044	1252	097077	128	100	12.8	Static – E. of Drill 2
222	20	20	1039	1228	097053	119	100	11.9	Foreman Driller
223	14	7	1045	1229	103589	104	100	10.4	Assistant Driller
224	4	2	1119	1336	097082	137	95	13.0	Static – Laying Liner
225	13B	13b	1220	1336	097073	76	95	7.2	Lining Assistant - Laying
226	15B	15b	1220	1338	097038	78	100	7.8	Lining Foreman - Laying
<b>Samplers for Hydrogen Sulphide</b>									
227	3	#	n/a	n/a	#	10	118	1.18	Bore Hole ONE
228	3	#	n/a	n/a	#	10	100	1.00	Bore Hole TWO
229	10	1	1013	1237	#	144	100	14.4	Static -Liner Edge
230	15	3	0944	1055	#	71	110	7.8	Static – W. of Drill 1
231	12	4	0913	1035	#	82	100	8.2	Foreman Driller – Hole 1
232	13	8	0913	1045	#	92	100	9.2	Assistant Driller – Hole 1
233	18	18	1044	1252	#	128	100	12.8	Static – E. of Drill 2
234	20	20	1039	1228	#	119	100	11.9	Foreman Driller – Hole 2
235	14	7	1045	1229	#	104	100	10.4	Assistant Driller – Hole 2
236	4	2	1119	1336	#	137	100	13.7	Static – Laying Liner
237	13B	13b	1220	1336	#	76	100	7.6	Lining Assistant - Laying
238	15B	15b	1220	1338	#	78	100	7.8	Lining Foreman - Laying

**Table 3 VCM and H<sub>2</sub>S Sampling Information for Site 3**

HSL Ref	Pump No.	Sampler Number	On	Off	Tube Reference Number	Exposure Time (min)	Flow Rate (ml/min)	Sample Volume (litres)	Location
<b>Samplers for Vinylchloride</b>									
313	n/a	100	~	~	097090	~	~	0.1	Engine Feed Gas 15/10/09
314	n/a	200	~	~	103533	~	~	0.2	Engine Feed Gas 15/10/09
316	1	1	0955	1255	103588	180	100	18.0	20m standoff downwind and up slope
317	4	2	0958	1258	097039	180	100		20m standoff downwind and down slope
318	6	3	0806	1108	097048	182	105	19.11	20m standoff downwind
319	3	11	~	~	103525	3	110	0.33	<b>Bore Hole 1</b> 27/10/09
320	12	5	0827	0900	097027	33	101	3.33	Foreman Driller -Hole 1
321	13	6	0828	0915	103559	47	104	4.89	Assistant Driller -Hole 1
322	3	4	~	~	103514	3	110	0.33	<b>Bore Hole 2</b> 27/10/09
323	14	7	0917	0958	097072	41	101	4.14	Foreman Driller -Hole 2
324	15	8	0917	1023	097054	66	104	6.86	Assistant Driller -Hole 2
325	3	12	~	~	~~~	3	110	0.33	<b>Bore Hole 3</b> 27/10/09
326	18	9	0958	1056	103537	58	101	5.86	Foreman Driller -Hole 3
327	20	10	1023	1106	103553	43	109	4.69	Assistant Driller -Hole 3
<b>Samplers for Hydrogen Sulphide</b>									
328	1	1	0955	1255	~	180	103	18.84	20m standoff downwind and up slope by leachate pump head. 15/10/09
329	4	2	0958	1258	~	180	100	18.00	20m standoff downwind and down slope by pipe 15/10/09
330	6	3	0806	1108	~	182	109	19.84	20m standoff downwind 27/10/09 (continuous).
331	3	11	~	~	~	3	109	0.327	<b>Bore Hole 1</b> 27/10/09
332	12	5	0827	0900	~	33	110	3.63	Foreman Driller -Hole 1
333	13	6	0828	0915	~	47	110	5.17	Assistant Driller -Hole 1
334	3	4	~	~	~	3	109	0.327	<b>Bore Hole 2</b> 27/10/09
335	14	7	0917	0958	~	41	99	4.06	Foreman Driller -Hole 2
336	15	8	0917	1023	~	66	106	7.00	Assistant Driller -Hole 2
337	3	12	~	~	~	3	109	0.327	<b>Bore Hole 3</b> 27/10/09
338	18	9	0958	1056	~	58	114	6.61	Foreman Driller -Hole 3
339	20	10	1023	1106	~	43	109	4.69	Assistant Driller -Hole 3

**Table 4 VCM and H<sub>2</sub>S Sampling Information for Site 4**

HSL Ref	Pump No.	Sampler Number	On	Off	Tube Reference Number	Exposure Time (min)	Flow Rate (ml/min)	Sample Volume (litres)	Location
<b>Samplers for Vinylchloride</b>									
412	n/a	100	~	~	097015	~	~	0.1	Feed Gas 1
413	n/a	200	~	~	103541	~	~	0.2	Feed Gas 2
414	6	1	0844	1143	098008	179	106	18.97	Worker 1 – Dipping
415	10	4	0842	1145	097097	183	103	18.85	HSE Staff - Observing
<b>Samplers for Hydrogen Sulphide</b>									
416	6	1	0844	1143	~	179	100	17.90	Worker 1 – Dipping
417	10	4	0842	1145	~	183	103	18.85	HSE Staff - Observing
<b>Samples for Headspace</b>									
418	Leachate from Well L 02								L 02
419	Leachate from Well L 01								L 01
<b>Landfill Gas Sample</b>									
420	Tedlar Bag Gas Sample								

**Table 5 VCM and H<sub>2</sub>S Sampling Information for Site 5**

HSL Ref	Pump No.	Sampler Number	On	Off	Tube Reference Number	Exposure Time (min)	Flow Rate (ml/min)	Sample Volume (litres)	Location
<b>Samplers for Vinylchloride</b>									
513	n/a	100	~	~	097055	~	~	0.1	Feed Gas 1
514	n/a	200	~	~	097051	~	~	0.2	Feed Gas 2
515	3	1	~	~	103580	3.3	105	0.315	Bore Hole 1
516	3	2	~	~	097069	3.0	105	0.315	Bore Hole 2
517	12	5	0910	1212	103504	182	100	18.20	Foreman Driller – Hole 1
518	13	6	0910	1302	103503	238	101	24.04	Assistant Driller – Hole 1
519	14	7	1212	1434	103556	142	96	13.63	Foreman Driller – Hole 2
520	15	8	1317	1434	097071	77	104	8.01	Assistant Driller – Hole 2
521	18	9	0954	1238	097092	166	102	16.93	Static – Downwind
522	20	10	0918	1233	103506	195	111	21.65	Static – Downwind
<b>Samplers for Hydrogen Sulphide</b>									
523	3	1	~	~	~	3.0	109	0.327	Bore Hole 1
524	3	2	~	~	~	3.0	109	0.327	Bore Hole 2
525	12	5	0910	1212	~	182	111	20.20	Foreman Driller – Hole 1
526	13	6	0910	1302	~	238	118	28.08	Assistant Driller – Hole 1
527	14	7	1212	1434	~	142	99	14.06	Foreman Driller – Hole 2
528	15	8	1317	1434	~	77	106	8.16	Assistant Driller – Hole 2
529	18	9	0954	1238	~	166	115	19.09	Static – Downwind
530	20	10	0918	1233	~	195	113	22.04	Static – Downwind
<b>Landfill Gas Sample</b>									
531	Tedlar Bag Gas Sample								

**Table 6 VCM and H<sub>2</sub>S Sampling Information for Site 6**

<b>Samplers for Vinylchloride</b>									
HSL Ref	Pump No.	Sampler Number	On	Off	Tube Reference Number	Exposure Time (min)	Flow Rate (ml/min)	Sample Volume (litres)	Location
612	~	100	~	~	097096	~	~	0.1	Feed 1 (Power plant)
613	~	200	~	~	097088	~	~	0.2	Feed 2 (Power Plant)
614	~	C1	~	~	103595	~	~	0.1	92CV (Old Site)
615	~	C2	~	~	097019	~	~	0.1	55CV (Old Site)
616	~	C5	~	~	097006	~	~	0.1	47CV (Cell 11)
617	~	C6	~	~	103508	~	~	0.1	119CV (Cell 13)
618	~	C7	~	~	097005	~	~	0.1	23CV (Old Site)
619	~	C8	~	~	097041	~	~	0.1	LM5A (Cell 13)
620	~	C9	~	~	103525	~	~	0.1	115CV (Cell 13)
621	~	C10	~	~	103575	~	~	0.1	44Cv (Cell 11)
622	~	C11	~	~	103551	~	~	0.1	117CV (Cell 13)
623	~	C12	~	~	097066	~	~	0.1	110CV (Cell 13)
624	~	C13	~	~	103502	~	~	0.1	103CV (Cell 11)
<b>Samplers for Hydrogen Sulphide</b>									
HSL Ref	Pump No.	Sampler Number	On	Off	Tube Reference Number	Exposure Time (min)	Flow Rate (ml/min)	Sample Volume (litres)	Location
625	~	C1	~	~	~	~	~	0.2	Feed Gas 1
626	~	C2	~	~	~	~	~	0.2	Feed Gas 2
<b>Landfill Gas Sample</b>									
Tedlar Bag Gas Sample									

## 4 RESULTS

### 4.1 RESULTS FOR ALL LANDFILL SITES

**Table 7 Data for Vinylchloride, all sites**

HSL Sample no.	Sample Volume (litres)	VCM (ng)	LoD (ppm)	VCM (mg/m <sup>3</sup> )	VCM (ppm)	Sample Origin
<b>Site 1</b>						
07172/09	18.4	Not Detected	0.0002	<LoD	<LoD	Static - downwind of Hole 1
07171/09	1.0	223	0.0016	0.22	0.087	Bore Hole 1
07174/09	12.6	Not Detected	0.0003	<LoD	<LoD	Foreman Driller - Hole 1
07173/09	12.4	Not Detected	0.0003	<LoD	<LoD	Assistant Driller - Hole 1
07175/09	0.1	936	0.0350	9.36	3.64	Feed Gas to Engine
07169/09	0.1	907	0.0350	9.07	3.53	Feed Gas to Engine
07170/09	0.2	1912	0.0078	9.56	3.72	Feed Gas to Engine
<b>Site 2</b>						
07194/09	7.8	Not Detected	0.0003	<LoD	<LoD	Static – downwind of Hole 1
07189/09	0.8	57	0.0020	0.07	0.029	Bore Hole 1
07195/09	8.2	Not Detected	0.0003	<LoD	<LoD	Foreman Driller -Hole 1
07196/09	9.2	Not Detected	0.0003	<LoD	<LoD	Assistant Driller -Hole 1
07197/09	12.8	Not Detected	0.0002	<LoD	<LoD	Static – downwind of Hole 2
07190/09	0.7	127	0.0022	0.18	0.071	Bore Hole 2
07198/09	11.9	Not Detected	0.0002	<LoD	<LoD	Foreman Driller -Hole 2
07199/09	10.4	Not Detected	0.0002	<LoD	<LoD	Assistant Driller - Hole 2
07193/09	14.4	Not Detected	0.0002	<LoD	<LoD	Static -Liner Edge
07200/09	13.0	Not Detected	0.0002	<LoD	<LoD	Static – Laying Liner
07201/09	7.2	Not Detected	0.0003	<LoD	<LoD	Lining Assistant - Laying
07202/09	7.8	Not Detected	0.0003	<LoD	<LoD	Lining Foreman - Laying
07191/09	0.1	31	0.0156	0.31	0.121	Feed Gas to Engine
07192/09	0.2	80	0.0078	0.40	0.156	Feed Gas to Engine
<b>Site 3</b>						
07926/09	18.0	Not Detected	0.0001	<LoD	<LoD	Static 1. No Drilling 15/10/09
07927/09	18.0	Not Detected	0.0001	<LoD	<LoD	Static 2 No Drilling 15/10/09
07928/09	19.1	Not Detected	0.0001	<LoD	<LoD	Static - Drilling
07929/09	0.3	180	0.0047	0.55	0.212	Bore Hole 1 27/10/09
07930/09	3.3	Not Detected	0.0005	<LoD	<LoD	Foreman Driller - Hole 1
07931/09	4.9	Not Detected	0.0003	<LoD	<LoD	Assistant Driller - Hole 1
07932/09	0.3	Not Detected	0.0047	<LoD	<LoD	Bore Hole 2 27/10/09
07933/09	4.1	Not Detected	0.0004	<LoD	<LoD	Foreman Driller - Hole 2
07934/09	6.9	Not Detected	0.0002	<LoD	<LoD	Assistant Driller - Hole 2
07935/09	0.3	92	0.0047	0.28	0.108	Bore Hole 3 27/10/09
07936/09	5.9	Not Detected	0.0003	<LoD	<LoD	Foreman Driller - Hole 3
07937/09	4.7	Not Detected	0.0003	<LoD	<LoD	Assistant Driller - Hole 3
07924/09	0.1	234	0.0156	2.34	0.908	Feed Gas to Engine
07925/09	0.2	421	0.0078	2.10	0.819	Feed Gas to Engine

<b>Continuation of Table 7 Data for Vinylchloride, all sites</b>						
<b>HSL Sample no.</b>	<b>Sample Volume (litres)</b>	<b>VCM (ng)</b>	<b>LoD (ppm)</b>	<b>VCM (mg/m<sup>3</sup>)</b>	<b>VCM (ppm)</b>	<b>Sample Origin</b>
<b>Site 4</b>						
08233/09	19.0	Not Detected	0.0001	<LoD	<LoD	Worker 1 – Dipping
08234/09	18.9	Not Detected	0.0001	<LoD	<LoD	HSE Staff - Observing
08231/09	0.1	110	0.0156	1.10	0.426	Feed Gas to Engine
08232/09	0.2	482	0.0078	2.41	0.938	Feed Gas to Engine
08237/09	0.1	204	0.0156	2.04	0.792	Feed Gas to Engine
08238/09	0.1	<LoD	0.0160	<LoD	<LoD	Leachate L02 (Headspace)
08239/09	0.1	<LoD	0.0160	<LoD	<LoD	Leachate L01 (Headspace)
<b>Site 5</b>						
08275/09	16.9	Not Detected	0.0001	<LoD	<LoD	Static – Downwind on Tip
08276/09	21.7	Not Detected	0.0001	<LoD	<LoD	Static – Downwind on fence
08269/09	0.3	1759	0.0049	5.58	2.17	<b>Bore Hole 1</b>
08271/09	18.2	Not Detected	0.0001	<LoD	<LoD	Foreman Driller – Hole 1
08272/09	24.0	5	0.0001	0.0002	0.0001	Assistant Driller – Hole 1
08270/09	0.3	2130	0.0049	6.76	2.63	<b>Bore Hole 2</b>
08273/09	13.6	Not Detected	0.0001	<LoD	<LoD	Foreman Driller - Hole 2
08274/09	8.0	Not Detected	0.0002	<LoD	<LoD	Assistant Driller - Hole 2
08267/09	0.1	9597	0.0156	95.97	37.3	Feed Gas to Engine
08268/09	0.2	17574	0.0078	87.87	34.2	Feed Gas to Engine
08279/09	0.1	7181	0.0156	71.81	27.9	Feed Gas to Engine
<b>Site 6</b>						
08889/09	0.1	35	0.016	0.35	0.136	92CV (Old Site)
08890/09	0.1	55	0.016	0.55	0.212	55CV (Old Site)
08893/09	0.1	43	0.016	0.43	0.166	23CV (Old Site)
08891/09	0.1	13	0.016	0.13	0.052	47CV (Cell 11)
08896/09	0.1	107	0.016	1.07	0.416	44Cv (Cell 11)
08899/09	0.1	analysis failed	0.016	analysis failed	analysis failed	103CV (Cell 11)
08892/09	0.1	386	0.016	3.86	1.501	119CV (Cell 13)
08894/09	0.1	49	0.016	0.49	0.192	LM5A (Cell 13)
08895/09	0.1	229	0.016	2.29	0.891	115CV (Cell 13)
08897/09	0.1	677	0.016	6.77	2.635	117CV (Cell 13)
08898/09	0.1	109	0.016	1.09	0.423	110CV (Cell 13)
08887/09	0.1	164	0.016	1.64	0.638	Feed 1 (Power plant)
08888/09	0.2	11	0.008	0.05	0.021*	Feed 2 (Power Plant)
Not assigned	0.1	191	0.016	1.91	0.742	TEDLAR BAG 100ML

\* problems during analysis make the quality of this result questionable

**Table 8 Data for Benzene, all sites**

HSL Sample no.	Sample Volume (litres)	Benzene (ng)	LoD (ppm)	Benzene (mg/m <sup>3</sup> )	Benzene (ppm)	Sample Origin
<b>Site 1</b>						
07172/09	18.4	Not Detected	0.0002	<LoD	<LoD	Static - downwind of Hole 1
07171/09	1.0	851.99	0.0031	0.85	0.263	Bore Hole 1
07174/09	12.6	Not Detected	0.0002	<LoD	<LoD	Foreman Driller - Hole 1
07173/09	12.4	Not Detected	0.0002	<LoD	<LoD	Assistant Driller - Hole 1
07175/09	0.1	1250.79	0.0309	12.51	3.859	Feed Gas to Engine
07169/09	0.1	1130.31	0.0309	11.30	3.487	Feed Gas to Engine
07170/09	0.2	2673.38	0.0154	13.37	4.124	Feed Gas to Engine
<b>Site 2</b>						
07194/09	7.8	Not Detected	0.0004	<LoD	<LoD	Static – downwind of Hole 1
07189/09	0.8	3636	0.0040	4.66	1.438	Bore Hole 1
07195/09	8.2	17.7	0.0004	0.002	0.001	Foreman Driller -Hole 1
07196/09	9.2	62.1	0.0003	0.007	0.002	Assistant Driller -Hole 1
07197/09	12.8	Not Detected	0.0002	<LoD	<LoD	Static – downwind of Hole 2
07190/09	0.7	927.4	0.0044	1.33	0.409	Bore Hole 2
07198/09	11.9	12.4	0.0003	0.001	0.0003	Foreman Driller -Hole 2
07199/09	10.4	17.8	0.0003	0.002	0.001	Assistant Driller - Hole 2
07193/09	14.4	Not Detected	0.0002	<LoD	<LoD	Static -Liner Edge
07200/09	13.0	56.0	0.0002	0.004	0.001	Static – Laying Liner
07201/09	7.2	Not Detected	0.0004	<LoD	<LoD	Lining Assistant - Laying
07202/09	7.8	Not Detected	0.0004	<LoD	<LoD	Lining Foreman - Laying
07191/09	0.1	364.0	0.0309	3.64	1.123	Feed Gas to Engine
07192/09	0.2	1002.2	0.0154	5.01	1.546	Feed Gas to Engine
<b>Site 3</b>						
07926/09	18.0	Not Detected	0.0002	<LoD	<LoD	Static 1. No Drilling 15/10/09
07927/09	18.0	Not Detected	0.0002	<LoD	<LoD	Static 2 No Drilling 15/10/09
07928/09	19.1	17.7	0.0002	0.001	0.0003	Static - Drilling
07929/09	0.3	486.9	0.0093	1.48	0.455	Bore Hole 1 27/10/09
07930/09	3.3	Not Detected	0.0009	<LoD	<LoD	Foreman Driller - Hole 1
07931/09	4.9	11.6	0.0006	0.002	0.001	Assistant Driller - Hole 1
07932/09	0.3	20.1	0.0093	0.061	0.019	Bore Hole 2 27/10/09
07933/09	4.1	25.3	0.0007	0.006	0.002	Foreman Driller - Hole 2
07934/09	6.9	24.5	0.0004	0.004	0.001	Assistant Driller - Hole 2
07935/09	0.3	380.1	0.0093	1.15	0.355	Bore Hole 3 27/10/09
07936/09	5.9	Not Detected	0.0005	<LoD	<LoD	Foreman Driller - Hole 3
07937/09	4.7	Not Detected	0.0007	<LoD	<LoD	Assistant Driller - Hole 3
07924/09	0.1	633.1	0.0309	6.33	1.953	Feed Gas to Engine
07925/09	0.2	1048.9	0.0154	5.24	1.618	Feed Gas to Engine

**Continuation of Table 8 Data for Benzene, all sites**

HSL Sample no.	Sample Volume (litres)	Benzene (ng)	LoD (ppm)	Benzene (mg/m <sup>3</sup> )	Benzene (ppm)	Sample Origin
<b>Site 4</b>						
08233/09	19.0	Not Detected	0.0002	<LoD	<LoD	Worker 1 – Dipping
08234/09	18.9	Not Detected	0.0002	<LoD	<LoD	HSE Staff - Observing
08231/09	0.1	1405	0.0309	14.05	4.34	Feed Gas to Engine
08232/09	0.2	6826	0.0154	34.13	10.53	Feed Gas to Engine
08237/09	0.1	2499	0.0309	24.99	7.71	Feed Gas to Engine
08238/09	n/a	<LoD	0.0310	<LoD	<LoD	Leachate L02 (Headspace)
08239/09	n/a	<LoD	0.0310	<LoD	<LoD	Leachate L01 (Headspace)
<b>Site 5</b>						
08275/09	16.9	Not Detected	0.0002	<LoD	<LoD	Static – Downwind on Tip
08276/09	21.7	Not Detected	0.0001	<LoD	<LoD	Static – Downwind on fence
08269/09	0.3	1125	0.0098	3.57	1.102	<b>Bore Hole 1</b>
08271/09	18.2	Not Detected	0.0002	<LoD	<LoD	Foreman Driller – Hole 1
08272/09	24.0	14	0.0001	0.001	0.0002	Assistant Driller – Hole 1
08270/09	0.3	3533	0.0100	11.22	3.460	<b>Bore Hole 2</b>
08273/09	13.6	Not Detected	0.0002	<LoD	<LoD	Foreman Driller - Hole 2
08274/09	8.0	Not Detected	0.0004	<LoD	<LoD	Assistant Driller - Hole 2
08267/09	0.1	5727	0.0309	57.27	17.67	Feed Gas to Engine
08268/09	0.2	11019	0.0154	55.09	17.00	Feed Gas to Engine
08279/09	0.1	4131	0.0309	41.31	12.75	Feed Gas to Engine
<b>Site 6</b>						
08889/09	0.1	242	0.051	2.42	0.746	92CV (Old Site)
08890/09	0.1	314	0.051	3.14	0.969	55CV (Old Site)
08893/09	0.1	347	0.051	3.47	1.069	23CV (Old Site)
08891/09	0.1	248	0.051	2.48	0.765	47CV (Cell 11)
08896/09	0.1	323	0.051	3.23	0.997	44Cv (Cell 11)
08899/09	0.1	analysis failed	0.051	analysis failed	analysis failed	103CV (Cell 11)
08892/09	0.1	998	0.051	9.98	3.077	119CV (Cell 13)
08894/09	0.1	232	0.051	2.32	0.717	LM5A (Cell 13)
08895/09	0.1	1457	0.051	14.57	4.494	115CV (Cell 13)
08897/09	0.1	1794	0.051	17.94	5.534	117CV (Cell 13)
08898/09	0.1	490	0.051	4.90	1.512	110CV (Cell 13)
08887/09	0.1	1229	0.051	12.29	3.792	Feed 1 (Power plant)
08888/09	0.2	403	0.051	2.02	0.622*	Feed 2 (Power Plant)
Not assigned	0.1	1404	0.051	14.04	4.331	TEDLAR BAG 100ML

\* problems during analysis make the quality of this result questionable

Table 9

Data for Hydrogen Sulphide, all sites

Sample Ref no.	HSL Sample no.	SO <sub>4</sub> <sup>2-</sup> (µg on filter)	SO <sub>4</sub> <sup>2-</sup> (mg/m <sup>3</sup> )	Sample Volume (litres)	LoD (SO <sub>4</sub> <sup>2-</sup> mg/m <sup>3</sup> )	H <sub>2</sub> S Equiv. (µg on filter)	LoD equiv. as H <sub>2</sub> S (mg/m <sup>3</sup> )	H <sub>2</sub> S (mg/m <sup>3</sup> )	H <sub>2</sub> S (ppm)	Sample Origin
<b>Site 1</b>										
119	07178/09	<3.2	<LoD	18.4	0.2	<1.2	0.1	<LoD	<LoD	Static - downwind of Hole 1
122	07181/09	79	79	1.00	3.2	28	1.1	28	<b>19.9</b>	<b>Bore Hole 1</b>
121	07180/09	<3.2	<LoD	12.6	0.3	<1.2	0.1	<LoD	<LoD	Foreman Driller - Hole 1
120	07179/09	<3.2	<LoD	12.4	0.3	<1.2	0.1	<LoD	<LoD	Assistant Driller - Hole 1
<i>Data for feed gas supplied by site operator measured on meter at time of sampling.</i>									<b>216</b>	Feed Gas to Engine
<i>Tedlar gas bag sample; Multirae data (after 7 weeks) (Oxygen concentration 7.5 %)</i>									<b>142</b>	Feed Gas to Engine
<b>Site 2</b>										
230	07218/09	<3.2	<LoD	7.8	0.4	<1.2	0.1	<LoD	<LoD	Static – downwind of Hole 1
227	07215/09	129	109	1.18	2.7	45.8	1.0	39	<b>27.5</b>	<b>Bore Hole 1</b>
231	07219/09	<3.2	<LoD	8.2	0.4	<1.2	0.1	<LoD	<LoD	Foreman Driller -Hole 1
232	07220/09	<3.2	<LoD	9.2	0.3	<1.2	0.1	<LoD	<LoD	Assistant Driller -Hole 1
233	07221/09	<3.2	<LoD	12.8	0.2	<1.2	0.1	<LoD	<LoD	Static – downwind of Hole 2
228	07216/09	23	23	1.00	3.2	8.3	1.1	8.3	<b>5.9</b>	<b>Bore Hole 2</b>
234	07222/09	<3.2	<LoD	11.9	0.3	<1.2	0.1	<LoD	<LoD	Foreman Driller -Hole 2
235	07223/09	<3.2	<LoD	10.4	0.3	<1.2	0.1	<LoD	<LoD	Assistant Driller - Hole 2
229	07217/09	<3.2	<LoD	14.4	0.2	<1.2	0.1	<LoD	<LoD	Static -Liner Edge
236	07224/09	<3.2	<LoD	13.7	0.2	<1.2	0.1	<LoD	<LoD	Static – Laying Liner
237	07225/09	<3.2	<LoD	7.6	0.4	<1.2	0.1	<LoD	<LoD	Lining Assistant - Laying
238	07226/09	<3.2	<LoD	7.8	0.4	<1.2	0.1	<LoD	<LoD	Lining Foreman - Laying
<b>Site 3</b>										
328	07912/09	<3.2	<LoD	18.8	0.2	<1.2	0.1	<LoD	<LoD	Static 1. No Drilling 15/10/09
329	07913/09	<3.2	<LoD	18.0	0.2	<1.2	0.1	<LoD	<LoD	Static 2 No Drilling 15/10/09
330	07314/09	4.6	0.2	19.8	0.2	1.6	0.1	0.1	<b>0.1</b>	Static - Drilling
331	07915/09	115.0	352	0.3	9.8	40.8	3.5	124.7	<b>88.4</b>	<b>Bore Hole 1</b> 27/10/09
332	07916/09	<3.2	<LoD	3.6	0.9	<1.2	0.3	<LoD	<LoD	Foreman Driller - Hole 1
333	07917/09	<3.2	<LoD	5.2	0.6	<1.2	0.2	<LoD	<LoD	Assistant Driller - Hole 1
334	07918/09	98.3	301	0.3	9.8	34.8	3.5	106.6	<b>75.5</b>	<b>Bore Hole 2</b> 27/10/09
335	07919/09	<3.2	<LoD	4.1	0.8	<1.2	0.3	<LoD	<LoD	Foreman Driller - Hole 2
336	07920/09	<3.2	<LoD	7.0	0.5	<1.2	0.2	<LoD	<LoD	Assistant Driller - Hole 2
337	07921/09	416.8	1275	0.3	9.8	147.8	3.5	452.0	<b>&gt; 320.4</b>	<b>Bore Hole 3</b> 27/10/09
338	07922/09	<3.2	<LoD	6.6	0.5	<1.2	0.2	<LoD	<LoD	Foreman Driller - Hole 3
339	07923/09	18	4	4.7	0.7	6.4	0.2	1.4	<b>1.0</b>	Assistant Driller - Hole 3
<b>Site 4</b>										
416	08253/09	<3.2	<LoD	17.9	0.2	<1.2	0.1	<LoD	<LoD	Worker 1 – Dipping
417	08254/09	6.8	0.4	18.9	0.2	2.4	0.1	0.1	<b>0.1</b>	HSE Staff - Observing
<i>Tedlar gas bag sample; Tube Sampler Data</i>									<LoD	Feed Gas to Engine
<i>Tedlar gas bag sample; Multirae Data (Oxygen concentration 18.1%)</i>									<b>1.0</b>	Feed Gas to Engine

**Continuation of Table 9 Data for Hydrogen Sulphide, all sites**

Sample Ref no.	HSL Sample no.	SO <sub>4</sub> <sup>2-</sup> (µg on filter)	SO <sub>4</sub> <sup>2-</sup> (mg/m <sup>3</sup> )	Sample Volume (litres)	LoD (SO <sub>4</sub> <sup>2-</sup> mg/m <sup>3</sup> )	H <sub>2</sub> S Equiv. (µg on filter)	LoD equiv. as H <sub>2</sub> S (mg/m <sup>3</sup> )	H <sub>2</sub> S (mg/m <sup>3</sup> )	H <sub>2</sub> S (ppm)	Sample Origin
<b>Site 5</b>										
529	08263/09	<3.2	<LOD	19.1	0.2	<1.2	0.1	<LOD	<LoD	Static – Downwind on Tip
530	08264/09	<3.2	<LOD	22.0	0.1	<1.2	0.1	<LOD	<LoD	Static – Downwind on fence
523	08257/09	<3.2	<LOD	0.3	9.8	<1.2	3.5	<LOD	<LoD	<b>Bore Hole 1</b>
525	08259/09	<3.2	<LOD	20.2	0.2	<1.2	0.1	<LOD	<LoD	Foreman Driller – Hole 1
526	08260/09	<3.2	<LOD	28.1	0.1	<1.2	0.0	<LOD	<LoD	Assistant Driller – Hole 1
524	08258/09	4.5	13.7	0.3	9.8	1.6	3.5	4.9	<b>3.4</b>	<b>Bore Hole 2</b>
527	08261/09	<3.2	<LOD	14.1	0.2	<1.2	0.1	<LOD	<LoD	Foreman Driller - Hole 2
528	08262/09	<3.2	<LOD	8.2	0.4	<1.2	0.1	<LOD	<LoD	Assistant Driller - Hole 2
<i>Tedlar gas bag sample; Multirae Data (Oxygen concentration 1.4 %)</i>									<b>70.0</b>	Feed Gas to Engine
<b>Site 6</b>										
<i>Tedlar gas bag sample; Multirae Data (Oxygen concentration 0.9 %)</i>									<b>186.0</b>	Feed Gas to Engine
<i>Tedlar gas bag sample; Tube SamplerData</i>									<b>97*</b>	Feed Gas to Engine
<i>Tedlar gas bag sample; Tube SamplerData</i>									<b>107*</b>	Feed Gas to Engine

\* problems during analysis make these results unreliable

**Table 10 Summary of VCM, H<sub>2</sub>S and Benzene Data by Site**

Sample Origin	VCM (ppm)	H <sub>2</sub> S (ppm)	Benzene (ppm)
<b>Site 1</b>			
Static - downwind of Hole 1	< LoD	<LoD	< LoD
Bore Hole 1	<b>0.087</b>	<b>19.9</b>	<b>0.26</b>
Foreman Driller - Hole 1	< LoD	<LoD	< LoD
Assistant Driller - Hole 1	< LoD	<LoD	< LoD
Feed Gas to Engine	<b>3.64</b>	<b>216</b>	<b>3.86</b>
Feed Gas to Engine	<b>3.53</b>	<b>142</b>	<b>3.49</b>
Feed Gas to Engine	<b>3.72</b>	76*	<b>4.12</b>
<b>Site 2</b>			
Static – downwind of Hole 1	< LoD	<LoD	< LoD
Bore Hole 1	<b>0.029</b>	<b>27.5</b>	<b>1.438</b>
Foreman Driller -Hole 1	< LoD	<LoD	<b>0.001</b>
Assistant Driller -Hole 1	< LoD	<LoD	<b>0.002</b>
Static – downwind of Hole 2	< LoD	<LoD	< LoD
Bore Hole 2	<b>0.071</b>	<b>5.86</b>	<b>0.409</b>
Foreman Driller -Hole 2	< LoD	<LoD	<b>0.0003</b>
Assistant Driller - Hole 2	< LoD	<LoD	<b>0.001</b>
Static -Liner Edge	< LoD	<LoD	< LoD
Static – Laying Liner	< LoD	<LoD	<b>0.001</b>
Lining Assistant - Laying	< LoD	<LoD	< LoD
Lining Foreman - Laying	< LoD	<LoD	< LoD
Feed Gas to Engine	<b>0.121</b>	Lost	<b>1.123</b>
Feed Gas to Engine	<b>0.156</b>	Lost	<b>1.546</b>
<b>Site 3</b>			
Static 1. No Drilling 15/10/09	< LoD	<LoD	< LoD
Static 2 No Drilling 15/10/09	< LoD	<LoD	< LoD
Static - Drilling	< LoD	<b>0.059</b>	<b>0.0003</b>
Bore Hole 1 27/10/09	<b>0.212</b>	<b>88.4</b>	<b>0.455</b>
Foreman Driller - Hole 1	< LoD	<LoD	< LoD
Assistant Driller - Hole 1	< LoD	<LoD	<b>0.001</b>
Bore Hole 2 27/10/09	< LoD	<b>75.5</b>	<b>0.019</b>
Foreman Driller - Hole 2	< LoD	<LoD	<b>0.002</b>
Assistant Driller - Hole 2	< LoD	<LoD	<b>0.001</b>
Bore Hole 3 27/10/09	<b>0.108</b>	<b>&gt; 320</b>	<b>0.355</b>
Foreman Driller - Hole 3	< LoD	<LoD	< LoD
Assistant Driller - Hole 3	< LoD	<b>0.968</b>	< LoD
Feed Gas to Engine	<b>0.908</b>	n/a	<b>1.953</b>
Feed Gas to Engine	<b>0.819</b>	n/a	<b>1.618</b>

Continuation of Table 10 Summary of Data

Sample Origin	VCM (ppm)	H <sub>2</sub> S (ppm)	Benzene (ppm)
<b>Site 4</b>			
Worker 1 – Dipping	< LoD	<LoD	< LoD
HSE Staff - Observing	< LoD	<b>0.090</b>	< LoD
Feed Gas to Engine	<b>0.426</b>	<b>1.00</b>	<b>4.34</b>
Feed Gas to Engine	<b>0.938</b>	<LoD	<b>10.53</b>
Feed Gas to Engine	<b>0.792</b>	n/a	<b>7.71</b>
Leachate L02	< LoD	n/a	< LoD
Leachate L01	< LoD	n/a	< LoD
<b>Site 5</b>			
Static – Downwind on Tip	< LoD	<LoD	< LoD
Static – Downwind on fence	< LoD	<LoD	< LoD
Bore Hole 1	<b>2.17</b>	<LoD	<b>1.102</b>
Foreman Driller – Hole 1	< LoD	<LoD	< LoD
Assistant Driller – Hole 1	<b>0.0001</b>	<LoD	<b>0.0002</b>
Bore Hole 2	<b>2.63</b>	<b>3.45</b>	<b>3.460</b>
Foreman Driller - Hole 2	< LoD	<LoD	< LoD
Assistant Driller - Hole 2	< LoD	<LoD	< LoD
Feed Gas to Engine	<b>37.3</b>	<b>70.0</b>	<b>17.67</b>
Feed Gas to Engine	<b>34.2</b>	41 *	<b>17.00</b>
Feed Gas to Engine	<b>27.9</b>	n/a	<b>12.75</b>
<b>Site 6</b>			
92CV (Old Site)	0.136	Not Tested	0.746
55CV (Old Site)	0.212	Not Tested	0.969
23CV (Old Site)	0.166	Not Tested	1.069
47CV (Cell 11)	0.052	Not Tested	0.765
44Cv (Cell 11)	0.416	Not Tested	0.997
103CV (Cell 11)	analysis failed	Not Tested	analysis failed
119CV (Cell 13)	1.501	Not Tested	3.077
LM5A (Cell 13)	0.192	Not Tested	0.717
115CV (Cell 13)	0.891	Not Tested	4.494
117CV (Cell 13)	2.635	Not Tested	5.534
110CV (Cell 13)	0.423	Not Tested	1.512
Feed 1 (Power plant)	0.638	186.0	3.792
Feed 2 (Power Plant)*	0.021 *	97*	0.622*
TEDLAR BAG 100ML	0.742	107*	4.331

\* problems during analysis make the quality of this result questionable

**Table 11 Summary of the range of measured concentrations (ppm) for VCM, H<sub>2</sub>S and Benzene.**

<b>Gas</b>	<b>Site</b>	<b>Static</b>	<b>Personal</b>	<b>Bore Hole</b>	<b>Feed Gas</b>
VCM (ppm)	1	< LoD	< LoD	0.09	3.5 - 3.7
	2	< LoD	< LoD	0.03 - 0.07	0.1 - 0.2
	3	< LoD	< LoD	0.11 - 0.21	0.8 - 0.9
	4	n/a	<LoD	n/a	0.43 - 0.94
	5	< LoD	< LoD - 0.0001	2.17 - 2.63	27.9 - 37.4
	6	n/a	n/a	0.05 - 2.64	0.6 - 0.7
H2S (ppm)	1	<LoD	<LoD	19.9	142 - 216
	2	<LoD	<LoD	5.9 - 27.5	no data
	3	<LoD - 0.06	<LoD - 0.968	75.5 - > 320	no data
	4	n/a	<LoD - 0.09	n/a	< LoD - 1
	5	<LoD	<LoD	<LoD - 3.45	70
	6	n/a	n/a	n/a	186
Benzene (ppm)	1	< LoD	< LoD	0.26	3.5 - 4.1
	2	< LoD	0.0003 - 0.001	0.4 - 1.44	1.1 - 1.6
	3	< LoD - 0.0003	< LoD - 0.002	0.02 - 0.46	1.6 - 1.9
	4	n/a	<LoD	n/a	4.34 - 10.5
	5	<LoD	< LoD - 0.0002	1.10 - 3.46	12.8 - 17.7
	6	n/a	n/a	0.72 - 5.53	3.8 - 4.3

## 5 DISCUSSION

### 5.1 MEASUREMENTS FOR VCM

Of the four sites visited where drilling took place, only Site 5 detected a personal VCM exposure (0.0001 ppm) which was above the limit of detection. The associated bore hole concentration was 2.17ppm which gives a dilution factor for VCM of 1:21,700.

This site also recorded the highest concentration of VCM in the bore hole (2.6 ppm), and in the accumulated feed supply to the power generation plant (37 ppm). The only other site where the bore hole VCM concentration was greater than 1 part per million level was at Site 6 (also 2.6 ppm). However, here only the existing bore holes were sampled since no drilling or other work activity was taking place, or being monitored. At the other three sites where drilling took place the VCM measured at the bore holes was in the approximate range of 0.1 to 0.2 ppm, i.e. about 10 times less than at Site 5. Consequently, any personal exposure measurements might be expected to be in the order of 0.00001 ppm. VCM at this level would not be detected since the limit of detection (LoD) for the personal results typically ranged from 0.00001 to 0.00005 ppm, (depending on the sample volume).

Background measurements made downwind of work activities at distances of 10 to 30 metres also showed no VCM which is again consistent with the expected dispersion and dilution of gas emitted from the bore hole.

There is no clear relationship between the Sites for the ratio of VCM in the bore hole compared to the accumulated feed gas. This is because the feed gas is comprised of gas delivered from all over the site and each bore hole will contribute differing amounts of each gas present in the mixture. This will be dependent on factors such as the type of waste deposited and the age of the cell. VCM would not normally be expected to occur in ambient air and therefore these measurements all relate to the activities taking place on the sites.

### 5.2 MEASUREMENTS FOR BENZENE

Of the four sites visited where drilling took place, three (Sites 2, 3 and 5) detected personal exposure to benzene (ranging from 0.0002 to 0.002 ppm). The absence of quantifiable personal and static exposure for benzene at Site 1 is likely to be due to the strong wind prevailing at the time of sampling. Only Site 3 gave a positive static result for benzene (0.0003 ppm), even though the three associated bore hole samplers did not give the highest concentrations relative to the other Sites. This static exposure may be attributed to the three bore holes being drilled consecutively and the same static sampler being used to monitor all three holes. The benzene measurements for both the personal and background samplers must be considered in the context of what might be expected in normal ambient air from a rural environment. The expected environmental concentrations of benzene are at least 1ppb in an urban area and 0.1ppb or less in a rural area. Therefore, it is likely that the benzene concentrations at Sites 2 and 3 (1 to 2 ppb) do relate to the work activity as they are all higher than the predicted environmental levels. At site 5 the static concentration is of similar magnitude to the predicted environmental levels so it can't be attributed with any confidence to emissions from the bore hole. Benzene was less than the LoD on the single personal sample taken during leachate well dipping at Site 4, and exposure was not monitored at Site 6.

Benzene was found in all the bore holes measured (Sites 1, 2, 3 and 5).. The LoD for the personal sampling results typically ranged from 0.2 to 0.9 ppb, (depending on the sample

volume). Some of the personal benzene exposures recorded were above the LoD at Sites 2, 3 & 5. The dilution factors calculated at each of these sites based on the maximum personal exposure compared to the associated bore hole concentration were 1:719 (Site 2), 1:9.5 (Site 3) and 1:5510 (Site 5)

There is no clear relationship between the sites for the ratio of benzene in the bore hole compared to the accumulated feed gas. However, typically the feed gas was approximately 5 to 10 times more concentrated. As discussed above for VCM, each bore hole will make a unique contribution to the overall profile of the gas fed to the power plant.

### **5.3 MEASUREMENTS FOR HYDROGEN SULPHIDE**

Of the four sites visited where drilling took place, hydrogen sulphide was only detected on one personal sample above the LoD. This was at Site 3 and the concentration was 0.97 ppb. The absence of a quantifiable personal exposure at Site 1 is, likely to be due to the high wind speed (as previously discussed). The positive measurement (60 ppb) from the static sampler at Site 3 is consistent with this site having the highest bore hole concentrations. The personal exposure measured at Site 4 was from a single sampler worn by an observer during the leachate well sampling exercise. It is not clear how this exposure occurred and the result should be treated cautiously.

Hydrogen sulphide was found in all the bore hole gas samples (Sites 1, 2, 3 and 5). No bore hole measurements were made at Site 4, and no personal samples taken at Site 6. The dilution factors at each site based on the highest personal exposure compared to the associated bore hole concentration were 1:719 (Site 2), 1:85 (Site 3) and 1:5510 (Site 5). The LoD for personal sampling measurements ranged from 71 to 214ppb, (depending on the sample volume). Many wells emit methane at about 50%, the LEL for methane is 5% and personal gas monitors are worn by site workers and contractors. The monitors have a low-level alarm set at 10% of the LEL (0.5% Methane). Since the alarms are rarely activated, this indicates better than a 100-fold dilution between the well and the driller's breathing zone. The study data supports this assertion.

There is no clear relationship between the Sites for the ratio of hydrogen sulphide in the bore hole compared to the accumulated feed gas. However, based on the limited data available the feed gas was approximately 10 times more concentrated.

The hydrogen sulphide analytical method is validated for workplace air sampling where the environment is usually well understood. There is a potential for other sulphides present in the collected air to also react, although this has not been fully tested. Sulphur dioxide, methanethiol and carbonyl sulphide have all been shown to have no significant interference. Consequently there are no significant concerns about the validity of the reported data.

## **6 CONCLUSIONS**

Measurements for benzene, hydrogen sulphide and vinyl chloride made during bore hole drilling were all at lower concentrations than would be of cause for concern. Dilution factors calculated based on the highest personal exposure for each contaminant compared to the associated bore hole concentrations were at least 1:320 for all three contaminants. This is supported by the established knowledge that wells generally emit methane at about 50%, and if workers use personal alarmed gas monitors set at a trigger level of 10% of the LEL (i.e. 0.5% methane) and these do not alarm, this indicates more than a 100-fold dilution between the well and the operative's breathing zone.. If the LEL alarm was triggered there is a potential risk not only from methane but from other trace gases. Hence, the steps taken to reduce the methane risk would be applicable to the trace gases.

## 7 REFERENCES

HSE, Control of Substances Hazardous to Health Regulations 2002 (COSHH)

Environment Agency (2004), LFTGN 04 *Guidance for monitoring trace components in landfill gas*. R&D Technical Report

Occupational Safety and Health Administration, Hydrogen Sulphide, OSHA 1008

# Good control practice for workers' exposure to gases in landfill

## Sampling and measurement report

Gases generated by decomposition of landfill contain, principally, methane and carbon dioxide, but may also contain hazardous concentrations of trace components. This project gathered information on the potential exposure of workers to these trace components during specific types of tasks, to provide evidence to develop guidance on good practice for the control of exposure. The study was conducted at six land fill sites identified as having the potential to generate high concentrations of three representative trace components, vinyl chloride, hydrogen sulphide and benzene. Comparisons of personal exposures were made with the levels found in the collected raw gas. The personal task based exposures (given the environmental conditions prevailing at the time monitoring was conducted) were insignificant for all three components and would not normally pose a health concern.

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