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Appeal by UK Waste Management Ltd:

Round 'O' Quarry, Cobbs Brow Lane, Skelmersdale, Lancashire.

Appeal Ref. APP/Q2371/A/97/288746

Supplementary Proof of Evidence on Landfill Gas Emissions

[Ref. *ARROW 4*]

For an on behalf of

ARROW

August 1998

Introduction and Summary

This proof has been produced in response to the Inspector's request for clarification on the issue of gas emissions, landfill gas concentrations, and the comparison between occupational and long term air quality standards. This arose out of the cross-examination of David Campbell on his proof UK5. Given the recent public debate regarding the health effects of landfill emissions, there is also a brief section on this related issue.

The proof is divided into four sections. The first section considers the landfill gas concentration data from the Waste Management Papers. The second considers the comparison of occupation and long term exposure standards. The third section examines the recent public debate surrounding the article on landfill and health effects in 'The Lancet'. Finally, pre-empting any possible discussion on the link between landfill and health, I have undertaken a very basic modelling of landfill flare and vent emissions.

Landfill Gas Composition

Landfill has is made up primarily of carbon dioxide and methane. Additionally there are a wide variety of gases which make up 3 to 5% by volume consisting of a wide variety of different chemical compounds, plus water vapour.

In terms of the trace gases, toxicity is raised as an issue in paragraph 3.5 of Waste Management Paper (WMP) 27. This notes that toxicity is a factor which should be considered, but the emphasis in the text is on the obvious occupational risks. This issue is further clarified by chapter 9 of WMP27. This considers the development of land around landfill sites. Although WMP27 does not specifically consider development of a landfill next to existing land uses, we would have to assume that the same precautionary assessment procedure must apply.

It is difficult to predict precisely the composition of landfill gas as it can vary according to what materials are placed in the landfill. The composition of the gas also varies over time as the different stages of decomposition take place. In addition to the production of a number of different chemical compound by the direct breakdown of substances in the waste, and by the action of bacteria, volatile substances in the waste fill can be driven off as gas by the heat generated during decomposition. Although hazardous materials such as solvents are usually dealt with as '*special waste*', hazardous substances can legally be incorporated within ordinary domestic, commercial or industrial wastes.

WMP27 gives a brief breakdown of the compounds that make up trace gases in Appendix A. However a more detailed breakdown of landfill gas concentrations is given in Appendix 1 of WMP26.

Occupational vs. Long Term Exposure

As noted above, the emphasis on toxicity in WMP27is related to occupational exposure. The 'safe' working levels are set by the Health and Safety Executive's '*EH40 series*'. However in relation to assessing the effects of emissions on public health these limits are not acceptable. As there are no long term exposure levels (LTELs) set for the type of pollutants found in the trace gas from landfills we have to apply a more arbitrary means - dividing the occupational figures by another factor. Table 1 list a number of figures for landfill trace gas concentrations, their occupational limits, and the calculated LTEL.

In conclusion, it can be clearly shown that exposure to landfill gas that has undergone little dilution does pose a potential health risk.

Health Effects and 'The Lancet' Study

It was an interesting coincidence that the publication of a EUROHAZCON in *The Lancet* on the possible effects of landfill on foetal development came so soon after the adjournment of the inquiry. I believe that this paper deserves a number of comments.

Firstly, the study shows a positive correlation between proximity to a landfill and the incidence of birth defects. The certainty of the results is not clear - this could be due to the disparate nature of the wastes in the different sites giving varying levels of health impact.

Secondly, and in agreement with the Lancet's '*commentary*' analysis, this is purely an epidemiological study looking at the incidence of certain illnesses over a geographical area. None of the statistics have been validated by associating particular emissions with health effects. In all my work on landfill and health in the UK I am not aware of any publicly available document which makes association between emissions and health effects. In my opinion the simple reason for why no detailed research has been carried out, including the development of a risk assessment based upon a source-receptor model, is that epidemiology is so much cheaper to carry out than environmental toxicology.

Finally, in relation to the subject of *The Lancet* article, what the study is looking at is birth defects. By the very nature of the study's subject other reported health effects such as cancer, neurological problems and respiratory problems are not significant. We must look to the many other studies which consider these other health effects to assess the potential effects of landfill on children and adults.

Developing a Source-Receptor Model for Landfills

It is clear of course that to demonstrate a link between landfill emissions and health we must develop a model which shows how the emissions enter the environment, how they are transported, and their fate… *a source-receptor model*. It is very difficult to undertake this for landfill as the required standard of data does not exist as one body of evidence. However, it is possible to produce a simple model which can give indications about the potential effects of landfill emissions.

The model is explained in detail in Appendix 2. It is a simplistic Gaussian plume model based loosely around the R91 model. It is not intended to produce precise results - this would be inappropriate in any case given the uncertainties in the data upon which the model operates. Many of the parameters relating to the flares, temperatures, etc., are assumed. If UK Waste were to provide more detailed information I would be willing to undertake a revision of the model during the inquiry.

This model gives results in terms of a multiplication factor. The pollutant emission is set a 1 mg m^{-3} and so to calculate the value of <u>any</u> pollutant you simply multiply the pollutant concentration in mg m^{-3} by the result of this model at the particular distance required. The results are plotted in a graph in figure 2. The maxima predicted from the model are:

- For unflared gas, the maximum concentration is 0.0034 mg m^{-3} (per mg m^{-3} release) at 140 metres;
- For flared gas, the maximum concentration is 0.00056 mg m^{-3} (per mg m^{-3} release) at 240 metres.

I have no reliable data on flare emissions as the information I have gathered to date is too variable to provide a reliable basis for modelling. Hence the rest of this study only considered the case of unflared gas.

The results show that for unflared landfill gas the LTEL will be exceeded for two compounds - benzene and vinyl chloride. Both compounds are 'known carcinogens'. If we include other effects such as the addition or synergism between substances then it is likely that other groups of chemicals will also exceed the LTEL.

While the variability in this model cannot be relied upon to provide an accurate figure, the strength of the assessment procedure enables us to show that there is a possibility for high concentrations of toxins to be produced from landfill gas. There are therefore obvious implications for public health should landfill gas be vented within 400 to 500 metres of any dwelling or occupied structure.

There are further recommendations for improving the model by suggesting the type and quality of data that would be required for a more detailed assessment.

In conclusion

There are predictable health impacts if the emissions from landfills are properly modelled. The only issue is really how we obtain the sort of quality data required to produce a reliable set of results that can form the input of a human health risk assessment.

In any case, this very rough model would indicate that there exists the potential for adverse health effects from the release of landfill gas.

Landfill Gas Composition

Landfill has is made up primarily of carbon dioxide (CO_2) and methane (CH_4). Additionally there are a wide variety of gases which make up 3 to 5% by volume consisting of a wide variety of different chemical compounds, plus water vapour.

The risk from CO_2 and CH_4 is essentially two-fold:

- CH_4 presents a risk of fire should it build up in any enclosed space, or explosion should the concentrations be between 5% and 15% by volume.
- Both CH_4 and CO_2 represent a risk of asphyxiation should concentrations build up above 20%. This is particularly a problem in underground voids such as sewers.

The accepted '*safe*' level for development to take place near a landfill site is a sub-surface CH_4 concentration of 1% by volume and a CO_2 level of 1.5% by volume[1].

In terms of the trace gases, toxicity is raised as an issue in paragraph 3.5 of WMP27:

> '*Some of the minor constituents of landfill gas could have toxic effects if present in high enough concentrations. Operators should undertake an assessment of risk and where necessary apply control measures as required by the control of Substances Hazardous to Health Regulations 1988. Trace gases do not usually represent a health hazard following normal atmospheric dilution. Hydrogen sulphide is toxic at low concentrations, having occupational exposure standards of 10ppm (8 hour time Weighted Average reference period) and 15ppm (short term exposure, 10 minute reference period) (HSE Guidance EH40).*'

This issue is further clarified by chapter 9 of WMP27. This considers the development of land around landfill sites. Although WMP27 does not specifically consider development of a landfill next to existing land uses, we would have to assume that the same precautionary assessment procedure must apply. In practice the development of a new landfill near existing developments is more problematic because it can be difficult to retrofit gas protection measures into old buildings.

It is difficult to predict precisely the composition of landfill gas as it can vary according to what materials are placed in the landfill. The composition of the gas also varies over time as the different stages of decomposition take place. The initial stages of decomposition, lasting only a few weeks or months, is an aerobic process, leading primarily to the production of carbon dioxide and water, and of course light volatile compounds boiled off by the heat generated by decomposition. Over the next five to ten years the waste in the landfill undergoes further degradation until it reaches an advanced state of anaerobic decomposition when methanogenic bacteria begin to break down the organic content of the landfill to produce methane.

In addition to the production of a number of different chemical compound by the direct breakdown of substances in the waste, and by the action of bacteria, volatile substances in the waste fill can be driven off as gas by the heat generated during decomposition. The heavier fraction of these substances will actually condense in the landfill gas collection system. A particular problem in terms of volatilisation are organic and chlorinated organic solvents, and the heavier hydrocarbons. Although hazardous materials such as solvents are

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1 Paragraph 1.31 and 7.9, Waste Management Paper (WMP) 27 - '*Landfill Gas*', DoE 1989.

usually dealt with as '*special waste*', hazardous substances can legally be incorporated within ordinary domestic, commercial or industrial wastes providing they are below the relevant threshold criteria[2] (so long as they are mixed at source, not transit).

WMP27 gives a brief breakdown of the compounds that make up trace gases in Appendix A (p.57). This is in fact extracted from Table 2.1 (p.134) of WMP26[3]. However a more detailed breakdown of landfill gas concentrations is given in Appendix 1 of WMP26 (p152-154, as referred to in the cross-examination of David Campbell on UK5).

For the purposes of this study I will be using the data from Appendix 1 of WMP26. The exception to this is the level for hydrogen sulphide which is not given in Appendix 1, although there is a volumetric figure given in Table 2.1. This has been converted[4] to a gas concentration assuming standard pressure, molecular weight 34 and a ambient temperature of 20ºC. The figures in Table 2.1 are therefore changed as follows:

- Typical value, 0.00002% v/v == 0.2 ppm == 0.28 mg m^{-3}
- Maximum value, 0.0014% v/v == 14 ppm == 19.8 mg m^{-3}
- Sulphate rich wastes, 35% v/v == 350,000ppm == 495,833 mg m^{-3}

Occupational vs. Long Term Exposure

As noted in the reference to WMP27 given above, the emphasis on toxicity is related to occupational exposure. This is accepted by the industry since there are many situations where operators could come into contact with landfill gas. In these situations the 'safe' working levels are set by the Health and Safety Executive's '*Occupational Exposure Limits*' - these levels are published every year in the 'EH40 series'[5]. However in relation to assessing the effects of emissions on public health these limits are not acceptable as they are based on a 8 hour per day or 10 minute explore over the course of a working lifetime. Unfortunately there are no established statutory long term exposure levels (LTELs) set for the type of pollutants found in the trace gas from landfills. For this reason we have to apply a more arbitrary means:

- Where EH40 sets an 'occupational exposure limit' (OEL), we take the OEL and divide it by 100;
- Where EH40 set a 'maximum exposure limit' (MEL), we take the MEL and divide it by 500 (in recognition that the MEL should never be exceeded).

There are a number of different practices for producing LTELs from OELs or MELs. The format I use is also used by other consultants such as Environmental Resources Management. Other consultants, for example AEA Technology, have used lower figures in past studies such as OEL/40 and MEL/100.

The exception to the above is the MEL for vinyl chloride. The EH40 document sets this as a

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2 Part III, Schedule 2, The Special Waste Regulations 1996, SI. 1996/972. A detailed explanation is given in Annex B (in particular, B5) of DoE Circular 6/96, '*Special Waste Regulations 1996*'.

3 Waste Management Paper 26 - '*Landfilling Wastes - A Technical Memorandum for the Disposal of Wastes on Landfill Sites*', DoE 1986.

4 From Appendix B, HMIP Technical guidance Note D1… mg m^{-3} = ppm * (molecular weight / 24) * (293 / 293)

5 Current version, EH40/98 - '*Occupational Exposure Limits 1998*', HSE 1998.

volumetric (v/v) figure. As with the examples before I have converted this to a gas concentrations assuming standard pressure, molecular weight 62 and 20ºC…

- 7ppm == 18.1 mg m^{-3}

In the table below I list a number of figures from Appendix 1 of WMP26, the MEL/OEL and the LTEL (the MEL/500 or OEL/100 figure). A factor comparing these figures in then calculated by dividing the WMP26 level by the LTEL.

Table 1: Comparison of Occupational and Long Term Standards

Compound	WMP26 levels mg m^{-3}	EH40 OEL mg m^{-3}	EH40 MEL mg m^{-3}	LTEL mg m^{-3}	WMP26 ÷ LTEL
Benzene	0.4 to 114		16	0.032	12.5 to 3,562
Toluene	8 to >460	191		1.91	4.2 to >240
Xylene	34 to 470	441		4.4	7.7 to 107
Hydrogen sulphide	0.28 to 19.8	14		0.14	2 to 141
Ethyl benzene	17 to 330	441		4.4	3.98 to 75
Styrene	<0.1 to 7		430	0.86	0.1 to 8.1
Tricholoroethylene	<0.1 to 170		550	1.1	0.1 to 155
Vinyl chloride	0.1 to 177		18.1	0.036	2.6 to 4,658
Tetrachloroethylene	0.1 to 350	345		3.45	0.02 to 1

The important thing to note here is that although the lower '*WMP25÷LTEL*' figure is in some cases smaller than 1, all the higher figures are greater then or equal to 1. If the public were exposed to poorly diluted gases for a long period of time - as noted in paragraph 3.5 of WMP27 - this would pose a health risk. For example, if we take the level of hydrogen sulphide (H_2S) emitted from sites where large quantities of gypsum (for example, plasterboard or filter cake rich in calcium sulphate) have been tipped, the level noted in Table 2.1 of WMP26 was 495,833 mg m^{-3}. Recalculating the OEL to an LTEL, such a level of H_2S would exceed the LTEL by 3,500,000. Therefore even if the gases from the site were diluted by a factor of a few million, the LTEL could still be exceeded.

Another issue with regard to chemical mixtures is the effect of '*addition*' and '*synergism*':

- Where two chemicals have broadly similar physiological or toxicological effects they can be considered to be the same for the purposes of risk assessment. They are considered to be 'additive'. For example benzene and ethyl benzene act in a similar manner and the figures for these pollutants could be summed as indicated in EH40[6].
- Synergism is where two chemicals act together to promote the effect of one or both. This is a very problematic thing to assess because work on the effects of chemical mixtures has only recently started. But there are some effects that are known, such as the combination of chloroform and carbon tetrachloride which produces an effect 4 times greater then the sum. The issue of synergism is also further complicated by other industrial emissions and background pollutants, particularly combustion pollutants such as nitrogen oxides or sulphur oxides.

In conclusion, it can be clearly shown that exposure to landfill gas that has undergone little dilution does potential pose a health risk.

6 Paragraphs 67 to 75 and Part 3, EH40/98

Health Effects and '*The Lancet*' Study

It was an interesting coincidence that the publication of a paper in *The Lancet* on the possible effects of landfill on foetal development came so soon after the adjournment of the inquiry. I believe that this paper deserves a number of comments.

Firstly, the results of the paper[7] are based purely on an epidemiological study looking at the incidence of certain birth defects on live and still born babies carried by parents living near landfills. The results of this study show a positive correlation between proximity to a landfill and the incidence of birth defects. The certainty of the results is not clear - the results demonstrate a clear effect, but the confidence in the figures covers a wide band making it difficult to show a trend above other possible effects. This could be due of course to the disparate nature of the wastes in the different sites giving varying levels of health impact - and hence introducing more error into the statistics.

Secondly, and in agreement with the Lancet's '*commentary*' analysis on page 417, this is purely an epidemiological study looking at the incidence of certain illnesses over a geographical area. None of the statistics have been validated by associating particular emissions with health effects. In all my work on landfill and health in the UK I am not aware of any publicly available document which makes association between emissions and health effects. The reasons for this are simple:

- None of the regulatory bodies have sponsored such detailed research - although the North West Regional of the Environment Agency did recently commission a study from the London School of Hygiene and Tropical Medicine[8] which reviewed other health studies;
- The industry has not produced any meaningful assessment of the health effects from landfill which actually develop a source-receptor model to demonstrate the presence or absence of any effect.

In my opinion the simple reason for why no detailed research has been carried out, including the development of a risk assessment model based upon a source-receptor model, is that epidemiology is so much cheaper to carry out than environmental toxicology. As Dr. Gerald Draper of the Committee on the Medical Aspects of Radiation in the Environment (COMARE) put to me in a memorable quote during a public debate on low level radiation and health…

> "*We do epidemiology because it's cheaper to count statistics than to take samples. In any case even if we had the money I can't imagine someone co-operating with such a study.*"

Finally, in relation to the subject of *The Lancet* article, what the study is looking at is birth defects. By the very nature of the study's subject other reported health effects such as cancer, neurological problems and respiratory problems are not significant. We must look to the many other studies which consider these other health effects to assess the potential effects of landfill on children and adults.

In conclusion, the EUROHAZCON does give us valuable new evidence for health effects from landfill sites. However it only considers a narrow range of effects, and so we must still

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[7] A copy of the article is provided in Appendix 1.

[8] '*Potential Human Health Effects of Landfill Sites*'. Report to the North West Region of The Environment Agency. Martine Vrijheid, Environmental Epidemiology Unit, London School of Hygiene and Tropical Medicine. March 1998.

have regard to the many other studies that have been produced on landfill and health.

Developing a Source-Receptor Model for Landfills

It is clear of course that to demonstrate a link between landfill emissions and health we must develop a model which shows how the emissions enter the environment, how they are transported, and their fate… ***a source-receptor model***. It is very difficult to undertake this for landfill as the required standard of data does not exist as one body of evidence. I have been collecting information from different sources such as site monitoring and environmental statements for three years, but it is still not enough to produce a detailed model and validate it. However, it is possible to produce a simple model which can give indications about the potential effects of landfill emissions.

Even having defined our '*system*' - a representation of the landfill and its emissions - the next problem is to find a model to actually calculate the dispersion of pollutants in air. Most of the dispersion modelling systems available are intended for larger scale emissions, and are often not ideal for use in near field applications (less than 250 metres). For this reason I have chosen to actually write a dispersion model specifically for this study, based around the 'R91' model, but without the more complex features that later models take account of such as terrain, mixing heights and gas density. In any case given that we are considering near-field effects issues such as mixing height and atmospheric stability are not so critical.

The model is explained in detail in Appendix 2. It is a simplistic Gaussian plume model based loosely around the R91 model. It is not intended to produce precise results - this would be inappropriate in any case given the uncertainties in the data upon which the model operates. In developing the model I have assumed no particular wind direction or meteorological conditions. Wind speeds are taken as an average for the year. Many of the parameters relating to the flares, temperatures, etc., are assumed. If UK Waste were to provide more detailed information I would be willing to undertake a revision of the model during the inquiry.

The model essentially considered two types of releases from a landfill site:

- Landfill gas that is released from a single point on a site;
- Landfill gas that is flared from a single point on a landfill site.

The essential difference between the two states we are considering - a flared and an unflared emission - is the plume rise function. Flared gas will be thermally buoyant while unflared gas will rise only as far as its kinetic energy will take it. The practical difference between these two states is that buoyant plumes rise higher, thus reducing ground level concentrations.

The model gives results in terms of a multiplication factor. The pollutant emission is set a 1mg m^{-3} and so to calculate the value of any pollutant you simply multiply the pollutant concentration in mg m^{-3} by the result of the model at the particular distance required.

The results of the two models were plotted on the same graph - table 2 - for comparison. The maxima predicted from the model are:

- For <u>unflared</u> gas, the maximum concentration is 0.0034 mg m^{-3} (per mg m^{-3} release) at 140 metres;
- For <u>flared</u> gas, the maximum concentration is 0.00056 mg m^{-3} (per mg m^{-3} release) at 240

metres.

Taking Table 1 given earlier, we can generate a more meaningful set of figures relating to modelled releases and the LTEL - this data is given in Table 3. This is done by multiplying the WMP26 levels by the maximum level from the model to produce the '*pollutant maxima*'. As with the previous table, this is divided by the LTEL to provide a comparison.

Table 3: Comparison of LTEL and Modelled Levels - Unflared Gas

Compound	WMP26 levels mg m^{-3}	Pollutant maxima, mg m-3	LTEL mg m^{-3}	WMP26 ÷ LTEL
Benzene	***0.4 to 114***	***0.0014 to 0.388***	***0.032***	***0.043 to 12.113***
Toluene	8 to 460	0.0272 to 1.564	1.91	0.014 to 0.819
Xylene	34 to 470	0.1156 to 1.598	4.4	0.026 to 0.363
Hydrogen sulphide	0.28 to 19.8	0.0010 to 0.067	0.14	0.007 to 0.481
Ethyl benzene	17 to 330	0.0578 to 1.122	4.4	0.013 to 0.255
Styrene	0.1 to 7	0.0003 to 0.024	0.86	0.000 to 0.028
Tricholoroethylene	0.1 to 170	0.0003 to 0.578	1.1	0.000 to 0.525
Vinyl chloride	***0.1 to 177***	***0.0003 to 0.602***	***0.036***	***0.009 to 16.717***
Tetrachloroethylene	0.1 to 350	0.0003 to 1.190	3.45	0.000 to 0.345

Note, '*modelling maxima*' level is 0.0034 mg m^{-3}

As can be seen, two compounds - benzene and vinyl chloride, both known carcinogens - both exceed the LTEL. While the variability in this model cannot be relied upon to provide an accurate figure, the strength of the assessment procedure enables us to show that there is a possibility for high concentrations of toxins to be produced from landfill gas. There are therefore obvious implications for public health should landfill gas be vented within 400 to 500 metres of any dwelling or occupied structure.

The data available to construct this model, and the lack of information on the specific features of the flares and gas collection for the proposed landfill, mean that this cannot be considered a wholly accurate model. What it is here to do is indicate the possibilities for pollutants reaching hazardous concentrations, inform the debate on the issue, and stimulate further work. The obvious need in this case is hard data. It qualitative data can be found then there is a more realistic change of getting a more accurate result. The use of better data would also mean that a more accurate model could be developed, narrowing the range of results still further. The priorities for further research are set out in detail at the end of Appendix 2.

In conclusion

There are predictable health impacts if the emissions from landfills are properly modelled. The only issue is really how we obtain the sort of quality data required to produce a reliable set of results that can form the input of a human health risk assessment.

In any case, this very rough model would indicate that there exists the potential for adverse health effects from the release of landfill gas.

Appendix 1: The Lancet Article

(note, the pages of the article are not numbered in accordance with this report)

Appendix 2: A Simple Model for Landfill Emissions

Introduction

This is a simplistic Gaussian plume model based loosely around the R91 model. It is not intended to produce precise results - this would be inappropriate in any case given the uncertainties in the data upon which the model operates.

The model essentially considered two types of releases from a landfill site:

- Landfill gas that is released from a single point on a site;
- Landfill gas that is flared from a single point on a landfill site.

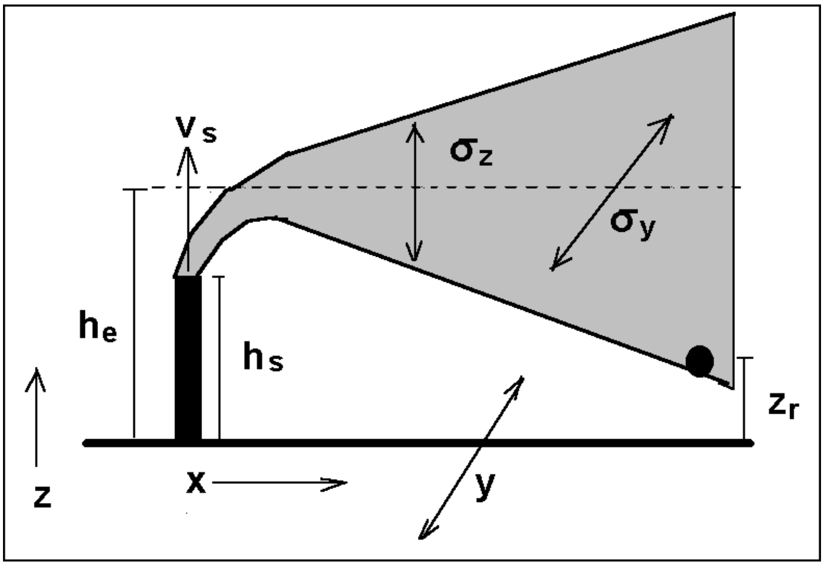
In developing the model I have assumed no particular wind direction or meteorological conditions. The model is set to average over the Pasquill-Gifford 'C' and 'D' stability categories (neutral conditions) - this represents about 75% of the possible meteorological conditions that occur during the year. Likewise wind speeds are taken as an average for the year, and separate calculations are carried out and the results integrated to produce the final figure. The model calculates 1 hour averages - accuracy should therefore be within ±50% to 75%.

Model Calculations and Variables

The essential difference between the two states we are considering - a flared and a unflared emission - is the plume rise function. Flared gas will be thermally buoyant while unflared gas will rise only as far as its kinetic energy will take it. The practical difference between these two states is that buoyant plumes rise higher, thus reducing ground level concentrations.

The emission model is described in the diagram below:

Figure 1: Illustration of Plume Dispersion



The important thing in this case is to set the height of the stack and the receptor correctly to the modelling baseline given that the distances are so small. I have assumed that the flare is 5 metres tall. I'm also assuming that the location of the flare stack is about three metres above the surrounding land. The height of the stack above the modelling baseline is therefore 8 metres. The receptor is set to the height of the average person - 1.5 metres.

The table below gives the parameters, values and formulas used in the model:

Table 2: Model Description

Parameter	**Sym.**	**Value**	**Formula**
Discharge velocity, $m\ s^{-1}$:	v_s	25	
Stack diameter, m:	d	0.8	
Volumetric mission rate, $m^3\ s^{-1}$:	V	25.1	$2 * \pi * (d/2)^2 * v_s$
Pollutant emission, $mg\ m^{-3}$	P	1	
Total emission, $mg\ s^{-1}$	Q	25.1	V * P
Moisture content, $mg\ m^{-3}$	n	100	
Discharge temperature, ^oC	t_d	20	
Ambient temperature, ^oC	t_a	12	
Thermal discharge, MW	E	0.2	$[Q * (1 - ((t_a+273) / (t_d+273))) / 2.9] - (0.0023 * (n/1000))$
Stack height, m	h_s	8	
Wind at stack height, $m\ s^{-1}$: u10 (@ 29%) = 2.5 $m\ s^{-1}$: u10 (@ 36%) = 6.5 $m\ s^{-1}$: u10 (@ 25%) = 11 $m\ s^{-1}$: u10 (@ 6%) = 15 $m\ s^{-1}$: u10 (@ 4%) = 20 $m\ s^{-1}$:	$u_{s(i-n)}$	 2.4 6.2 10.4 14.2 19.0	 $u10 * (h_s / 10)^p$ Note, the percentages in brackets define $f_{(i - n)}$
Urban roughness (cat. C/D)	p	0.23	
Effective stack height, m u10 = 2.5 $m\ s^{-1}$: u10 = 6.5 $m\ s^{-1}$: u10 = 11 $m\ s^{-1}$: u10 = 15 $m\ s^{-1}$: u10 = 20 $m\ s^{-1}$:	$h_{e(i-n)}$	*Buoy; Non-B* 66.7; 20.6 30.6; 12.9 21.3; 10.9 17.8; 10.1 15.3; 9.6	 Buoyant = $h_s + [20.5 * E^{0.6} * h_s^{0.4} * u_s^{-1}]$; Non-buoyant = $h_s + (1.5 * v_s * d) / u_s$
Receptor height, m	z_r	1.5	
Lateral dispersion coefficient, m	σ_y	$\sigma_y(x)$	$0.10 * x * (1 + 0.0001 * x)^{0.5}$
Vertical dispersion coefficient, m	σ_z	$\sigma_z(x)$	$0.07 * x * (1 + 0.0009 * x)^{0.5}$
Down wind distance, m	x		
Off-centreline distance, m	y		
Concentration at receptor, $mg\ m^{-3}$:	$C(x,y,z_r)$		$\sum_{(i=1\ n=5)} \{ f_{(i - n)} * [Q / (2 * \pi * \sigma_y * \sigma_z * u_{s(i-n)}) * \exp [- (y^2 / (2 * \sigma_y^2))] * (\exp [- ((z_r - h_{e(i-n)})^2 / (2 * \sigma_z^2))] + \exp [- ((z_r + h_{e(i-n)})^2 / (2 * \sigma_z^2))] \}$

Many of the above parameters relating to the flares, temperatures, etc., are assumed. If UK Waste were to provide more detailed information I would be willing to undertake a revision of the model during the inquiry.

The main points to comment on are:

- The thermal buoyancy calculation is not critical, although the non-buoyant plume calculation is heavily dependent upon stack characteristics. A more accurate discharge velocity and stack diameter would be very useful.
- In terms of meteorology, wind speed distribution is not very critical, but atmospheric

stability is. The use of category C/D should cover about 75% of stability conditions but the lack of data for categories A and B will cause significant underestimates in the near field.

- The dispersion coefficients are set for 1 hour averaging. It would provide more stability and accuracy in the results to shift to annual averages but that would require more complex information about topography, atmospheric stability and surface features to provide a qualitative distance.
- As no lateral concentrations were calculated - only the concentrations under the plume centreline were considered - the term '$exp [- (y^2 / (2 * s_y^2))]$' is redundant, and was not coded in the final model (y = 0, hence the whole exponential term is equivalent to 1).
- It would be very useful to build in some aspect of gas density into the model. Many of the pollutants of concern have less than neutral buoyancy. The main concern would be the effect of '*ground fogging*' with these pollutants during highly stable conditions.

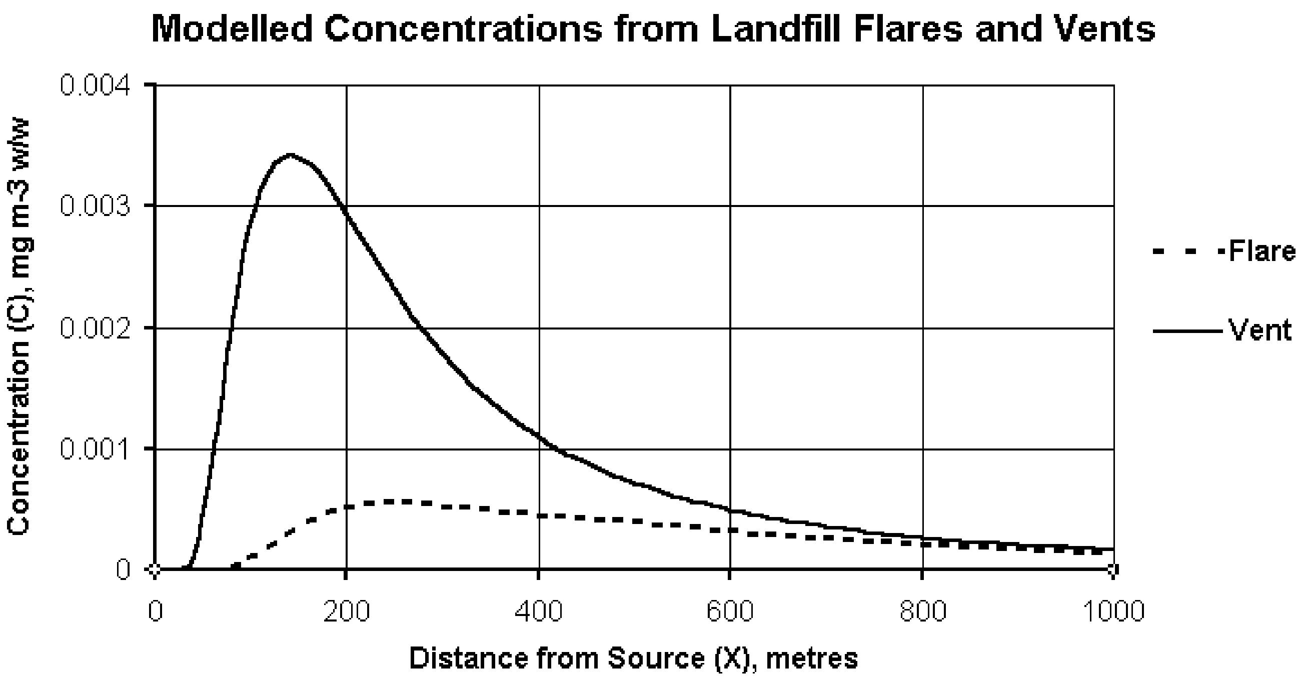
The model was written as a pair of simple Excel 97 spreadsheets - one for flared gas and one for unflared gas. The results of these two models were combined in a spreadsheet, and a common graph generated from this data, in order to give a more comparative set of results. The two models also were modified to find the exact distance at which peak concentrations occurred.

Results

This model gives results in terms of a multiplication factor. The pollutant emission is set a 1mg m^{-3} and so to calculate the value of any pollutant you simply multiply the pollutant concentration in mg m^{-3} by the result of this model at the particular distance required.

The results of the two models were plotted on the same graph for comparison:

Figure 2:



The maxima predicted from the model are:

- For <u>unflared</u> gas, the maximum concentration is 0.0034 mg m^{-3} (per mg m^{-3} release) at 140 metres;
- For <u>flared</u> gas, the maximum concentration is 0.00056 mg m^{-3} (per mg m^{-3} release) at 240 metres.

The graph clearly shows the difference plume buoyancy has on the ground level concentrations of landfill gas.

Taking Table 1 given earlier, we can generate a more meaningful set of figures relating to modelled releases and the LTEL - this data is given in Table 3. This is done by multiplying the WMP26 levels by the maximum level from the model to produce the '*pollutant maxima*'. As with the previous table, this is divided by the LTEL to provide a comparison.

I have no reliable data on flare emissions as the information I have gathered to date is too variable to provide a reliable basis for modelling. Hence the rest of this study only considered the case of unflared gas. However, the combustion gases produced by flaring will be significant - especially because of the contribution burning methane has on nitrogen oxides formation, and the products of incomplete combustion such as dioxin.

<u>Table 3: Comparison of LTEL and Modelled Levels - Unflared Gas</u>

Compound	WMP26 levels mg m^{-3}	Pollutant maxima, mg m-3	LTEL mg m^{-3}	WMP26 ÷ LTEL
Benzene	***0.4 to 114***	***0.0014 to 0.388***	***0.032***	***0.043 to 12.113***
Toluene	8 to 460	0.0272 to 1.564	1.91	0.014 to 0.819
Xylene	34 to 470	0.1156 to 1.598	4.4	0.026 to 0.363
Hydrogen sulphide	0.28 to 19.8	0.0010 to 0.067	0.14	0.007 to 0.481
Ethyl benzene	17 to 330	0.0578 to 1.122	4.4	0.013 to 0.255
Styrene	0.1 to 7	0.0003 to 0.024	0.86	0.000 to 0.028
Tricholoroethylene	0.1 to 170	0.0003 to 0.578	1.1	0.000 to 0.525
Vinyl chloride	***0.1 to 177***	***0.0003 to 0.602***	***0.036***	***0.009 to 16.717***
Tetrachloroethylene	0.1 to 350	0.0003 to 1.190	3.45	0.000 to 0.345

Note, '*modelling maxima*' level is 0.0034 mg m^{-3}

As can be seen, two compounds - benzene and vinyl chloride, both known carcinogens - both exceed the LTEL. While the variability in this model cannot be relied upon to provide an accurate figure, the strength of the assessment procedure enables us to show that there is a possibility for high concentrations of toxins to be produced from landfill gas. There are therefore obvious implications for public health should landfill gas be vented within 400 to 500 metres of any dwelling or occupied structure.

For information, the high level of hydrogen sulphide noted earlier would equate to a ground concentration of 1,686 mg m^{-3} - 12,000 times the LTEL.

Further work

The data available to construct this model, and the lack of information on the specific features of the flares and gas collection for the proposed landfill, mean that this cannot be considered a wholly accurate. What it is here to do is indicate the possibilities for pollutants reaching hazardous concentrations, inform the debate on the issue, and stimulate further work on the issue.

The obvious need in this case is hard data. If qualitative data can be found then there is a more realistic change of getting a more accurate result. The use of better data would also mean that a more accurate model could be developed, narrowing the range of results still further.

The priorities for further research are:

1. To obtain a better set of data for more landfills, and more recently filled landfills. The data in WMP26 is very out of date, and the fact it is only for 6 landfills means that it could be very unrepresentative of the possible range of values.
2. It will be necessary to define a standard set of criteria to describe a landfill flare, its characteristics and performance. David Campbell did mention that the Environment Agency were preparing such information - this could be the basis for such a standard criteria, but there would also have to be further research on the degradation of performance over the lifetime of the flare.
3. As well as better monitoring of the constituents of landfill gas, there needs to research to demonstrate the range of pollutants produced by gas flaring, and burning in spark ignition engines or gas turbines. In particular there should be careful assessment of the production of dioxins and other products of incomplete combustion such benzo-a-pyrene.
4. There needs to be some form of agreement of the form that the near-field assessment model for a landfill flare should take.
5. Finally, the only realistic way to assess the potential for harm from landfill emissions is to conduct a full human health risk assessment. There will therefore have to be agreement on the form such a model should take, what environmental media it considers, the health related variables to include in the model (e.g., cancer potency factors) and the '*acceptable*' level of risk that the public should be expected to tolerate.