

# **ACTION GUIDELINE LEVELS FOR METHANE GAS PRODUCED FROM LANDFILL**

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# **ACTION GUIDELINE LEVELS FOR METHANE GAS PRODUCED FROM LANDFILL**

## **1. Introduction**

In late 2008, methane gas from an adjacent former landfill site was detected in the Brooklands Green housing estate in Cranbourne Victoria. Incident mitigation involved a multiagency response from CFA, EPA, City of Casey and Victoria Police. As a result of this incident, the Victorian State Government Ombudsman conducted an investigation and released a report detailing the findings of the investigation. The report identified a number of action items for the Victorian Government agencies involved in the incident to follow up.

Also a result of the incident, AFAC, via the Hazardous Materials Working Group, has requested that guidelines be established for emergency response actions in the event of future methane leaks from former landfill sites into residential dwellings or other structures.

## **2. Production of Landfill Gas**

Landfill gas is produced via three processes – bacterial decomposition, volatilisation and chemical reactions.

- *Bacterial Decomposition.* Most landfill gas is produced by bacterial decomposition. This occurs when organic waste is broken down by bacteria naturally present in the waste and in the soil used to cover the landfill. Organic waste includes food, garden waste, street sweepings, textiles, wood and paper products. Bacteria decompose organic waste in four phases and the composition of the gas changes during each phase. The final product is the landfill gas containing mainly methane and carbon dioxide.
- *Volatilisation.* Landfill gases can be created when certain wastes, particularly organic compounds, change from a liquid or solid into a vapour. This process is known as volatilisation. Non methane organic compounds such as trichloroethylene, benzene, and vinyl chloride can be found in landfill gas and are thought to be the result of the volatilisation of certain chemicals disposed of in the landfill.
- *Chemical Reactions.* Toxic components of landfill gas, including non methane organic compounds can be created by the reactions of certain chemicals present in the waste. For example, if hypochlorite bleach and acid come into contact with each other within the landfill, then chlorine gas can result.

*Reference: Landfill Gas Primer; An Overview for Environmental Health Professionals; US Agency for Toxic Substances and Disease Registry 1997.*

## **3. Components of Landfill Gas**

<b>Component</b>	<b>Percent by Volume</b>	<b>Characteristics</b>
Methane	45 – 60	Methane is a naturally occurring gas. It is colourless and odourless. Landfills account for a large proportion of man made methane emissions
Carbon Dioxide	40 – 60	Carbon dioxide is naturally found at small concentrations in the atmosphere (0.03%). It is colourless, odourless and slightly acidic.

Table Continued

Component	Percent by Volume	Characteristics
Nitrogen	2 – 5	Nitrogen comprises about 79% of the atmosphere and is odourless, tasteless and colourless.
Oxygen	0.1 – 1	Oxygen comprises about 21% of the atmosphere and is odourless, tasteless and colourless.
Ammonia	0.1 – 1	Ammonia is a colourless gas with a pungent odour.
Non methane organic compounds (NMOC)	0.01 – 0.6	NMOCs are organic compounds other than methane. NMOCs may occur naturally or be formed by synthetic chemical processes. NMOCs most commonly found in landfill gas include acrylonitrile, benzene, dichloroethanes, dichloromethane, carbonyl sulphide, ethyl benzene, hexane, MEK, tetrachloroethylene, trichloroethylene, vinyl chloride and xylenes.
Sulphides	0 – 1	Sulphides such as hydrogen sulphide, dimethyl sulphide and mercaptans are naturally occurring gases that give landfill gas its rotten egg smell. Sulphides can cause unpleasant odours even at low concentrations.
Carbon Monoxide	0 – 0.2	Carbon monoxide is a colourless, odourless, toxic gas

Reference: *Landfill Gas Primer; An Overview for Environmental Health Professionals; US Agency for Toxic Substances and Disease Registry 1997.*

#### 4. Movement of Landfill Gas

Once gases are produced under the landfill surface, they generally move away from the landfill. Gases tend to expand to fill the available space, so the gases move, or migrate, through the limited pore spaces within the refuse and the soil covering of the landfill. The natural tendency of landfill gases that are lighter than air, such as methane, is to move upward, usually through the landfill surface. Upward movement of landfill gas can be inhibited by densely compacted waste or landfill cover material. When upward movement is inhibited, the gas tends to migrate horizontally to other areas within the landfill or to areas outside the landfill, where it can resume its upward path. Basically the gases follow the line of least resistance. Some gases, such as carbon dioxide, are denser than air and will collect in subsurface areas such as utility corridors. Three main factors influence the migration of landfill gases: diffusion (concentration), pressure and permeability.

- *Diffusion (concentration).* Diffusion describes a gas's natural tendency to reach a uniform concentration in a given space, whether that space is a room, a cavity or the earth's atmosphere. Gases in a landfill move away from areas of high gas concentration to areas with lower gas concentrations. Because gas concentrations are generally higher in the landfill than in the surrounding areas, landfill gases diffuse out of the landfill to surrounding areas where gas concentrations are lower.
- *Pressure.* Gases accumulating in a landfill create areas of high pressure in which gas movement is restricted by compacted refuse or soil covers, and areas of low pressure in which gas movement is unrestricted. The variation in pressure throughout the landfill results in gases moving from areas of high pressure to areas of low pressure. Movement of gases from areas of high to low pressure is known as convection. As more gases are generated, the pressure in the landfill increases, usually causing sub-surface pressures in the landfill to be higher than either the atmospheric pressure or relevant indoor air pressures. When pressure in the landfill is higher, gases tend to move to ambient air or relevant indoor air spaces.

- *Permeability.* Gases will also migrate according to where the pathways of least resistance occur. Permeability is a measure of how well gases and liquid flow through connected spaces or pores in refuse and soils. Dry, sandy soils are highly permeable, while moist clays tend to be much less permeable. Gases tend to move through areas of high permeability rather than through areas of low permeability. Landfill covers are often made of low permeability soils such as clay. Gases in covered landfills therefore may be more likely to move horizontally than vertically.

*Reference: Landfill Gas Primer; An Overview for Environmental Health Professionals; US Agency for Toxic Substances and Disease Registry 1997.*

## 5. Conditions Affecting Landfill Gas Migration

Expanding on the points listed in Section 4, the direction, speed and distance of landfill gas migration depends on a number of factors:

- *Landfill Cover Type.* If the landfill cover consists of relatively permeable material such as gravel or sand, then gas will migrate up through the landfill cover. If the landfill cover consists of silts and clays, the cover is not very permeable and gas will tend to migrate horizontally underground. If one area of the landfill is more permeable than the rest then gases will migrate through those areas.
- *Natural and Man Made Pathways.* Drains, trenches and buried utility corridors (such as tunnels and pipelines) can act as conduits for gas movement. The natural geology often provides underground pathways such as fractured rock, porous soil and buried stream channels where gas can migrate.
- *Wind Speed and Direction.* Landfill gas naturally vented into the air at the landfill surface is carried by the wind. The wind dilutes the gas with fresh air as it moves to areas beyond the landfill. Wind speed and direction determine the gas's concentration in the atmosphere, causing variations in concentration from day to day or even from hour to hour.
- *Moisture.* Wet surface soil conditions may prevent landfill gas from migrating through the top of the landfill into the atmosphere above. Rain and moisture may also seep into pore spaces in the landfill and push out gases in these spaces.
- *Groundwater levels.* Gas movement is influenced by variations in the groundwater table. If the water table is rising into an area, it will force the landfill gas upwards.
- *Temperature.* Increases in temperature stimulate gas movement. There is also a tendency to also increase gas diffusion rates at higher temperatures. Overall, landfill gas moves more quickly in warmer conditions. Although the landfill itself generally maintains a stable temperature, cooling and warming cycles can cause the soil to crack causing landfill gas to migrate upward or horizontally.
- *Barometric and Soil Gas Pressure.* The difference between the soil gas pressure and barometric pressure allows gas to move either vertically or laterally depending on whether the barometric pressure is higher or lower than the landfill gas pressure. When barometric pressure is falling, landfill gas will tend to migrate out of the landfill into surrounding areas. As barometric pressure rises, gas may be retained temporarily in the landfill.

*Reference: Landfill Gas Primer; An Overview for Environmental Health Professionals; US Agency for Toxic Substances and Disease Registry 1997.*

## **6. Landfill Gas Travel Distances**

It is difficult to predict the distances that landfill gases will travel due to the numbers of factors affecting the ability of landfill gas to migrate underground, however distances of up to 500 metres have been observed. In the USA, computer models have been applied to this issue with inconclusive results.

A study was carried out in New York State by the New York State Department of Health and of the 38 landfill checked, gas migrated underground up to 300 metres at one landfill, 150 metres at four landfills and 80 metres or less from the landfill boundary at 33 landfills.

## **7. Landfill Gas Entry into Buildings and Homes**

Gases migrating from a landfill may eventually reach buildings and homes. Foundation cracks and gaps, pressure differences between the inside and outside of the building or home, mechanical ventilation systems and leakage areas (utility points, construction joints or drain points) provide an entry points for gases.

It has been found that buildings with basements provide the easiest access for gases migrating in from the soil. At Brooklands Green it was found that the houses most susceptible to gas ingress were those that had required the use of stabilisation piers into the ground as part of the foundation slab and were located directly adjacent to the disused landfill.

The amount of gases entering a building or home depends on a number of factors, including the construction and maintenance practices. The gas concentration in indoor air also depends on the building or home design, the air exchange rate and the distance of the building or home from the landfill.

## **8. Existing Action Guides in other Jurisdictions**

One of the key safety issues with landfill gas is the flammability of the methane component. Methane is an odourless, colourless gas and is lighter than air. The flammable range of methane is approximately 5 to 15% by volume in air.

A number of agencies around the world have set guideline action levels when methane concentrations reach certain trigger levels. These are summarised below:

- Confined space regulations in the Australian States and Territories require that continuous monitoring be employed if the flammable concentration of a given material reaches 5% of the lel. Activity in the space should cease and appropriate control measures be implemented if the flammable concentration reached 10% of the lel.
- In the USA, the individual States have regulatory limits for methane gas in buildings on site. Typically the trigger level is set at 1.25% by volume (25% of the lel). This is mandated in US Environment Protection Agency Regulations. If this level is exceeded, the States usually require the landfill operator to undertake appropriate actions to mitigate the effects of gas accumulation in those structures until permanent remediation measures at the landfill can be implemented. Typically, State Governments in the USA require methane monitoring in buildings at landfill sites to be undertaken on a quarterly basis.

- The United Kingdom and Scottish Environmental Protection Agencies have jointly published a guidance note called “Guidance for the Management of Landfill Gas”. With respect to methane, this guide contains a requirement that the monitoring and sampling of landfill gas shall be carried out quarterly with a trigger value of 1% methane by volume (20% of the lel). If the trigger level is exceeded, then certain actions must be undertaken. These include:

- The operator to take immediate remedial action.
- The relevant Environment Protection Agency to be informed of the exceedance.
- Monthly monitoring of the relevant area to be undertaken until the gas concentration has fallen below the trigger level.
- Within one month of the exceedance, the site operator shall submit a report to the relevant Environment Protection Agency detailing the trigger level breach, the emergency action taken and any further proposed remedial actions.

Emergency plans for landfill sites typically approved by the UK and Scottish EPAs contain the following actions for buildings and services within 250 metres of the landfill:

- At 10% of the lel and rising. Inform regulator and other relevant authorities. Implement continuous monitoring. Prepare for implementation of evacuation procedures. Consider the installation of audible alarms.
  - At 18 to 20% of the lel. Instruct monitoring personnel on evacuation/ventilation/isolation of ignition sources. Immediately inform regulator and other relevant authorities. Prepare for rapid evacuation of the site.
  - At 20% of the lel. Immediately inform regulator and other relevant authorities. Assess the risk and immediately begin monitoring of adjacent buildings.
  - Above 20% of the lel and rising. Immediately inform regulator and other relevant authorities. Immediately request additional assistance. Immediately follow evacuation procedures.
- In the USA, the Agency for Toxic Substances and Disease Registry have published the “Landfill Gas Guide for Environmental Health Professionals”. The Agency for Toxic Substances and Disease Registry is a US Federal Agency based in Atlanta Georgia and is part of the Federal Department of Health and Human Services. The landfill gas guideline contains the following recommendation:
    - Based on the US Environment Protection Agency Regulations, owners and operators of landfills must ensure that the concentration of methane gas does not exceed 25% of the lel for methane (1.25% by volume) in indoor samples collected at the facilities’ structures. If this figure is repeatedly exceeded the regulators require corrective action to be taken. This corrective action may include evacuating buildings where an explosion hazards exists, until landfill gas emissions are controlled.

## 9. Recommendations

Based on:

- The range of action guidelines in other jurisdictions described earlier in this document.
- The potential risk of methane explosions at certain given concentrations of methane in the atmosphere.
- The need to avoid over responding and over stimulating community concern.
- The experiences gained by Victorian Fire Services at the Stevensons Road Brooklands Green Estate.

It is recommended that for Australian landfill sites and any potential off site impacts that:

- If the methane levels in structures adjacent to existing or former landfill sites exceed 20% of the lel, the Fire Services are notified and respond under normal road conditions (Code 3).

Continuous air monitoring is to be established (if not already in place) and agreed control measures are put in place by the appropriate authorities (eg, local government and the EPA with the support of the Fire Services) to reduce methane levels.

The Fire Services are to validate the effectiveness of the implemented control measures and remain on scene until the concentration of methane falls below 20% of the lel.

- If the methane levels in structures adjacent to existing or former landfill sites exceed 50% of the lel, the Fire Services are notified and respond under emergency conditions (Code 1).

Continuous air monitoring is to be established (if not already in place) and control measures are put in place to reduce methane levels.

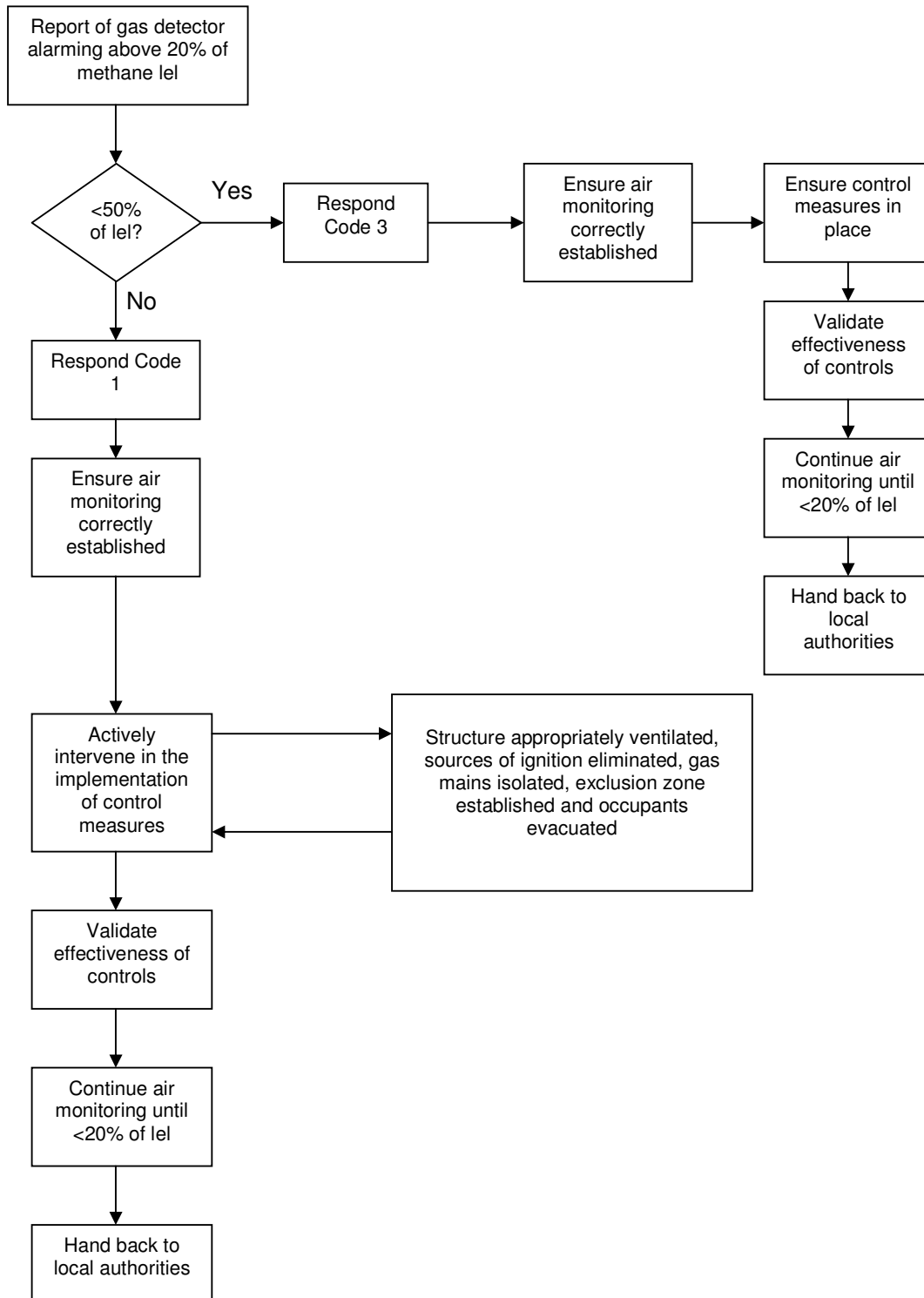
The Fire Services are to actively intervene in the implementation of control measures and ensure that structures are adequately ventilated, all sources of ignition in the structures are eliminated, all doors and windows are open, gas mains are isolated, exclusion zones are established as required and occupants are evacuated.

The Fire Services are to remain on scene until methane concentrations have been reduced below 20% of the lel.

The 50% of lel trigger for Code 1 response potentially allows sufficient time for the Fire Services to arrive on scene and begin mitigation activities before the methane concentration reaches the lel.

These recommendations are summarised in the following flow chart:

Recommendations Flow Chart



## **APPENDIX 1: USA LANDFILL GAS EXPLOSIONS**

Although landfill gas explosions are not a common occurrence, in the USA a number of incidents known or suspected to have been caused by landfill gas explosions have been documented. These are described below:

1999: An 8 year old girl was burned on her arms and legs when playing in an Atlanta playground. The area was reportedly used as an illegal dumping ground many years prior to the incident.

1994: While playing soccer in a park built over an old landfill in Charlotte North Carolina a woman was seriously burned by a methane explosion.

1987: Off site gas migration is thought to have caused a house to explode in Pittsburgh Pennsylvania.

1984: Landfill gas migrated to and destroyed one house near a landfill in Akron Ohio. Ten houses were temporarily evacuated.

1983: An explosion destroyed a residence across the street from a landfill in Cincinnati Ohio. Minor injuries were reported.

1975: In Sheridan Colorado landfill gas accumulated in a storm drain that ran through a landfill. An explosion occurred when several children playing in the pipe lit a candle resulting in serious injury to the children.

1969: Methane gas migrated from an adjacent landfill into the basement of an armoury in Winston North Carolina. A lit cigarette caused the gas to explode killing three men and seriously injuring five others.

## APPENDIX 2: SELECTED UK LANDFILL GAS INCIDENTS

<b>DATE</b>	<b>LOCATION</b>	<b>INCIDENT</b>
1995	Bramfield Herts	Installing electro-fusion welded plastic joint. Landfill gas ignited and lifted borehole head. 1 injured.
1991	Area 10	Nature reserve formed on old landfill site. Teenagers gained unauthorised access to underground culvert. Lit match and ignited gas. 3 injured.
1991	Reading	Gas smelled in warehouse, site evacuated for 24 hours. Analysis showed it to be landfill gas.
1990	Thurmaston Leicester	Premises built on former landfill site. Gas entering through cracks in the floor. Ventilation and gas monitoring recommended.
1990	Ebbw Vale	Drilling in shaft used for venting on a landfill site. Spark from unprotected drill ignited gas. 3 injured
1989	Tonbridge	Factory units built on former landfill site. Gas detected by monitors and levels triggered the alarm at 5%LEL. The fire brigade evacuated the whole site.
1988	Huncote Leicester	Methane detected around the lower explosive limit (LEL) within a recreation centre. The centre was built in 1978 on the site of a landfill closed in 1974. Design of the centre did incorporate ventilation to alleviate problems although subsequent settlement of waste left void spaces for gases to collect. The centre closed whilst remediation was investigated.
1988	Appley Bridge Lancashire	Partial blockage of passive venting trench was thought to have allowed excessive off site migration of LFG. An accumulation of methane in the site offices some 50m off site was ignited and exploded causing structural damage. No staff occupied the building at the time.
1988	Eastwood Quarry Nottinghamshire	Despite a passive vent system installed to prevent off site migration, landfill gas continued to be detected around residential properties as close as 10 metres to the boundary of a redundant landfill.
1987	Stone Dartford	Temporary throttling back of gas abstraction during Christmas vacation was thought to have allowed excessive off site migration of LFG. An accumulation of methane, forming an explosive mixture within a house less than 50 metres from the site boundary was ignited. An occupant suffered mild burns and the building was structurally damaged.
1987	Darlington Leeds	Occupants of a house were evacuated when methane was found to have migrated from an adjacent landfill site, accumulating in a cellar to explosive levels.
1986	Loscoe Derbyshire	Coinciding with a rapid drop in barometric pressure, methane migrating from an adjacent landfill site was drawn into a bungalow less than 20m from the site boundary. An explosive mixture was ignited, totally destroying the building and injuring 3 occupants.
1982	Middleton Broom	Methane detected in houses bordering landfill sites gave rise to serious anxieties amongst residents. Despite remediation further accumulations were found in surface water drains and service ducts in 1983.

### **APPENDIX 3: REFERENCES**

1. Multi Agency Management Team Arrangements, Stevensons Road Cranbourne Landfill Gas Migration. Victorian Government, October 2009.
2. Requirements for Landfill Gas Control, Monitoring and Emergency Procedures. Scottish Environment Protection Agency, 2008.
3. Review of Landfill Gas Incidents and Guidance. E.M. Gregson, 2008.
4. Landfill Gas Primer; An Overview for Environmental Health Professionals; Agency for Toxic Substances and Disease Registry 1997.

Chapter 1: Introduction.

Chapter 2: Landfill gas Basics.

Chapter 3: Landfill Gas Health and Safety Issues.

Chapter 4: Monitoring of Landfill Gas.

Chapter 5: Landfill Gas Control Measures.

Chapter 6: Communication.

5. Landfill gas facts: Missouri Dept of Natural Resources 1997.
6. Section 6, Environmental Monitoring, Part C, Methane Environmental Monitoring Program. Wyoming Dept of Environmental Quality 1997.
7. Australian Standard AS 2865 – 2009, Safe Working in Confined Spaces.
8. Brooklands Green Estate, Investigation into Methane Gas Leaks. Ombudsman Victoria Report, October 2009.