11 LANDFILL GAS HAZARD ASSESSMENT

11.1 Introduction

11.1.1 This section presents the risk assessment of landfill gas (LFG) hazards arising from the construction and operational phases of the "Tseung Kwan O – Lam Tin Tunnel and Association Works" (the Project).

11.1.2 The outlined scope of the Project under this Assignment is to provide a highway connecting TKO at Po Shun Road in the east and Trunk Road T2 in the west with the associated interchange. It comprises the following:

- a dual two-lane highway approximately 4.8 km long. About 2.6 km of the highway is in the form of tunnel;
- slip roads, depressed roads, viaducts, TKO Interchange, ventilation building, tunnel portal facilities and around 3 ha reclamation on TKO side;
- slip roads, branch Tunnels, viaducts, Lam Tin Interchange, tunnel portal facilities, ventilation and administration buildings on Kowloon side;
- the associated building, civil, structural, marine, electrical and mechanical, traffic control and surveillance system (TCSS), landscaping, and environmental protection and mitigation works.

11.1.3 In particular, the tunnels, roads and associated facilities at the Lam Tin Interchange fall within the 250m Consultation Zone of the Sai Tso Wan Landfill (**Figure 11.1**).

11.1.4 Sai Tso Wan Landfill was operated between 1978 and 1981. It covers about 14 ha and is estimated to have received about 1.6 million tones of domestic and industrial waste. Waste is believed to be up to 50m deep. Prior to waste deposition, the site was underlain by French drains for the collection of groundwater and leachate. On completion of waste deposition, the landfill was capped with a final cover layer of silty sand containing a trace of clay. The final cover comprises depths averaging 7.5m on the +80mPD afteruse platform and 3.5m on the side slopes.

11.2 Environmental Legislation, Standards and Guidelines

11.2.1 Relevant legislation and associated guidance notes applicable to the assessment of the LFG hazards include:

- Section 1.1(f) in Annex 7 of the Technical Memorandum on EIAO (EIAO-TM);
- Section 3.3 in Annex 19 of the EIAO-TM;
- Landfill Gas Hazard Assessment for Development Adjacent to Landfills (ProPECC PN 3/96); and
- Landfill Gas Hazard Assessment Guidance Note (1997) (EPD/TR8/97, Guidance Note).

11.2.2 Under Annex 7 of the EIAO-TM, an evaluation of the potential risk posed by landfill gas is required for any development which is proposed within 250m of the edge of waste of a landfill site, known as Landfill Consultation Zone. Since a section of the tunnels, roads and associated facilities at the Lam Tin Interchange fall within the Consultation Zone of Sai Tso Wan Landfill, a Qualitative Landfill Gas Hazards Assessment (QLFGHA) is required to assess the potential risk due to landfill gas migration from Sai Tso Wan Landfill to the Project Site and recommend the mitigation measures to be undertaken for the Project.

11.2.3 *ProPECC PN 3/96* and *Guidance Note* for the assessment of the hazards which landfill gas may present to developments close to landfills have been issued by the EPD. These documents provide an assessment framework to be followed when evaluating the risks related to developments described under Section 6.5, Chapter 9 of the Hong *Kong Planning Standards and Guidelines*. The *ProPECC PN 3/96* and *Guidance Note* apply to all developments proposed within the Landfill Consultation Zone.

11.3 Assessment Criteria and Methodology

Criteria

11.3.1 In accordance with the *Landfill Gas Hazard Assessment Guidance Note*, the risk due to landfill gas may be evaluated based upon the following three criteria:

- Source – location, nature and likely quantities/ concentrations of landfill gas which has the potential to affect the development;
- Pathway – the ground and groundwater conditions, through which landfill gas must pass in order to reach the development; and
- Target – elements of the development that are sensitive to the effects of landfill gas.

Source

11.3.2 The classification of the Source (i.e. Sai Tso Wan Landfill) should be undertaken as follows:

Minor Landfill sites at which gas controls have been installed and proven to be effective by comprehensive monitoring which has demonstrated that there is no migration of gas beyond the landfill boundary (or any specific control measures) and at which control of gas does not rely solely on an active gas extraction system or any other single control measure which is vulnerable to failure; or
Old landfill sites where the maximum concentration of methane within the waste, as measured at several locations across the landfill and on at least four occasions over a period of at least 3 months (preferably longer), is less than 5% by volume (v/v).

Medium Landfill site at which some form of gas control has been installed (e.g. lined site or one where vents or barriers have been retrospectively installed) but where there are only limited monitoring data to demonstrate its efficacy to prevent migration of gas; or
Landfill site where comprehensive monitoring has demonstrated that there is no migration of gas beyond the landfill boundary but where the control of gas relies solely on an active gas extraction system or any other single control system which is vulnerable to failure.

Major Recently filled landfill site at which there is little or no control to prevent migration of gas or at which the efficacy of the gas control measures has not been assessed; or
Any landfill site at which monitoring has demonstrated that there is significant migration of gas beyond the site boundary.

11.3.3 The "significance" of migration should be assessed by reference to the concentration, frequency and location at which gas is detected. For guidance, it should be assumed that any concentration of methane or carbon dioxide greater than 5% v/v above background levels in any monitoring well outside the landfill's boundary indicates significant migration. Lower concentrations may still be "significant" if they are observed in more than one monitoring

well, on several occasions or in monitoring wells located some distance from the site boundary. In general, concentrations of greater than 1% v/v methane or 1.5% v/v carbon dioxide (above background levels in each case) indicate less than adequate control of the gas at source.

11.3.4 In classifying the source term, account needs to be taken of the likelihood and probable effect of a failure of the gas controls. Thus, if it has been demonstrated that there is no migration of gas and there is little danger of the gas controls failing (e.g., if these comprise solely of passive measures such as a liner) it can be assumed that the site represents a "Minor" Source. Where there is no gas migration but this may be as a result of a single, "vulnerable" control measure (e.g., an active extraction system with no warning of failure), the site should be regarded as a "Medium" or even a "Major" Source depending on the other factors (e.g., size of site and age of waste).

11.3.5 Where the effectiveness of the gas controls has not been proven by off-site monitoring or if there is some doubt as to the adequacy of the monitoring, this should be taken into account when considering the impact of the control measures on the Source term. Assessments should always err on the side of caution and, in general, if the effectiveness cannot be demonstrated, the assessment should be undertaken on the same basis as if the controls were not in place.

11.3.6 The reliability of the monitoring, for determining the efficacy of the gas controls, needs to take account of the design, number and location of the monitoring points together with the frequency and duration over which monitoring has been undertaken. Monitoring should have been undertaken under different weather conditions including, in particular, periods of low or falling atmospheric pressure.

Pathway

11.3.7 The broad classification of the Pathway should be undertaken as follows:

Very short / direct	Path length of less than 50m for unsaturated permeable strata and fissured rock or less than 100m for man-made conduits
Moderately short / direct	Path length of 50-100m for unsaturated permeable soil or fissured rock or 100-250m for man-made conduits
Long / indirect	Path length of 100-250m for unsaturated permeable soils and fissured rock

11.3.8 In classifying the pathway, however, adjustment to the above general guidelines will often be required to take account of other factors which will affect the extent of gas migration including the following:

- particular permeability of the soils;
- spacing, tightness and direction of the fissures/joints;
- topography;
- depth and thickness of the medium through which the gas may migrate (which may be affected by groundwater level);
- the nature of the strata over the potential pathway;
- the number of different media involved; and
- depth to groundwater table and flow patterns.

11.3.9 Thus, although there may be permeable soil between the landfill site and a proposed development, say 80m from the edge of the site, if the soil layer is very shallow and thin with its upper surface exposed to the atmosphere, then it will be appropriate to consider this as a long/indirect pathway. This could of course alter if the land between the landfill site and the development was paved over or altered in some other way which reduced the potential for gas release. Similarly, if the land is flat, the surface may be prone to waterlogging which will also effectively seal it at times of heavy rain. In general, a conservative approach should be adopted and it should be assumed that any such permeable surface soils may become less permeable in the future.

11.3.10 If it is known that a conduit (man-made or natural feature such as a fault plane) leads directly from the landfill to the development area, it should be regarded as a "direct/short" pathway even if it is longer than 100m.

Target

11.3.11 Different types of target may be broadly classified as follows:

High sensitivity	Buildings and structures with ground level or below ground rooms/voids or into which services enter directly from the ground and to which members of the general public have unrestricted access or which contain sources of ignition. This would include any developments where there is a possibility of additional structures being erected directly on the ground on an ad hoc basis and thereby without due regard to the potential risks.
Medium sensitivity	Other buildings, structures or service voids where there is access only by authorized, well trained personnel, such as the staff of utility companies, who have been briefed on the potential hazards relating to landfill gas and the specific safety procedures to be followed. Deep excavations.
Low sensitivity	Buildings/structures which are less prone to gas ingress by virtue of their design (such as those with a raised floor slab). Shallow excavations. Developments which involve essentially outdoor activities but where evolution of gas could pose potential problems.

11.3.12 The classification of the above LFG sources, pathway and target are categorized. Having determined into which categories of source, pathway and target the combination of landfill and development fall, a preliminary assessment of the overall risk may be made by reference to **Table 11.1**. The potential implications associated with the various qualitative risk categories are summarized in **Table 11.2**.

Table 11.1 Classification of Risk Category

Source	Pathway	Target Sensitivity	Risk Category
Major	Very short / direct	High	Very High
		Medium	High
		Low	Medium
	Moderately short / direct	High	High
		Medium	Medium
		Low	Low
	Long / indirect	High	High
		Medium	Medium
		Low	Low
Medium	Very short / direct	High	High
		Medium	Medium
		Low	Low
	Moderately short / direct	High	High
		Medium	Medium
		Low	Low
	Long / indirect	High	Medium
		Medium	Low
		Low	Very Low
Minor	Very short / direct	High	High
		Medium	Medium
		Low	Low
	Moderately short / direct	High	Medium
		Medium	Low
		Low	Very Low
	Long / indirect	High	Medium
		Medium	Low
		Low	Very Low

Table 11.2 Summary of General Categorization of Risk

Category	Level of Risk	Implication
A	Very high	The type of development being proposed is very undesirable and a less sensitive form of development should be considered. At the very least, extensive engineering measures, alarm systems and emergency action plans are likely to be required.
B	High	Significant engineering measures will be required to protect the planned development.
C	Medium	Engineering measures will be required to protect the proposed development.
D	Low	Some precautionary measures will be required to ensure that the planned development is safe.
E	Very Low (insignificant)	The risk is so low that no precautionary measures are required.

11.3.13 Five generic forms of protection will be used in mitigating the hazards to development. These generic forms corresponding to the five risk levels are set out in **Table 11.3**. The terms used in **Table 11.3** are defined in **Table 11.4**.

Table 11.3 Generic Protection Measures for Planning Stage Categorization

Category	Generic Protection Measures
A	For the planned development active control of gas, supported by barriers and detection systems. Another, less sensitive form of development should also be considered.
B	Active control of gas, including barriers and detection systems (1).
C	Use of "semi active" or enhanced passive controls. Detection systems in some situations.
D	Passive control of gas only.
E	No precautionary measures required.

Note:
(1) The gas protection measures required to allow the safe development of a Category A risk development will need to be more extensive than those for a Category B risk development.

Table 11.4 Definition of Control Terms

Term	Definition
Active Control	Control of gas by mechanical means e.g. ventilation of spaces with air to dilute gas, or extraction of gas from the development site using fans or blowers.
"Semi active" Control	Use of wind driven cowls and other devices which assist in the ventilation of gas but do not rely on electrically powered fans.
Passive Control	Provision of barriers to the movement of gas e.g. membranes in floors or walls, or in trenches, coupled with high permeability vents such as no-fines gravel in trenches or voids/permeable layers below structures.
Detection System	Electronic systems based upon, for example, catalytic oxidation or infra-red measurement principles, which can detect low concentrations of gas in the atmosphere and can be linked to alarms and/or telemetry systems.

11.4 Assessment of Potential Risk

Source

11.4.1 Sai Tso Wan Landfill was operated between 1978 and 1981. The restoration works under the Urban Landfills Restoration Contract on the Sai Tso Wan Landfill commenced in April 1997 and were completed in May 1998. The Aftercare Period started in May 1998 for 20 years. The restoration works at Sai Tso Wan Landfill has created a recreation ground which was opened for public use in April 2004. An active landfill gas management system has been constructed by the landfill restoration contractor. The system comprises a network of extraction pipes and wells, which deliver the gas to an on-site landfill gas flare facility. The final cover depths average 7.5m on the +80mPD afteruse platform and 3.5m on the side slopes.

11.4.2 A number of gas monitoring wells have been installed around Sai Tso Wan Landfill to monitor the potential landfill gas migration. The location of these monitoring wells is shown in **Figure 11.2**. The monitoring data from November 2009 to October 2010 are summarised in **Table 11.5** and the details are presented in **Appendix 11.1**.

Table 11.5 Landfill Gas Monitoring Results in Sai Tso Wan Landfill (November 2009 to October 2010)

Well/ Probe		Methane (%)		Carbon Dioxide (%)	
		Range	Average	Range	Average
DPR2		0.0	0.0	0.0-0.8	0.3
DPR3		0.0	0.0	0.0-1.2	0.3
DPR5		0.0	0.0	0.0-1.1	0.4
DPR11		0.0	0.0	0.0-0.2	0.0
DRP12		0.0	0.0	0.0	0.0
DRP13		0.0	0.0	0.0-0.1	0.0
DRP16		0.0	0.0	0.0-0.4	0.1
DRP18		0.0	0.0	0.0-0.7	0.2
DRP19		0.0	0.0	0.0-0.7	0.2
G1	A	0.0	0.0	0.0-0.2	0.0
	B	0.0	0.0	0.0-1.0	0.2
	C	0.0	0.0	0.0-1.2	0.1
G2	A	0.0	0.0	0.0-0.2	0.1
	B	0.0	0.0	0.0-2.0	0.4
	C	0.0	0.0	0.0-1.3	0.2
G3	A	0.0	0.0	0.0-0.4	0.1
	B	0.0	0.0	0.0-0.4	0.1
	C	0.0	0.0	0.0-0.2	0.0
G4	A	0.0	0.0	0.0-0.4	0.2
	B	0.0	0.0	0.0-0.4	0.2
	C	0.0	0.0	0.0-0.2	0.1
GW1		0.0	0.0	0.0-0.2	0.0
GW2		0.0	0.0	0.0-0.5	0.1
GW3		0.0	0.0	0.0-0.6	0.1
GW4		0.0	0.0	0.0-0.6	0.2
GW6		0.0	0.0	0.0-1.5	0.2
GW7		0.0	0.0	0.0-0.7	0.2
GW8		0.0	0.0	0.0-0.4	0.0
GW9		0.0	0.0	0.0-0.8	0.3

11.4.3 As shown in **Table 11.5**, the methane concentrations in all perimeter gas monitoring wells are not detectable.

11.4.4 The carbon dioxide concentration fluctuates between undetectable (0.0%) and 1.5% across the monitoring wells. Elevated carbon dioxide concentrations could be due to background variation or methane being oxidized. In accordance with the EPD's Guidance Note, levels of CO_2 that exceed 5% above background would be considered "significant" migration. In the absence of any background CO_2 information for reference, it is conservatively assumed that the potential for off-site migration of landfill gas cannot be eliminated.

11.4.5 The quality of groundwater monitored around Sai Tso Wan Landfill was also reviewed. The location of the groundwater monitoring wells is shown in **Figure 11.3**. The monitoring results are presented in **Appendix 11.1** and summarized in **Table 11.6.** In general, the organic content of the groundwater is low. Hence, the chance of methane generated from

groundwater will be low.

Table 11.6 Groundwater Quality Monitoring Results in Sai Tso Wan Landfill (March 2010 and September 2010)

Well	Chemical Oxygen Demand (mg/L)		Total Organic Carbon (mg/L)	
	Range	Average	Range	Average
GW1	<2-51	27	1-3	2
GW2	4-38	21	<1-3	2
GW3	<2	<2	<1	<1
GW4	3-30	17	1-3	2
GW6	4-23	14	<1-4	3
GW7	3-5	4	<1-1	1
GW8	5-7	6	<1-1	1
GW9	7-13	10	<1	<1

11.4.6 Given the small size, age and current use as recreation ground of the landfill, the recent landfill gas and groundwater monitoring results, the active landfill gas management system, and based on previously approved EIA reports, namely the EIA for further development of TKO, it would be reasonable to classify Sai Tso Wan Landfill as a "**Medium**" source.

Pathway

11.4.7 According to Hong Kong Geological Survey Map, the geological formation beneath Sai Tso Wan Landfill comprises natural earth and waste. The geological formation outside the boundary of Sai Tso Wan Landfill comprises fine to medium grained granite. It is noted that a Northwest to Southeast trending fault line cuts across the Sai Tso Wan Landfill.

11.4.8 While groundwater data at the Project sites is not available, recent groundwater monitoring data has been obtained. The data is contained in **Appendix 11.1**. The location of the groundwater monitoring wells is shown in **Figure 11.3** and the monitored groundwater level are summarised in **Table 11.7**.

Table 11.7 Groundwater Level in Sai Tso Wan Landfill (March 2010 and September 2010)

Borehole	Groundwater Level (mPD)		
	Range	Lowest	Average
GW1	11.11-12.97	11.11	12.04
GW2	44.68-49.18	44.68	46.93
GW3	50.94-51.57	50.94	51.26
GW4	54.64-54.67	54.64	54.66
GW6	42.80-49.34	42.80	46.07
GW7	13.00-15.71	13.00	14.36
GW8	17.99-18.70	17.99	18.35
GW9	27.72-27.73	27.72	27.73

11.4.9 The minimum groundwater level ranged from +11.11 mPD to +54.64 mPD across the landfill. The tunnels and facilities are located at around -15 mPD to +5mPD, which will be around 6 m to 70 m below the groundwater table of Sai Tso Wan Landfill. As the solubility of methane in water is low, the presence of groundwater generally provides a barrier to the migration of

landfill gas.

11.4.10 In general, the path length between Sai Tso Wan Landfill and the construction area of project site is less than 50m to 250m, and therefore the pathway in general is categorised as **Very Short/Direct**. It should be noted that the final cover of the Sai Tso Wan Landfill is at approximately +80mPD elevation.

11.4.11 The ventilation building of TKO-LT Tunnel is approximately 50m south of the landfill at an elevation of approximately -16mPD, and therefore the pathway is categorised as **Moderately Short/Direct**.

11.4.12 The TKO-LT Tunnel that connects to Tseung Kwan O is approximately 60m south of the landfill, and therefore such pathway is categorised as **Moderately Short/Direct**. The slip road tunnel S2 is approximate 65m south of the landfill, and therefore such pathway is also categorised as **Moderately Short/Direct**. While the tunnel that connects to Trunk Road T2 is approximately 195m southwest from the landfill, and therefore the pathway is categorised as **Long /Indirect**.

11.4.13 The administration building, training ground, detention area, fuel filling station, electric vehicle charging station, sewage pumping station and car parking are located at a platform approximately 120m southwest to the Sai Tso Wan Landfill at an elevation of approximately +5mPD, and therefore the pathway is categorised as **Long /Indirect**.

11.4.14 The recovery vehicle bases are located at least 120m south of the landfill at an elevation of approximately -13mPD, and therefore the pathway is categorised as **Long/Indirect**.

11.4.15 The drainage pumping station is located at least 143m south of the landfill at an elevation of approximately -22mPD, and therefore the pathway is categorised as **Long/Indirect**.

Target

Construction Phase

11.4.16 During construction, the project site would be occupied by construction workers who are well trained and with proper and safe construction methodology to be followed. Also, the construction would be mainly carried out in an outdoor environment. Therefore, in general the group is considered as **Low Sensitivity** targets except for specific targets as below.

11.4.17 For deep excavations and other construction activities in indoor or enclosed areas, such as construction of tunnels, administration building, ventilation building, plant rooms, etc, the works would be carried out by trained construction workers with proper construction methodologies and safety procedures to be followed. Therefore, this group is considered as **Medium Sensitivity** targets.

Operational Phase

11.4.18 As shown in **Figure 11.1**, part of the TKO-LT Tunnel, particularly the tunnels, roads, buildings, tunnel facilities of the Lam Tin Interchange, falls within the 250m Consultation Zone of the Sai Tso Wan Landfill.

11.4.19 The buildings, training ground, car parking and other tunnel facilities are located approximately 50m to 250m from the landfill at elevation of +5mPD to -22mPD. These building would be occupied by operational staff, who will have been briefed on the potential hazards relating to the landfill gas. The target sensitivity of these groups are categorised as **Medium Sensitivity**.

11.4.20 For maintenance activities within service voids, manholes, and other confined spaces, if any, the works should be performed by authorized and trained personnel who have been briefed on the potential hazards relating to landfill gas and the specific safety procedures to be followed. The risk level for this group is categorized as **Medium Sensitivity**.

11.4.21 Both the tunnels connecting to Trunk Road T2 and to TKO are longer than 230m and therefore mechanical ventilation is required. These mechanically ventilated tunnels would be accessed by vehicles from the general public who might not be aware of the potential landfill gas hazard. However, as the tunnels are mechanically ventilated and the area is less likely to be susceptible to accumulation of landfill gas, and therefore this group is categorized as **Medium Sensitivity**.

Source-Pathway-Target Analysis

11.4.22 Based on the information above, qualitative source-pathway-target analysis has been undertaken and is summarized in **Table 11.8** according to EPD's assessment framework.

Table 11.8 Qualitative Risk Assessment Matrix

Source	Pathway	Target Sensitivity	Risk
From Sai Tso Wan Landfill - active landfill gas management system (Medium Source)	**During Construction**		
	Path length of less than 50m for unsaturated permeable soil or fissured rock (Very Short/ Direct Pathway)	Construction workers in general outdoor construction area (Low Sensitivity Target)	**Low**
		Construction workers for deep excavation and other works at indoor/enclosed area (construction of buildings, plant rooms, tunnels, etc.) (Medium Sensitivity Target)	**Medium**
	During Operation		
	Path length of 50m-100m for unsaturated permeable soil or fissured rock (Moderately Short/ Direct Pathway)	Staffs and maintenance workers working at indoor area: Administration Building, maintenance vehicle garage/workshop, Ventilation Building (Medium Sensitivity Target)	**Medium**
		Vehicles inside mechanically ventilated tunnel connects to TKO (Medium Sensitivity Target)	**Medium**

Source	Pathway	Target Sensitivity	Risk
	Path length of 100-250m for unsaturated permeable soil or fissured rock (Long / Indirect Pathway)	Staffs and maintenance workers working at indoor area of Tunnel Facilities (Medium Sensitivity Target)	**Low**
		Vehicles inside mechanically ventilated tunnel connects to Trunk Road T2 (Medium Sensitivity Target)	**Low**

11.4.23 The **Overall Risk Levels** for both construction phase and operational phases associated with the Sai Tso Wan Landfill are **Medium**, based on the highest level of risk for the potential impacts identified. According to EPD's *Guidance Note*, engineering measures will be required to protect the project site.

11.5 Recommendations

11.5.1 This section provides general advice and recommendations to minimize the landfill gas risks during the construction and operation of the Project.

General Hazards Related to Landfill Gas

11.5.2 The typical composition of landfill gas is about 60% volume of methane and 40% volume of carbon dioxide, although these percentages can vary widely depending on the site conditions. Also present are trace quantities of hydrogen sulphide, nitrogen and gaseous hydrocarbons such as hexane, octane and heptane.

11.5.3 All contractors participating in the works and operational staff should be aware of that methane and carbon dioxide may present in the soil and all works should be undertaken on the basis of an "assumed presence of landfill gas". In addition the following properties of landfill gas should be noted.

11.5.4 Methane is odorless and colorless, although in landfill gas it is typically associated with numerous highly odoriferous compounds which give some warning of its presence. However, the absence of odour should not be taken to mean that there is no methane. Methane levels can only be reliably confirmed by using appropriately calibrated portable methane detectors.

11.5.5 Landfill gas migration may be a hazard because of the combustibility and in some cases explosive nature of methane. Methane is a flammable gas and will burn when mixed with air between approximately 5 and 15% (v/v) (the Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL) respectively). If a mixture of methane and air with a composition between these two values is ignited in a confined space, the resulting combustion may give rise to an explosion. Methane is also an asphyxiant.

11.5.6 Carbon dioxide, the other major component of landfill gas is an asphyxiating gas and causes adverse health effects at relatively low concentrations. The long-term Occupational Exposure Limit (OEL) is 0.5% (v/v). Like methane, it is odourless and colourless and its presence (or absence) can only be confirmed by using appropriately calibrated portable detectors.

11.5.7 Landfill gas has the potential to cause fire, explosion or asphyxiation if it migrates into and

accumulates in confined space such as building basements, underground car parks, lift shafts, pumping stations, and maintenance chambers. For the same reasons, temporary structures such as site huts and any other unventilated enclosures erected during construction stage are also exposed to landfill gas hazards. Underground services, such as sewer drains, storm drains and service ducts, may also be exposed to the potential hazards as they act as pathways for landfill gas. Besides, any faults present in geological formation also act as pathways for landfill gas.

Recommended Precautionary Measures

11.5.8 According to Table 4.2 of the EPD's *Landfill Gas Hazard Assessment Guidance Note*, the generic protection measures required include "Use of 'semi-active' or enhanced passive gas control. Detection systems in some situations". The recommended preventive measures are presented below.

Construction Phase

Appointment of Safety Officer

11.5.9 A Safety Officer, trained in the use of gas detection equipment and landfill gas-related hazards, should be present on site throughout the groundworks phase. The Safety Officer should be provided with an intrinsically safe portable instrument, which is appropriately calibrated and able to measure the following gases in the ranges indicated below:

Methane	0-100% LEL and 0-100% v/v
Carbon dioxide	0-100%
Oxygen	0-21%

Safety Measures

11.5.10 For staff who work in, or have responsibility for "at risk" area, such as all excavation workers, supervisors and engineers working within the Consultation Zone, should receive appropriate training on working in areas susceptible to landfill gas, fire and explosion hazards.

11.5.11 An excavation procedure or code of practice to minimize landfill gas related risk should be devised and carried out.

11.5.12 No worker should be allowed to work alone at any time in or near to any excavation. At least one other worker should be available to assist with a rescue if needed.

11.5.13 Smoking, naked flames and all other sources of ignition should be prohibited within 15m of any excavation or ground-level confined space. "No smoking" and "No naked flame" notices should be posted prominently on the construction site and, if necessary, special areas should be designed for smoking.

11.5.14 Welding, flame-cutting or other hot works should be confined to open areas at least 15m from any trench or excavation.

11.5.15 Welding, flame-cutting or other hot works may only be carried out in trenches or confined spaces when controlled by a "permit to work" procedure, properly authorized by the Safety Officer (or, in the case of small developments, other appropriately qualified person).

11.5.16 The permit to work procedure should set down clearly the requirements for continuous monitoring for methane, carbon dioxide and oxygen throughout the period during which the hot works are in progress. The procedure should also require the presence of an

appropriately qualified person, in attendance outside the 'confined area', who should be responsible for reviewing the gas measurements as they are made, and who should have executive responsibility for suspending the work in the event of unacceptable or hazardous conditions. Only those workers who are appropriately trained and fully aware of the potentially hazardous conditions which may arise should be permitted to carry out hot works in confined areas.

11.5.17 Where there are any temporary site offices, or any other buildings located within the Sai Tso Wan Landfill Consultation Zone which have enclosed spaces with the capacity to accumulate landfill gas, then they should either be located in an area which has been proven to be free of landfill gas (by survey using portable gas detectors); or be raised clear of the ground by a minimum of 500mm. This aims to create a clear void under the structure which is ventilated by natural air movement such that emission of gas from the ground are mixed and diluted by air.

11.5.18 Any electrical equipment, such as motors and extension cords, should be intrinsically safe.

11.5.19 During piping assembly or conduiting construction, all valves/seals should be closed immediately after installation. As construction progresses, all valves/seals should be closed to prevent the migration of gases through the pipeline/conduit. All piping /conduiting should be capped at the end of each working day.

11.5.20 During construction, adequate fire extinguishing equipment, fire-resistant clothing and breathing apparatus (BA) sets should be made available on site.

11.5.21 Fire drills should be organized at not less than six monthly intervals.

11.5.22 The contractor should formulate a health and safety policy, standards and instructions for site personnel to follow.

11.5.23 All personnel who work on the site and all visitors to the site should be made aware of the possibility of ignition of gas in the vicinity of excavations. Safety notices (in Chinese and English) should be posted at prominent position around the site warning danger of the potential hazards.

11.5.24 Service runs within the Consultation Zone should be designated as “special routes”; utilities companies should be informed of this and precautionary measures should be implemented. Precautionary measures should include ensuring that staff members are aware of the potential hazards of working in confined spaces such as manholes and service chambers, and that appropriate monitoring procedures are in place to prevent hazards due to asphyxiating atmospheres in confined spaces. Detailed guidance on entry into confined spaces is given in *Code of Practice on Safety and Health at Work in Confined Spaces* (Labour Department, Hong Kong).

11.5.25 Periodically during ground-works construction within the 250m Consultation Zone, the works area should be monitored for methane, carbon dioxide and oxygen using appropriately calibrated portable gas detection equipment. The monitoring frequency and areas to be monitored should be set down prior to commencement of ground-works either by the Safety Officer or an approved and appropriately qualified person.

Monitoring

11.5.26 Routine monitoring should be carried out in all excavations, manholes, chambers, relocation of monitoring wells and any other confined spaces that may have been created. All measurements in excavations should be made with the extended monitoring tube located not more than 10 mm from the exposed ground surface. Monitoring should be performed

properly to make sure that the area is free of landfill gas before any man enters into the area.

11.5.27 For excavations **deeper than 1m**, measurements should be carried out:

- at the ground surface before excavation commences;
- immediately before any worker enters the excavation;
- at the beginning of each working day for the entire period the excavation remains open; and
- periodically throughout the working day whilst workers are in the excavation.

11.5.28 For excavations between **300mm and 1m deep**, measurements should be carried out:

- directly after the excavation has been completed; and
- periodically whilst the excavation remains open.

11.5.29 For excavations **less than 300mm deep**, monitoring may be omitted, at the discretion of the Safety Officer or other appropriately qualified person.

11.5.30 Depending on the results of the measurements, actions required will vary and should be set down by the Safety Officer or other appropriately qualified person. As a minimum, these should encompass those actions specified in **Table 11.9**.

Table 11.9 Actions in the Event of Landfill Gas Being Detected in Excavations/ Confined Areas

Parameter	Measurement	Action
Oxygen	< 19 %	• Ventilate to restore oxygen to > 19 %
	< 18 %	• Stop works • Evacuate personnel/prohibit entry • Increase ventilation to restore oxygen to > 19 %
Methane	> 10 % LEL (i.e. > 0.5 % by volume)	• Prohibit hot works • Ventilate to restore methane to < 10% LEL
	> 20 % LEL (i.e. > 1 % by volume)	• Stop works • Evacuate personnel/prohibit entry • Increase ventilation to restore methane to < 10 % LEL
Carbon Dioxide	> 0.5 %	• Ventilate to restore carbon dioxide to < 0.5%
	> 1.5 %	• Stop works • Evacuate personnel/prohibit entry • Increase ventilation to restore carbon dioxide to <0.5%

11.5.31 The exact frequency of monitoring should be determined prior to the commencement of works, but should be at least once per day, and be carried out by a suitably qualified or qualified person before starting the work of the day. Measurements shall be recorded and kept as a record of safe working conditions with copies of the site diary and submitted to the Engineer for approval. The Contractor may elect to carry out monitoring via an automated monitoring system. In this event, the gas levels specified in **Table 11.8** shall be so programmed to automate the actions in the table and in the event of the trigger levels being breached, to activate suitable audible and visual warning devices.

11.5.32 The hazards from landfill gas during the construction stage within the Sai Tso Wan Landfill Consultation Zone should be minimized by suitable precautionary measures recommended in Chapter 8 of the *Landfill Gas Hazard Assessment Guidance Note*. A copy of which is enclosed in **Appendix 11.2**. In the operational phase, if it is necessary to carry out construction works, landfill gas precautionary measures same as those recommended for the construction stage above should be followed.

Design Phase

11.5.33 According to **Table 11.2**, engineering measures are required to protect the tunnel, interchange and its facilities from the landfill gas risk due to the Sai Tso Wan Landfill. These preventive measures required include the use of 'semi active' or enhanced passive gas controls, as well as detection system in some situations. However, as the details of the Project are not yet available, only generic preventive measures can be recommended. At the subsequent detailed design stage, this assessment shall be reviewed and the detailed design (drawings and specification) of the precautionary measures as well as the requirement for maintenance and monitoring should be prepared by a competent person and should be submitted to EPD for vetting.

Building Protection Design Measures

11.5.34 Engineering measures for building structures with ground level or below ground rooms / voids (such as buildings, plant rooms, workshops) including the following should be adopted in the detailed design:

- Gas-resistant polymeric membranes which can be incorporated into the floor or wall construction as a continuous sealed layer. Membranes should be able to demonstrate low gas permeability and resistant to possible chemical attack and may incorporate aluminum wafers to improve performance. Typical details of the gas resistant membrane is shown in Figure 11.4;
- Other building materials, e.g. dense well-compacted concrete or steel shuttering which provide a measure of resistance to gas permeation;
- Creation of a clear void under the structure which is ventilated by natural structure and provides preferential pathways for release of gas (Figure 11.5 refers);
- Synthetic composite geotextiles which provide a free-venting cellular structure and provide preferential pathways for release of gas;
- Provision of mechanical ventilation to ensure sufficient air change at all time.

Design Measures for Sub-Surface Building Services

11.5.35 As shown in **Figures 11.6 to 11.10**, generic protection measures for the sub-surface building services including the following are recommended:

- A gas barrier used to prevent movement of gas through services may form part of a more extensive barrier to prevent general mitigation towards the development. The gas barrier may be made of clay (or clay-rich soils), bentonite or polymeric membranes (e.g. HDPE). In the case of water pipes and sewers which are not always fully filled, water traps e.g. U-bends, should be provided to effectively seal off the conduit and prevent gas-phase transport;
- Vent pipes or gridded manhole covers may be used to avoid build-up of gas in underground utilities manholes. Venting stacks may be built into inspection chambers or connected to collection pipes in high permeability drainage layers adjacent to gas barriers. Under all circumstances, care should be taken when accessing any manhole

chambers especially those which are not fitted with vents and necessary safety procedures must be followed; and

- For building services penetrating through the ground, collar seal should be adopted to prevent gas ingress into the room where the service pipes/cables enter the building.

Design Measures for Tunnels within Consultation Zone

11.5.36 The recommendations given below are designed to reduce the risk of gas ingress to the tunnels sections that falls within the Sai Tso Wan Landfill Consultation Zone.

- A low permeability gas membrane to be incorporated into the lining of the tunnel sections that fall within the landfill Consultation Zone.
- Adopt a conservative lapping and sealing method for the membrane lining and ensure rigorous protection/inspection measures are enabled during the placement/sealing and joining of the gas membrane during construction.
- Consider the cost-effectiveness of the use of additional internal join/surface sealants/liners/finishes, etc, with the proposed construction joint design or pursue superior designs at the tunnel interface specifically to combat cracking and aid watertightness over the lifetime of the tunnels.
- Provision of mechanical ventilation to ensure sufficient air change at all time.

Design of LFG Precautionary Measures

11.5.37 When the detailed design of the Project is available, the detailed design consultant / contractor is required to undertake review on this assessment taking into account of the more readily available detailed information to finalize the design of the landfill gas precautionary measures recommended in this report. The detailed design of gas precautionary measures and a landfill gas monitoring programme should be submitted to EPD for vetting.

11.5.38 The design of the landfill gas precautionary measures to be adopted on-site should be performed by a competent professional person who has knowledge on LFG precautionary measures. The design should also be checked and certified by a qualified independent consultant. The contractor should ensure that the required precautionary measures are implemented and constructed in accordance with the design and maintenance and monitoring programme should be established as a precautionary measure.

11.5.39 Along with the detailed precautionary measure designs, the monitoring programme and detailed actions should be submitted to EPD for approval in the detailed design stage.

Operational Phase

Guidance for Entry into Service Rooms / Voids, Manholes and Chambers

11.5.40 During the operation phase, any service voids, manholes, chambers or culvert within the proposed site, which is large enough to permit access to personnel should be subject to entry safety procedures. Works in confined spaces are controlled by the *Factories and Industrial Undertakings (Confined Spaces) Regulation* of *the Factories and Industrial Undertakings Ordinance* and *the Code of Practice for Safety and Health at Work in Confined Space* should be followed to ensure compliance with the Regulation.

11.5.41 In general, when work is being undertaken in confined spaces, sufficient approved resuscitation equipment, breathing apparatus and safety torches should be made available. Persons involved in or supervising such work should be trained and practiced in the use of such equipment. A permit-to-work system for entry into confined spaces should be developed by an appropriately qualified person and the system should be consistently

employed. The safety measures recommended in Chapter 8 of the *Landfill Gas Hazard Assessment Guidance Note* should also be strictly followed.

11.5.42 All the access to confined spaces should be restricted only to authorized personnel who are aware of the landfill gas hazard. No general public should be permitted or allowed to access the service voids, manholes, chambers or wells.

Other Safety Measures and LFG Monitoring During Operation

11.5.43 Operational staff and maintenance workers should be informed of the potential LFG hazards, and appropriate safety procedures (such as guidance for entering confined area as indicated above) should be followed.

11.5.44 During operation, regular monitoring of methane, carbon dioxide and oxygen should be done at the tunnel, subway, and any other underground structures within the landfill consultation zone a precautionary measure.

11.5.45 Inspection and LFG monitoring should be carried out at buildings and enclosures (e.g. administration building, ventilation building, workshop, tunnel etc) prior to the operation as preventive measures. The monitoring should be continued through the operation of the Project. In particular for the first year of operation, monthly monitoring is recommended. Should the monitoring reveal the presence of landfill gas within the tunnel, buildings or other confined area, the seal of the joints shall be inspected and consideration shall be given to seal the cracks.

11.5.46 In addition, if any construction is required for the maintenance work during operational stage, the responsible party should follow the precautionary measures and monitoring works as recommend in **Sections 11.5.9 to 11.5.32** of this report.

11.6 Environmental Monitoring and Audit

11.6.1 For the construction and operation within the Consultation Zone of Sai Tso Wan Landfill, the monitoring requirement specified in **Sections 11.5.26 to 11.5.31** and **Sections 11.5.43 to 11.5.46** shall be followed.

11.7 Conclusion

11.7.1 The landfill gas hazard assessment shows that the overall level of landfill gas risk posed by the Sai Tso Wan Landfill onto the Lam Tin Interchange section and related tunnel facilities of the Project would be categorised as "**Medium**". Appropriate precautionary measures have been proposed to minimize the landfill gas risk for the proposed project site during construction and operational phases. In particular, it is noted that landfill gas membrane should be installed at the tunnels, underground structures, and basement & ground floor of the buildings within the Consultation Zone of the Sai Tso Wan Landfill. Routine monitoring is recommended as a precautionary measure.

11.7.2 As the detailed information on the Project (e.g. Design) is not yet available, this assessment is based on best available information to date. A review on this report should be conducted to finalize the protection design based on the finalized project information at detailed design stage. The detailed design of the LFG precautionary measures and monitoring programmes shall be submitted to EPD for vetting. The requirement of submitting the precautionary measures designs, detailed LFG hazard assessment, and a detailed monitoring programme should be included in the scope of the subsequent detailed design study.

11.7.3 Provided that all the recommended precautionary measures are implemented properly, the safety of all personnel and general public (i.e. passengers of vehicles using the TKO-LT

Tunnel) presence at the proposed Project site would be safeguarded and there would be no adverse impact anticipated on the feasibility of the proposed Project.

11.7.4 The landfill gas hazard assessment has been conducted in accordance to and compiled with the section 1.1(f) in Annex 7 and section 3.3 in Annex 19 of the EIAO-TM and "Landfill Gas Hazard Assessment Guidance Note" (1997) issued by EPD.