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9. Landfill Gas Hazard

9.1 Legislation, Standards and Guidelines

9.1.1.1 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 a landfill (hereafter referred to as the Consultation Zone). As a certain section of the Project site falls within the Consultation Zone of the Pillar Point Valley Landfill (PPVL) (see **Figure 9.1**), a Qualitative Landfill Gas Hazards Assessment (QLFGHA) is required to assess the potential risk due to landfill gas migration from the PPVL to the temporary work sites or/and facilities for the operation of the Project within the Consultation Zone in accordance with the requirements stipulated in Clause 3.4.10 and Appendix H of the EIA Study Brief (No. ESB-348/2021), as well as the criteria and guidelines stated in Annexes 7 and 19 of the *EIAO-TM*. Among the entire Project area, only a very small section of the proposed elevated/ at-grade road and development (Administration Building, Maintenance Compound, Recovery Area, temporary re-provisioning of EMSD vehicle servicing centre, Temporary Works Area, proposed slope works and Temporary Overhead Conveyor Belt) fall within the 250m PPVL Consultation Zone.

9.1.1.2 The assessment follows the "source-pathway-target" analysis approach adopted in the EPD's *Guidance Note on Qualitative Landfill Gas Hazard Assessment (EPD/TR8/97)* (*Guidance Note*) (1) and *Practice Note for Professional Person (ProPECC PN 3/96)* (1).

9.2 Scope of this Study

9.2.1.1 As the Project is at its planning stage, detailed information (e.g. detailed design of the buildings and underground utilities, etc.) are not available at the time of this assessment. This QLFGHA is therefore conducted based on the best available information. During the subsequent detailed design stage, a review of the findings and recommendations of this assessment will be carried out and a detailed QLFGHA will be prepared. The detailed QLFGHA Report together with the detailed design of landfill gas protection measures will be submitted to EPD for vetting.

9.2.1.2 The following tasks have been undertaken as part of this review:

- review background information (including landfill gas and groundwater monitoring data) and studies related to the PPVL;
- identify the nature and extent of the PPVL which might have potential impacts on the construction and operation of the Project;
- identify possible pathways through the ground, underground cavities and utilities and the nature of these pathways through which landfill gas must traverse if they were to reach the Project site;
- identify the potential receivers which are sensitive to the landfill gas risk;

(1) Landfill Gas Hazard Assessment Guidance Note, 1997, EPD.

(2) ProPECC PN3/96 Landfill Gas Hazard Assessment for Developments adjacent to Landfills, Dec 1996, EPD.

- conduct a qualitative assessment of the degree of risk which the landfill gas migration may impose on the identified receivers for each of the source-pathway-receiver combinations; and
- recommend and design suitable level of precautionary measures and contingency plan for the potential receivers, if needed.

9.3 Landfill Gas Hazard Assessment Criteria and Methodology

9.3.1 General

9.3.1.1 In accordance with the *Guidance Note*, the risk due to landfill gas may be evaluated based upon the following three criteria:

- **Source** – the rate and concentration of landfill gas generation by the concerned landfill(s);
- **Pathway** – the nature of and length of potential pathways through which landfill gas can migrate and leachate flow, such as geological strata, utility services; and
- **Target** – the level of vulnerability of various elements of the Project site or facilities to landfill gas.

9.3.1.2 Each of these criteria is further described in the sections below.

9.3.2 Source

9.3.2.1 The classification of the Source (i.e., the landfill) is determined as follows:

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 landfill gas control measures has not been assessed; or

Any landfill site at which monitoring has demonstrated that there is significant migration of landfill gas beyond the site boundary.

Medium Landfill site at which some form of landfill 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 landfill gas; or

Landfill site where comprehensive monitoring has demonstrated that there is no migration of landfill gas beyond the landfill boundary but where the control of landfill gas relies solely on an active gas extraction system or any other single control system which is vulnerable to failure.

Minor Landfill sites at which landfill gas controls have been installed and proven to be effective by comprehensive monitoring which has demonstrated that there is no migration of landfill gas beyond the landfill boundary (or any specific control measures) and at which control of landfill 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 6 months, is less than 5% (v/v).

9.3.3 Pathway

9.3.3.1 Generally, three types of pathway are considered for the transmission of landfill gas. They are:

- *Man-made* pathways e.g., utility connections, stormwater channels, etc.,
- *Natural* pathways such as rock jointing planes, fissures and other naturally occurring phenomena which may promote or give rise to the transmission of gas over distances; and
- A *combination* of the previous two categories. An example of the latter may be, for instance, where a specific geological feature promotes gas transmission but which stops short of directly linking the landfill and target. A man made connection, however may also co-exist near the edge of the geological feature, which in combination with the former, may act to link the two sites. In this instance, careful assessment of the likelihood of the mechanism acting to link the two pathways needs to be undertaken before assigning an appropriate pathway classification.

9.3.3.2 The broad classification of a pathway is 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 to 100m for unsaturated permeable soil or fissured rock or 100 to 250 m for man-made conduits
Long/indirect	Path length of 100 to 250m for unsaturated permeable soils and fissured rock

9.3.3.3 In classifying the pathway, however, adjustments to the above general guidelines will often be required to take account other factors which will affect the extent of landfill gas migration, these include the following:

- a broad assessment of the specific permeability of the soil;
- spacing, tightness and direction of the fissures/joints;
- topography;
- depth and thickness of the medium through which the landfill 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 groundwater flow patterns.

9.3.4 Target

9.3.4.1 Different levels of vulnerability or sensitivity of potential targets for landfill gas are 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 authorised, 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, and 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, and developments which involve essentially outdoor activities but where evolution of gas could pose potential problems.

9.3.4.2 The above examples of the targets for landfill gas are to be used as a general guide only and specific aspects of a development may render it more or less sensitive than indicated. Account has been taken of any circumstances when assigning a target to one of the three indicated categories.

9.3.5 Assessment of Risk Criteria

9.3.5.1 Following the determination of the categories of source, pathway and target in which the landfill, pathway and development fall, a qualitative assessment of the overall risk may be made by reference to **Table 9.1** which is extracted from the *Guidance Note*. The potential implications associated with the various qualitative risk categories are summarised in **Table 9.2**.

9.3.5.2 It should be noted that different levels of risk determine the likely extent of the protection measures required to ensure the safety of a development. The development under very high-risk category is undesirable and a less sensitive form of development shall be considered.

Table 9.1 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 9.2 Summary of General Categorisations of Risk

Level of Risk	Implication
Very high	At the very least, extensive engineering measures and alarm systems are likely to be required. An emergency actions plan should also be developed so that appropriate actions may be immediately taken in the event of high landfill gas concentrations being detected within the development.
High	Significant engineering measures will be required to protect the planned development.
Medium	Engineering measures required to protect the development.
Low	Some precautionary measures will be required to ensure that the planned development is safe.
Very low	No protection or precautionary measures are required.

9.4 Nature of PPVL

9.4.1 Landfill History

9.4.1.1 PPVL is located to the east of Castle Peak in New Territories. The landfill site covers an area of about 33.79 ha. The landfill commenced operation in August 1983 and was closed in 1996. Around 11 million tonnes of domestic, commercial & industrial (C&I), construction, and clinical wastes, dewatered sewage sludge and stabilized incineration residues were disposed at the landfill during its 14 years of operation.

9.4.1.2 After the closure of PPVL, a contractor was appointed under EP/SP/45/03 to restore the landfill. The landfill restoration works commenced in 2004 and completed in 2006. Major restoration works at PPVL include:

- Placement of a high integrity cap across the top platform of the landfill to reduce infiltration, reduce leachate generation and control leachate levels;
- Modification to the existing leachate and groundwater collection systems to intercept and direct leachate to the onsite leachate treatment works;
- Passive venting of landfill gas in specific areas to mitigate gas migration off-site;
- Active landfill gas extraction to control and collect landfill gas for use at the leachate treatment works;
- Realignment of a natural stream at the toe of the landfill and the formation of a platform on the eastern left bank of the stream for the construction of the treatment compound; and
- Construction of leachate treatment works for the treatment of the collected leachate.

9.4.2 Historical Landfill Gas and Leachate Control

9.4.2.1 The landfill was designed to incorporate extensive measures to contain, collect, and treat landfill gas and leachate. Such measures included the installation of a liner system across the narrow floor of the valley. The liner system also consisted of a groundwater and leachate collection layer with discharge pipes while the two layers are separated by an impermeable PVC or HDPE membrane. Both leachate and groundwater collected have been discharged to the sewer beneath the landfill access road since 1989.

9.4.2.2 A comprehensive environmental monitoring programme has been implemented to monitor landfill gas generated within the landfill and at the perimeter monitoring wells along the landfill site boundary. Recent landfill gas monitoring results obtained from EPD have been reviewed. Figure 9.2 shows the locations of the monitoring wells, and the landfill gas monitoring results are summarised in **Table 9.3** (see **Appendix 9.1** for details).

Table 9.3 Summary of Landfill Gas Monitoring Results of the Perimeter Monitoring Wells at PPVL (From August 2021 to July 2022)

Location	Methane (% gas)		Carbon Dioxide (% gas)	
	Range	Average	Range	Average
GM1	0.0 – 0.0	0.0	7.2 – 11.9	9.6
GM2	0.0 – 0.0	0.0	2.0 – 10.9	7.3
GVQ1	0.0 – 0.0	0.0	0.1 – 10.5	6.2
GVQ2	0.0 – 0.0	0.0	0.1 – 13.5	6.8
GVQ3	0.0 – 0.0	0.0	0.0 – 4.1	2.1
GM4	0.0 – 0.0	0.0	4.1 – 6.9	5.0
GM5	0.0 – 0.0	0.0	2.8 – 8.1	5.3
P5	0.0 – 0.1	0.0	0.9 – 3.7	1.9

9.4.2.3 Nil or minimal concentration of methane has been observed for all perimeter monitoring wells at PPVL which indicates that there is no sub-surface off-site migration of methane at the landfill. Low concentrations of carbon dioxide have been observed in these monitoring wells. The average carbon dioxide concentrations detected in all perimeter monitoring wells ranged from 1.9% to 9.6% (v/v). In accordance to the *Guidance Note*, any concentration of carbon dioxide greater than 5% (v/v) above the background levels would be considered "significant migration". In the absence of any background carbon dioxide level as a reference, the potential for off-site migration of landfill gas cannot be completely avoided.

9.4.2.4 Recent groundwater monitoring results obtained from EPD have also been reviewed. The locations of the groundwater monitoring wells and monitoring results are presented in Figure 9.2 and **Table 9.4** (see **Appendix 9.2** for details), respectively. The monitoring results do not indicate groundwater contamination with leachate. The results suggest that the potential of landfill gas generated from the groundwater is very low.

Table 9.4 Summary of Groundwater Monitoring Results at PPVL (From July 2021 to July 2022)

Location	Ammoniacal nitrogen (mg/L)		Chemical Oxygen Demand (COD) (mg/L)	
	Range	Average	Range	Average
PWQM2	0.11 – 0.14	0.13	<4 – 11	7
PWQM3	0.11 – 0.26	0.15	4 – 17	9
PWQM4	0.11 – 0.27	0.15	2 – 7	4
PWQM5	0.11 – 0.62	0.27	6 – 12	8
PWQM6	0.11 – 0.14	0.13	2 – 10	5
PWQM7	0.10 – 0.15	0.13	5 – 12	8
PWQM8	0.11 – 0.14	0.12	5 – 77	31
PWQM9	0.11 – 5.80	2.22	4 – 14	8
GV2	0.11 – 0.15	0.13	3 – 8	5
GV4	0.11 – 0.14	0.13	<2 – 4	3
GV5	0.10 – 0.14	0.12	2 – 5	4
GWQ(A)2	0.11 – 0.14	0.13	<4 – 5	5
GWQ(A)3	0.11 – 0.14	0.13	<2 – 6	4
GWQ(A)4	0.58 – 0.74	0.66	4 – 9	7
GWQ(B)1	- *	- *	- *	- *
GWQ(B)2	0.10 – 1.50	0.40	<2 – 5	3
GWQ(B)3	0.11 – 0.14	0.13	<2 – 6	3
GWQ(B)4	0.11 – 0.14	0.13	3 – 5	4

Notes:

* No groundwater detected.

9.4.2.5 In summary, minimal concentrations of methane and low concentrations of carbon dioxide were detected in the perimeter monitoring wells along the PPVL boundary. It is conservatively assumed that off-site migration of landfill gas might be possible The groundwater monitoring results did not indicate groundwater contamination with leachate. Hence, the potential risk of landfill gas generation from leachate contaminated groundwater will be very low.

9.5 Potential for the Project to Intercept Landfill Gas

9.5.1 Geology and Hydrogeology

9.5.1.1 As shown in **Figure 9.3**, the geology of the Project site near PPVL is mainly fill overlying fine to medium grained granite. Whilst geological lineaments were observed within the PPVL Consultation Zone, none of them pass through the landfill.

9.5.1.2 Based on historical ground investigation records (see **Figure 9.3** for details), there is no significant fault lines trend from the landfill towards the Project site. Slope engineering measures were implemented to the slope adjacent to the PPVL which are likely to break the gas migration pathway, if any.

9.5.2 Utilities

9.5.2.1 No man-made underground service channels, tunnels or culverts are identified which could create preferential pathway between PPVL and the sensitive targets identified in **Section 9.6.1**.

9.6 Sensitive Targets for Landfill Gas Risk

9.6.1 Proposed Design of the Project

9.6.1.1 As shown in **Figure 9.4**, the proposed Administration Building, Maintenance Compound and temporary re-provisioning of EMSD vehicle servicing centre fall within the 250m PPVL Consultation Zone. The approximate distance from the PPVL waste boundary to the proposed Administration Building, Maintenance Compound and temporary re-provisioning of EMSD vehicle servicing centre is around 148 m, 87 m and 19 m, respectively. The proposed Administration Building will be located at the south-eastern edge of the PPVL waste boundary and the temporary re-provisioning of EMSD vehicle servicing centre and Maintenance Compound will be located immediately south of the PPVL waste boundary.

9.6.1.2 As the proposed elevated/ at-grade road, Recovery Area, Temporary Works Area, proposed slope works and Temporary Overhead Conveyor Belt within the PPVL Consultation Zone will be operated in open space, there will be no potential for landfill gas accumulation at the facility. Therefore, it is not further assessed in this report.

9.6.2 Construction Methodology

9.6.2.1 Blasting is not required for the construction of the proposed Administration Building, Maintenance Compound and temporary re-provisioning of EMSD vehicle servicing centre. However, the site formation works for the proposed elevated/ at-grade road, Administration Building, temporary re-provisioning of EMSD vehicle servicing centre and Temporary Overhead Conveyor Belt, and the proposed slope works at Southern Portal area will require some open excavation works and mechanical breaking (surface excavation) works, respectively.

9.7 Qualitative Assessment of Risks due to Landfill Gas

9.7.1 Introduction

9.7.1.1 This section reviews the information presented in the preceding sections and evaluates the data presented with reference to the assessment definitions given in the *Guidance Note*. The qualitative assessment of the potential hazard from landfill gas to the proposed targets is then concluded.

9.7.2 Source

9.7.2.1 Restoration works at PPVL, including installation of a low permeability capping system, a landfill gas control system (including the active landfill gas extraction and passive venting systems), and the leachate collection and treatment works were completed in 2006 to contain, manage and control landfill gas and leachate generated from the landfill. The recent landfill gas monitoring results indicate no or insignificant levels of methane in the perimeter monitoring wells.

9.7.2.2 Taking into account the landfill conditions (i.e., the landfill still actively generating landfill gas, but has properly restored and being well-maintained), the multiple landfill gas controls implemented, and the last 12 months landfill gas monitoring data, the PPVL is classified as a "medium" source of potential landfill gas risk.

9.7.3 Pathway

9.7.3.1 The potential pathways through which landfill gas from PPVL may migrate (if it does) to the Project site comprise only natural features (i.e., fissures or joints in rock). No significant fault lines trend from the PPVL towards the Project site and geological lineaments across the landfill were identified. There is no direct man-made pathway for the transmission of landfill gas from the PPVL to the proposed Administration Building, Maintenance Compound and temporary re-provisioning of EMSD vehicle servicing centre.

9.7.3.2 Considering the separation distance and possible migration pathways between the PPVL and the proposed Administration Building, Maintenance Compound and temporary re-provisioning of EMSD vehicle servicing centre, the potential landfill gas pathways from the PPVL to the proposed Administration Building, Maintenance Compound and temporary re-provisioning of EMSD vehicle servicing centre are classified as "long/indirect", "moderately short/direct" and "very short/ direct", respectively.

9.7.4 Targets

9.7.4.1 Landfill gas related impacts are most likely to occur in areas at, or below grade at the Project. The identified targets associated with the construction and operation of the Project are presented below.

Target 1 – Construction Site of the Project

9.7.4.2 The construction of the proposed elevated/ at-grade road within the 250 m Consultation Zone of PPVL will involve excavation works. Any excavation areas with a trench or pit depth greater than 1.2 m (can generally be considered as confined space with respect to landfill gas accumulation risk) are at a higher risk of accumulation of landfill gas if there is sub-surface migration of landfill gas from PPVL. However, open excavation will be used for the site formation works. Landfill gas, if any, migrated to the construction areas of the Project can be easily dispersed and diluted in the atmosphere. Construction works involving working in deep trenches or utility pits will be undertaken by trained staff who will be well informed of the potential landfill gas migration hazard and follow the specific safety procedures. This target is thus classified as "medium sensitivity".

Target 2 – Operation of the Administration Building, Maintenance Compound, temporary re-provisioning of EMSD Vehicle Servicing Centre

9.7.4.3 During operation, the proposed Administration Building, Maintenance Compound, temporary re-provisioning of EMSD vehicle servicing centre will be occupied by operating staff. Underground confined spaces (such as manhole and utility pits) and ground level rooms with underground utility connections are places where landfill gas can potentially be accumulated. Restricted access to the manholes and utility pits by authorised and well-trained personnel who is fully aware of the potential landfill gas hazards and the specific safety procedures is expected. These rooms/ voids are thus considered to have "medium sensitivity". Ground level rooms of unrestricted staff access or have sources of ignition (e.g., electrical or other equipment) are considered to have "high sensitivity". This target is conservatively classified as "medium to high sensitivity".

9.7.5 Source-Pathway-Target Analysis

9.7.5.1 On the basis of the source, pathways and targets identified above, a source-pathway-target analysis has been undertaken and is presented in **Table 9.5** in accordance with the assessment framework described in EPD's *Guidance Note*.

9.7.5.2 The source-pathway-target analysis shows that landfill gas risk posed by the PPVL is "medium" during construction phase and "low to high" during operation phase.

Table 9.5 Qualitative Assessment of Landfill Gas Hazard Associated with PPVL

Source	Pathway	Target	Qualitative Risk
PPVL – Passive control, active extraction, comprehensive monitoring **(Category: Medium)**	Less than 50m from PPVL, no fault/fissure, no man-made conduits **(Category: Very short/ direct)**	Target 1 (Construction site of the Project) – Open excavation works, working in confined space by trained staffs **(Category: Medium sensitivity)**	**Medium**

Source	Pathway	Target	Qualitative Risk
	Around 150 m from PPVL, no fault/fissure, no man-made conduits **(Category: Long/indirect)**	Target 2 (Operation of the Administration Building) – Underground confined spaces and ground level rooms with underground utility connections with restricted access **(Category: Medium sensitivity)**	**Low**
		Target 2 (Operation of the Administration Building) – Ground level rooms of unrestricted staff access, or with source of ignition **(Category: High sensitivity)**	**Medium**
	Around 90 m from PPVL, no fault/fissure, no man-made conduits **(Category: Moderately short/direct)**	Target 2 (Operation of the Maintenance Compound) – Underground confined spaces and ground level rooms with underground utility connections with restricted access **(Category: Medium sensitivity)**	**Medium**
		Target 2 (Operation of the Maintenance Compound) – Ground level rooms of unrestricted staff access, or with source of ignition **(Category: High sensitivity)**	**High**
	Less than 50 m from PPVL, no fault/fissure, no man-made conduits **(Category: Very short/ direct)**	Target 2 (Operation of the temporary re-provisioning of EMSD vehicle servicing centre) – Underground confined spaces and ground level rooms with underground utility connections with restricted access **(Category: Medium sensitivity)**	**Medium**

Source	Pathway	Target	Qualitative Risk
		Target 2 (Operation of the temporary re-provisioning of EMSD vehicle servicing centre) – Ground level rooms of unrestricted staff access, or with source of ignition **(Category: High sensitivity)**	**High**

9.8 General Hazards Related to Landfill Gas

9.8.1.1 All contractors participating in the construction of the Project within the Consultation Zone should be made aware of the potential of methane and carbon dioxide present in the soil and all works should be undertaken on the basis of an "assumed presence of landfill gas". The staffs of the Administration Building, Maintenance Compound and temporary re-provisioning of EMSD vehicle servicing centre should also be made aware of potential accumulation of landfill gas within underground utility pits/rooms and rooms have direct connection with underground utility pits or manholes. In addition, the following properties of landfill gas should be noted.

9.8.1.2 *Methane* is odourless and colourless, although in landfill gas it is typically associated with numerous highly odoriferous compounds which gives 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.

9.8.1.3 *Methane* is a flammable gas and will burn when mixed with air between approximately 5 and 15% (v/v). 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.

9.8.1.4 *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.

9.8.1.5 *Gas density*. Methane is lighter than air whereas carbon dioxide is heavier than air. Typical mixtures of landfill gas are likely to have a density close to or equal to that of air. However, site conditions may result in a ratio of methane to carbon dioxide which may make the gas mixture lighter or heavier than air. As a result, landfill gas may accumulate in either the base or top of any voids or confined spaces.

9.9 Recommendations

9.9.1.1 This section of the report provides general advice and recommendations for mitigating the environmental impacts related to landfill gas during the construction and operation of the Project for elements within the Consultation Zone.

9.9.2 Recommended Precautionary and Protection Measures for Construction Phase

9.9.2.1 The construction works to be undertaken at the Project site will involve construction team and others with risks resulting from contact with landfill gas. For example, when laying underground utilities or other situations, personnel may have to enter confined spaces. Precautionary measures to be adopted during construction at the Project Site are outlined in Paragraphs 8.3 to 8.49 of EPD's *Guidance Note*. The following guidance has been extracted from and appended to this to ensure a robust and comprehensive set of measures to protect the construction team are provided.

Safety Measures

- During all works, safety procedures should be implemented to minimise the risks of fires and explosions and asphyxiation of construction team (especially in confined space).
- Safety officers, specifically trained with regard to landfill gas related hazards and the appropriate actions to take in adverse circumstances, should be present on the site throughout the works, in particular, when works are undertaken below grade.
- All personnel who work on site and all visitors to the site should be made aware of the possibility of ignition of gas in the vicinity of the works.
- Those staff who work in, or have responsibility for "at risk" areas, including bore piling and excavation works, should receive appropriate training on working in areas susceptible to landfill gas.
- Any offices/quarters set up on site should take precautions against landfill gas ingress, such as landfill gas monitoring and alarm devices. Other storage premises, e.g. shipping containers, where this is not possible should be well ventilated prior to entry.
- Adequate precautions to prevent the accumulation of landfill gas under site buildings and within storage shed should be taken by raising buildings off the ground where appropriate and "airing" storage containers prior to entry by personnel and ensuring adequate ventilation at all times.
- Smoking and naked flames should be prohibited within confined spaces. "No Smoking" and "No Naked Flame" notices in Chinese and English should be posted prominently around the construction site. Safety notices should be posted warning of the potential hazards.
- During the construction works, adequate fire extinguishers and breathing apparatus sets should be made available on site and appropriate training given in their use.
- Welding, flame-cutting or other hot works may only be carried out in confined spaces when controlled by a "permit to work" procedure, properly authorised by the Safety Officer. The permit to work procedure should set down clearly the requirements for continuous monitoring of 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 who shall be responsible for reviewing the gas measurements as they are made, and who shall have executive responsibility for suspending the work in the event of unacceptable or hazardous conditions. Only those staffs 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.

Monitoring

9.9.2.2 Monitoring will be undertaken when construction works are carried out in confined space within the Consultation Zone. The monitoring requirements and procedures specified in Paragraphs 8.23 to 8.28 of EPD's *Guidance Note* are highlighted below:

- Periodically during ground-works construction, the works area should be monitored for methane, carbon dioxide and oxygen using appropriately calibrated portable gas detection equipment. The equipment should be intrinsically safe and calibrated according to the manufacturer's instructions.
- The monitoring frequency and areas to be monitored should be set down prior to commencement of works either by the Safety Officer or by an appropriate qualified person.
- Routine monitoring should be carried out in all excavations, manholes and chambers and any other confined spaces that may have been created by, for example, the temporary storage of building materials on the site surface.
- All measurements in excavations should be made with the monitoring tube located not more than 10mm from the exposed ground surface.
- A standard form, detailing the location, time of monitoring and equipment used together with the gas concentrations measured, should be used when undertaking manual monitoring to ensure that all relevant data are recorded.
- Monitoring of excavations should be undertaken as follows:

  For excavations deeper than 1m, measurements should be made:

  - at the ground surface before excavation commences;
  - immediately before any staff enters the excavation;
  - at the beginning of each working day for the entire period the excavation remains open; and
  - periodically through the working day whilst the construction team is in the excavation.

  For excavations between 300mm and 1m deep, measurements should be made:

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

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

- If methane (flammable gas) or carbon dioxide concentrations are in excess of the trigger levels or that of oxygen is below the levels specified in the Emergency Management in the following section, then evacuation will be initiated.

Actions in the Event of Gas Being Detected

9.9.2.3 Depending on the results of the measurements, actions required will vary and should be set down by the Safety Officer or another appropriately qualified person. As a minimum these should encompass those actions specified in **Table 9.6**.

Table 9.6 Actions in the Event of Gas Being Detected

Parameter	Measurement	Action
O_2	< 19% v/v	Increase underground ventilation to restore O_2 to >19% v/v
	< 18% v/v	Stop works Evacuate all personnel Increase ventilation further to restore O_2 to >19% v/v
CH_4	> 10% LEL	Prohibit hot works Increase ventilation to restore CH_4 to <10% LEL
	>20% LEL	Stop works Evacuate all personnel Increase ventilation further to restore CH_4 to <10% LEL
CO_2	>0.5% v/v	Increase ventilation to restore CO_2 to <0.5% v/v
	> 1.5% v/v	Stop works Evacuate all personnel Increase ventilation further to restore CO_2 to <0.5% v/v

Emergency Management

9.9.2.4 In order to ensure that evacuation procedures are implemented in the event of the trigger levels specified in **Table 9.6** above being exceeded, it is recommended that a professional, such as the Safety Officer, is nominated, with duties, to be responsible for dealing with any emergency which may occur due to landfill gas.

9.9.2.5 In an emergency situation, the nominated person or his deputies, shall have the necessary authority and shall ensure that the confined space is evacuated, and the necessary works implemented for reducing the concentrations of gas. The following organisations shall also be contacted as appropriate:

- Hong Kong Police Force;
- Fire Services Department; and
- Environmental Protection Department.

9.9.3 Recommended Precautionary and Protection Measures for Design Phase

9.9.3.1 According to the source-path-target analysis in **Section 9.7.5**, the risk category during construction and operation phases are “medium” and “low to high”, respectively. This implies that engineering measures will be required during the detailed design stage to ensure that the construction and operation at the Project is safe. During the detailed design stage, the detailed design consultant should provide a more detailed assessment and finalize the design of the gas protective measures or ventilation to underground confined utility pits, manholes and ground floor rooms. The detailed design (drawings and specification) of landfill gas protection measures as well as the requirement for maintenance and monitoring should be prepared by a competent professional person and

submitted to EPD for vetting. These measures include a combination of passive and active systems. Examples of these measures as recommended in EPD's *Guidance Note* are listed below for reference. The typical designs of the measures are presented in **Appendix 9.3**.

Passive control measures:

- Gas-resistant polymeric membranes which can be incorporated into floor or wall construction as continuous sealed layer (see Illustration 1 in **Appendix 9.3**). Membranes should be able to demonstrate low gas permeability and resistance to possible chemical attack and may incorporate aluminium wafers to improve performance.
- Other building materials such as 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 air movements such that any emissions of gas from the ground are mixed and diluted by air (see Illustration 2 in **Appendix 9.3**).
- Synthetic composite geotextiles which provide a free-venting cellular structure and provide preferential pathways for release of gas.

Active control measures:

- A void under the structure, as discussed for passive control, but which is continuously ventilated by a fan, such that any emissions of gas from the ground are mixed and diluted in the air flow before discharge to atmosphere (see Illustration 2 in **Appendix 9.3**). The rate of ventilation is usually expressed in terms of the number of air changes (volume of the void) per hour and is designed to ensure that, based on the potential rate at which gas will enter the void, the size of the room/pits, the chance of methane to accumulate to the lower exposure limit (i.e. 5% gas) is not possible. Discharge to atmosphere usually takes place above the eaves level of the building or, in the case of high-rise structures, at a minimum height of 10 m above ground and away from air intakes to the building.
- Construction of a granular layer incorporating perforated collector pipes which is continually ventilated by a fan, such that any emissions of gas from the ground are drawn towards the end of the pipes and diluted in the air flow before discharge to atmosphere above the eaves level of the building, or in the case of high-rise structures, at a minimum height of 10 m above ground and away from air intakes to the building.
- Creation of a positive pressure zone below the building structure by injection of air from a blower into the granular layer.
- Creation of a positive air pressure zones within building structures to counteract possible leakage of gas into the building from the ground.

Active control should always be used in conjunction with passive barriers such as low gas permeable membranes or paint in floors, in order that there is no leakage of air/gas flow through a floor or wall into a structure. Gas detection systems should also be used to monitor gas in extracted air flow, and to monitor internal spaces inside buildings. Active systems are normally required for high-risk sites where landfill gas has been measured in the ground at or close to the development site, and where buildings are close to the source of landfill gas.

9.9.3.2 Landfill gas may also enter the building/void via service entries. Measures to prevent gas migration through service entries are listed below:

Gas Barriers

- Barriers used to prevent movement of landfill gas through service entries may be made of clay (or clay-rich soils), bentonite or polymeric membranes (such as HDPE). The design detail at the point where the service penetrates the membrane is important and use should be made of pre-formed shrounds (or cloaks), skirts and fillets. A schematic for a natural material cut-off barrier is shown in Illustration 3 in **Appendix 9.3**.
- It will also be appropriate to consider routing all services through a sealed culvert or duct which is either completely lined in naturally gas-resistant material (e.g. clay, low permeability paint) or which is lined with an HDPE membrane.
- In the case of water pipes and sewers which are not always fully filled, water traps, such as U-bends, should be provided to effectively seal off the conduit and prevent gas-phase transport.
- In order to prevent the ingress of landfill gas into a building via the interface between the service pipe and the backfilled soil, it is important that the annulus around any service entry points is effectively blocked by means of sealant, collars or puddle flanges as appropriate (see Illustration 4 in **Appendix 9.3**).

Gas Vents

- Vent pipes or griddled manhole covers may be used to avoid build-up of landfill gas in underground utilities manholes. Venting stacks may be built into inspection chambers or connected to collection pipes within high permeability drainage layers adjacent to landfill gas barriers. A typical vented manhole arrangement is shown in Illustration 5 in **Appendix 9.3**.
- A further type of venting arrangement, which may be appropriate to multiple service entries, comprises a vented gas interceptor cavity through which service pipes pass, as shown in Illustration 6 in **Appendix 9.3**. The aim of this protection measure is to locate the barrier component within the building sub-structure in a sealed entry box which is fitted with a vent stack.

9.9.3.3 With respect to the nature of the target during the operation phase of the Project, it is considered that providing sufficient venting for underground utility manholes /pits or applying low gas permeability paints will be an adequate and cost-effective measures. For ground floor rooms, providing sufficient nature or active ventilation will be considered as an effective measures to avoid potential accumulation of methane gas within rooms.

9.9.4 Recommended Precautionary and Protection Measures for Operation Phase

9.9.4.1 All operation and maintenance staff should be informed of the potential landfill gas hazards. The operation team will be responsible to train and to ensure that their staff take appropriate safety precautions at all times when entering enclosed rooms or any service voids, manholes, chambers or culvert within the proposed site.

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

9.9.4.3 During operation, regular monitoring of landfill gas should be conducted at buildings and enclosures (e.g. proposed Administration Building, Maintenance Compound, temporary re-provisioning of EMSD vehicle servicing centre, service manholes, etc.) within the Consultation Zone to verify the effectiveness and to ensure the continued performance of the implemented protection measures. Should abnormality be observed, it should be reported to EPD and the PPVL operator.

9.9.4.4 Along with the detailed design of the landfill gas protection measure, the monitoring programme and detailed actions should be included in the detailed assessment during the designed design stage and submitted to EPD for approval.

9.10 Environmental Monitoring and Auditing

9.10.1.1 For the construction and operation within PPVL Consultation Zone, the monitoring requirement specified in **Section 9.9.2** and **Section 9.9.4** shall be followed.

9.11 Conclusion

9.11.1.1 This Section has provided a qualitative assessment on potential hazards associated with landfill gas migration from the PPVL to the proposed Project site. PPVL is considered as a “medium” source of gas migration due to the landfill condition and multiple landfill gas controls implemented. The source-pathway-target analysis shows that landfill gas risk posed by the PPVL to the Project is “medium” during construction phase and “low to high” during operation phase.

9.11.1.2 In general, underground rooms or void spaces should be avoided as far as practicable at the Administration Building, Maintenance Compound and temporary re-provisioning of EMSD vehicle servicing centre of the site within the Consultation Zone. Other precautionary and protection measures during design, construction and operation phases of the Project have been recommended for elements within the Consultation Zone. It is expected that with the proposed precautionary measures in place, the potential risk of landfill gas migration to the respective targets will be minimal.