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14. LANDFILL GAS HAZARD

14.1 Introduction

14.1.1 This section presents the assessment of potential landfill gas (LFG) hazard arising from the construction and operation of the Project. Mitigation measures have been proposed to minimise the identified landfill gas hazards. The landfill gas hazard assessment (LFGHA) has been conducted in accordance with the requirements in Landfill Gas Hazard Assessment for Development Adjacent to Landfills (ProPECC PN 3/96) and Landfill Gas Hazard Assessment Guidance Note (2022) (EPD/TR8/97), as well as the requirements set out under Clause 3.4.15 of the EIA Study Brief for the Project.

14.1.2 The Project covers the development of TKO 132 and 137. The development of TKO 132 does not fall within any consultation zone of the landfills. The development of TKO 137 falls within the 250m consultation zone for South East New Territories Landfill (SENT) and its extension (SENTX), therefore, the LFG hazard assessment was conducted for TKO 137 only.

14.2 Environmental Legislation, Standards and Guidelines

14.2.1 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 Environmental Impact Assessment Process (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);
- Landfill Gas Hazard Assessment Guidance Note (2022) (EPD/TR8/97) (LFGHA Guidance Note); and
- The Hong Kong Planning Standards and Guidelines (HKPSG), Chapter 9.

14.2.2 ProPECC PN 3/96 and the LFGHA Guidance Note provide an assessment framework to be followed when evaluating the risks related to developments close to landfills as described under Section 6.5, Chapter 9 of the HKPSG. ProPECC PN 3/96 and LFGHA Guidance Note apply to all developments proposed within a Landfill Consultation Zone, which is the area of land surrounding the landfill boundary as defined by a line running parallel to and 250 m away from the edge of the waste if this can be identified or, if not, the recognised landfill site boundary.

14.2.3 In accordance with aforementioned framework, the following tasks have been undertaken to assess potential LFG hazard associated with the SENT and SENTX to potentially sensitive elements of the Development situated within the Consultation Zone.

- Review of background information (including landfill gas monitoring data) and studies related to the SENT and SENTX;
- Identification of the nature and extent of the sources, including the likely concentrations and / or amounts of hazardous emissions which might have the potential for impacts on the Project and impacts from the Project to the potential receivers;
- Identification of the possible pathways through the ground, underground cavities or groundwater and the nature of these pathways through which the hazardous emissions must traverse if they were to reach the Project;
- Identification of the potentially sensitive receivers associated with the Project which are sensitive to the impacts of the hazardous emissions;
- Qualitative assessment on the degree of risk which the hazardous emissions may impose on the receivers for each the source-pathway-receiver combinations;

- Design and implementation of suitable level of precautionary / protection measures and contingency plan for the Project and the potential receivers, if needed, in rendering the proposed development as safe as reasonably practicable;
- Establishment and implementation of a maintenance and monitoring programme for ensuring the continued performance of the implemented precautionary / protection measures.

14.3 Assessment Methodology

14.3.1 In general, the evaluation of the hazards posed by landfill gas to a proposed development involves a qualitative risk assessment, the framework for which is detailed in the LFGHA Guidance Note. Such an assessment includes the following steps:

- Review of background information to determine the likelihood of landfill gas having an impact on the proposed development. Such information will include historical information about how the landfill was engineered and operated, geological and hydrogeological data and results of any environmental monitoring.
- Evaluation of the nature and extent of the source(s) of landfill gas, including the likely concentrations and volumes of hazardous emissions which may have the potential to affect the proposed development.
- Identification and evaluation of possible pathways along which gas could travel from the landfill site to the development site, through the ground, underground cavities, utilities and groundwater.
- Identification of the different elements of the proposed development which will be sensitive to the impacts of landfill gas. Such potential "targets" will include building basements and ground level rooms, underground car parks, service ducts and manholes, unventilated excavations and other confined spaces at or below ground level.
- A qualitative assessment of overall risk for each Source-Pathway-Target combination into one of five risk categories (Very high, High, Medium, Low and Very Low) using professional judgement.

Criteria

14.3.1.1 In accordance with the LFGHA Guidance Note, risk associated with landfill gas may be evaluated by assessment of the following three criteria:

- **Source** – location, nature and likely quantities/ concentrations of landfill gas with 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 a development that may be sensitive to the effects of landfill gas.

Source

14.3.1.2 The classification of the Source (i.e. SENT and SENTX) is 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 a 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.

14.3.1.3 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 landfills boundary indicates significant migration in accordance with the LFGHA Guidance Note. 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.

14.3.1.4 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).

14.3.1.5 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 considered 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.

14.3.1.6 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

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

- **Very short / direct** - Path length <50m for unsaturated permeable strata and fissured rock or < 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

In classifying the pathway, 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.

14.3.1.8 Thus, although there may be permeable soil between the landfill site and a proposed development, 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 alter if the land between the landfill site and the development was paved over or altered which reduced the potential for gas release. Similarly, if the land is flat, the surface may be prone to water logging 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.

14.3.1.9 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

14.3.1.10 Target sensitivities are broadly classified as follows:

High sensitivity	Buildings or 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	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 or 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). Excavations or developments which involve essentially outdoor activities but where evolution of gas could pose potential problems.

Risk Categorisation

14.3.1.11 Having determined into which categories of LFG 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 14.1** in accordance with the S3.20 of the LFGHA Guidance Note. The potential implications associated with the various qualitative risk categories are summarised in **Table 14.2**. Five generic forms of protection are used for control of hazards to a development. These correspond to the risk levels set out in **Table 14.3** with the terms used defined in **Table 14.4.**

Table 14.1 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 14.2 Summary of General Categorisation of Risk

Category	Level of Risk	Implication
A	Very High (Undesirable)	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.

Table 14.3 Generic Protection Measures for Planning Stage Categorisation

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 gas 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 14.4 Definition of Control Terms

Terms	Definition
Active	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	Use of wind driven cowls and other devices which assist in the ventilation of gas but do not rely on electrically powered fans.
Passive	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. vents such as gravel in trenches or a clear void/permeable layer below structures.
Detection	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.

14.4 Description of Environment

14.4.1 SENT and SENTX are located at TKO Area 101 and covers about 100 ha, half of which has been reclaimed from Shek Miu Wan (Junk Bay). To the north and east of the landfill lies Clear Water Bay Country Park; to the west is Tseung Kwan O InnoPark (TKOIP) and to the south is CEDD's Fill Bank at TKO 137. SENT is one of the three strategic landfills in Hong Kong with a design capacity of 43 million cubic meters.

14.4.2 The SENTX occupies about 13 hectares (ha) of additional land at TKO Area 101 and about 30 ha of land within the existing SENT which provides a total capacity of about 6.5 million cubic meters. The SENTX forms a logical extension to the existing SENT. The extension is designated for reception of only construction waste to minimise potential odour problems and to provide additional landfill capacity to maintain a continuous disposal service for construction waste in the urban and southeastern parts of the territory. SENTX is expected to be closed with its restoration works completed prior to the population intake at TKO 137. The existing barging facility used by the SENT/SENTX contractor shall be maintained up to the completion of restoration works of the SENT/SENTX.

14.4.3 The TKOIP located immediately to the north of TKO 137 is currently connected by a single trunk road to TKO New Town via Wan Po Road. Wan Po Road is also the road connection for

LOHAS Park development on top of the MTR station and depot for MTR TKO Line, with planning capacity for 25,500 households. Besides, the Cross-Bay Link links up TKOIP and LOHAS Park with the TKO-Lam Tin Tunnel, which provides a second and direct external road connection for the area including TKO 137. With the repositioning of industrial estates to support innovation and technology industry development, there is also scope to explore land development in support of such, and synergy with TKO 137 as well as support for infrastructure development including possible railway extension.

14.4.4 The proposed development at TKO 137 is adjacent to the SENT and SENTX and falls partially within the 250m consultation zone of the landfill as shown in **Figure 14.1**, therefore the Project Proponent is required to undertake a landfill gas hazard assessment and submit a report to the Environmental Protection Department (EPD) for vetting.

14.4.5 The development area boundary of TKO 132 covers mainly the open seas of Chiu Keng Wan, Junk Bay and Lei Tue Mun with inclusion of limited areas of Green Belts along the seashore. No landfill lies within the vicinity of the development boundary therefore landfill gas hazard assessment is not required according to the ProPECC PN3/96.

14.5 Identification of Landfill Gas Generation, Characteristics and Hazards

Landfill Gas Generation

14.5.1 Infiltration of water into a landfill causes gases to be generated as decomposition of organic materials occurs. Once biodegradation has started the oxygen is soon exhausted and as no replenishment of the free oxygen is available, the waste mass becomes anaerobic. During anaerobic fermentation methanogens generate methane and carbon dioxide, the primary constituents of landfill gas. A typical composition of LFG is about 60% by volume of methane and 40% by 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.

14.5.2 Due to the high variability in the settings of biodegradation, waste composition, and individual site characteristics, the rate of degradation and the volume of landfill gas produced per unit of waste can vary greatly. The generation of LFG is dependent on numerous environmental conditions including temperature, pH, substrate availability, moisture content and oxygen content.

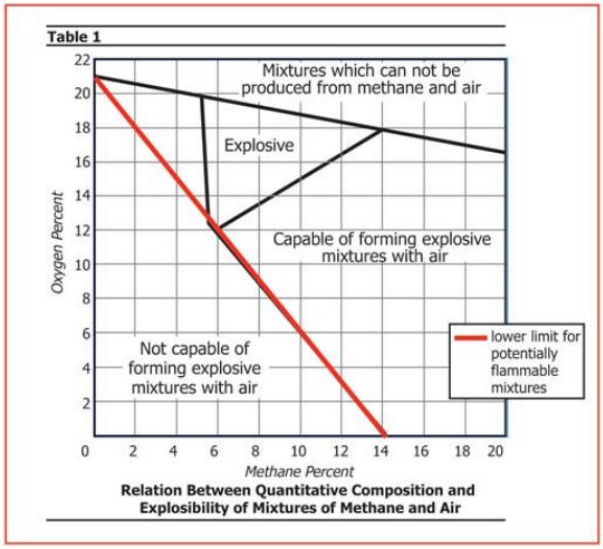
Landfill Gas Characteristics

14.5.3 Whilst methane has relatively low solubility in water, is colourless and odourless, and generally of little influence in groundwater quality, it occurs in gaseous form in the unsaturated zone. The gas, which is also an asphyxiant, is highly flammable and can be explosive when all the following conditions exist at the same time:

- Its concentration in air is between 5% of the Lower Explosive Limit (LEL) and 15% of the Upper Explosive Limit (UEL);
- the gas is in a confined space; and
- a source of ignition exists.

14.5.4 The relationship between methane and oxygen where flammable mixtures can occur is shown in (from 30 CFR § 57.22003, MSHA Illustration 27).

Plate 14.1 Flammability Levels of Methane and Oxygen



14.5.5 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.

14.5.6 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 collect in the bottoms of trenches or excavations or may rise up and accumulate beneath structures and foundations.

Landfill Gas Hazard

14.5.7 Given the potentially flammability, asphyxiant properties and gaseous density of LFG, potential hazard arises in the event that LFG is able to migrate from the landfill and accumulate in confined spaces such as building basements, underground car parks, lift shafts, pumping stations, and maintenance chambers etc. For the same reasons, temporary structures such as site huts and any other unventilated enclosures erected during construction stage may also be exposed to landfill gas hazards. Underground services, such as sewer drains, storm drains and service ducts, may also be susceptible to the potential hazards as they act as pathways for LFG. Besides, any faults present in geological formation also act as pathways for LFG.

Landfill Gas Migration

14.5.8 Methane will migrate along pressure gradients from areas where it is present at higher pressures to areas where it is present at lower pressures. The primary mechanism for significant methane migration in subsurface unsaturated soils is pressure-driven flow. Diffusion also occurs but at rates too low to result in unacceptable indoor air concentrations under reasonably likely scenarios.

The ability for landfill gas to migrate beyond the waste boundary varies according to the type of landfill construction details, presence of gas and leachate control measures, restoration details and permeability of the ground through which gas must travel. Factors such as changes in atmospheric pressure can also encourage gas migration.

If gas is able to intercept any buried service routes especially where the utility has been laid in an open conduit or the trench excavation has been backfilled around the utility line with coarse

gravel; these may also be susceptible to potential hazards and/or they may act as preferential gas migration pathways.

14.6 Quantitative Assessment of Potential Risk

Source – SENT

14.6.1 SENT commenced its operation in September 1994 and received domestic, commercial and industrial (C&I), construction and demolition, chemical and clinical wastes, dewatered sewage sludge and stabilised incineration residues. Since 6 January 2016, SENT has been designated to receive only construction waste for disposal. After 27 years of landfilling operations, SENT was exhausted and closed on 21 November 2021 whilst SENTX started receiving construction waste on the same day upon completion of initial extension works. At present, restoration works for the closed SENT are on-going.

14.6.2 The landfill has been designed to incorporate extensive measures to contain, collect and treat/utilise landfill gas. Such measures include the state-of-the-art technologies (including a composite liner system, active landfill gas extraction and landfill gas treatment and utilisation) in accordance with international best practices for landfill operations. Blower systems are installed to extract the LFG via a network of gas collection wells and collection pipes within the waste mass of the landfill. The LFG is used to generate electricity for on-site usage and also as heat energy source for the leachate treatment facilities. Surplus LFG is also reprocessed in on-site facilities by Hong Kong and China Gas Company Limited (Towngas) for conveyance the Towngas supply grid with flare units installed to flare off any residual/unused LFG. The landfill contractor is required to undertake routine maintenance and monitoring of the landfill gas control systems to ensure they are operating satisfactorily.

14.6.3 A comprehensive environmental monitoring programme has been implemented to monitor landfill gas generated around the landfill waste boundary including the perimeter boreholes around the landfill (refer to **Appendix 14.1**). Under the existing SENT's contract, the landfill contractor is required to continue the control and monitoring of landfill gas for an aftercare period of 30 years following the closure and full restoration of the SENT.

14.6.4 A comprehensive environmental monitoring programme has been implemented to monitor the levels of leachate head within waste mass of the landfill, off-site leachate migration/ groundwater contamination and concentration of landfill gas at the perimeter boreholes around the landfill. As the landfill is lined and leachate is collected for treatment, the leachate head within waste mass of the landfill is well under control.

Source - SENTX

14.6.5 The EIA Report (AEIAR-117/2008) for the SENTX was approved under the EIAO in May 2008 and an Environmental Permit (EP-308/2008) was granted on 5 August 2008. Since then, the administration has decided to reduce the scale of the extension scheme assessed in the approved EIA Report, and the SENTX now only receives construction waste. Environmental Reviews were undertaken in 2011 and 2016 to address the findings of the approved EIA Report as a result of the changes to the SENTX and Variations of the Environmental Permit (EP-308/2008/A and EP-308/2008/B) were granted on 6 January 2012 and 20 January 2017, respectively.

14.6.6 The SENTX occupies about 13 hectares (ha) of additional land in TKO 137 and about 30 ha of land within the existing SENT which provides a total capacity of about 6.5 million m^3.

14.6.7 Under the SENTX contract requirements, the contractor is required to control off-site landfill gas migration such that the methane and carbon dioxide concentrations at the perimeter monitoring wells do not exceed 1% v/v and 1.5% v/v above the background levels, respectively. As presented in the approved EIA Report (AEIAR-117/2008), the SENTX is classified as a

"medium" source considering the multiple landfill gas control measures, recent (April 2022 - March 2024) landfill gas monitoring data and stringent contractual requirements for controlling off-site landfill gas migration.

14.6.8 It is envisaged that construction waste (waste arising from construction activities that is mixed with some inert material) will generate significantly lower quantities of landfill gas than municipal solid waste and sludge. Thus, the quantity of landfill gas generated in the extension scheme is expected to be lower than that estimated in the approved EIA Report (AEIAR-117/2008). Nevertheless, landfill gas control measures aim to ensure that landfill gases generated can be managed in a controlled and safe manner.

Categorisation of LFG Source

14.6.9 SENT and SENTX have been designed to incorporate control measures including a composite liner, active gas extraction and landfill gas treatment and utilisation in accordance with international best practices for landfill operations to collect and treat/utilise landfill gas. Effective LFG management is being implemented to achieve the following:

- To eliminate risk of explosion or combustion due to the presence of LFG within, below, above and inside the landfill site;
- To eliminate hazards to flora or fauna due to toxicity or asphyxiant effects of LFG external to the landfill site;
- To minimise the effect of odours from LFG causing nuisance in the vicinity of the landfill site;
- To minimise uncontrolled egress of LFG from the landfill site;
- To eliminate migration of LFG to service ducts or enclosed/confined spaces of any onsite buildings;
- To protect any temporary or permanent structures or chambers on the landfill site;
- To prevent unnecessary air ingress into the landfill;
- To prevent unnecessary build-up of LFG pressure within the landfill;
- To relieve positive pressures of LFG at the landfill boundary and near the surface;
- To facilitate the controlled extraction of LFG from the landfill;
- To facilitate the ultimate flaring and utilisation of LFG; and
- To provide signs designating hazards and precautions to avoid on-site accidents.

14.6.10 The landfill contractor routinely maintains the landfill gas extraction system to ensure it is operating satisfactorily. A comprehensive monitoring programme has been implemented to monitor landfill gas generated around the landfill waste boundary including boreholes around the landfill perimeter. The locations of relevant monitoring wells and landfill gas monitoring data are provided in **Appendix 14.1**. A summary of landfill gas monitoring data is provided in **Appendix 14.2**.

14.6.11 The range of average methane, carbon dioxide and oxygen concentrations at peripheral monitoring locations for SENT and SENTX are summarised in **Table 14.5**.

Table 14.5 LFG Monitoring Results at SENT and SENTX (April 2022 – March 2024)

Location	Range of Average Methane %v/v	Range of Average Carbon Dioxide %v/v	Range of Average Oxygen %v/v
SENT	0.00 - 0.65	0.00 - 3.32	3.59 - 20.68
SENTX	0.01 - 7.95	0.00 - 1.38	11.35 - 19.85

14.6.12 According to the SENTX monitoring data, of the 24 LFG monitoring wells (namely LFG1 to LFG24), no significant methane detections indicative of potential gas migration are identified, except at LFG13, where concentrations >5% of the Lower Explosive Limit (LEL) have been recorded on 14 occasions over the monitoring period, with a maximum concentration of 25.8%. For the nearest neighbouring monitoring wells (LFG12 and LFG14), no elevated methane was

detected in LFG12 (to the north) whilst in LFG14 (to the east and closer the waste boundary), methane was only detected on three of the eighteen monitoring occasions at concentrations of 0.2%, 0.3% and 2.2%. This monitoring data suggests the occasional methane detections at LFG13 are localised and that no widespread methane 'plume' is migrating from the waste.

14.6.13 With respect to carbon dioxide, temporal concentrations exceeding 1.5% are recorded in monitoring locations (LFG1, LFG2, LFG3, LFG6, LFG20 - LFG24). Monitoring locations LFG20 - LFG 24 are located to the east of SENTX , hence, pose no significant risk to the future developments. Peripheral monitoring locations LFG1, LFG2, LFG3 and LFG6 are located on the western side of SENTX and are closest to the future development, however detections remain relatively low and present no evidence of consistent carbon dioxide migration.

14.6.14 From SENT monitoring data, 58 upgradient and downgradient gas probes remain operational as of March 2024 and no significant methane is detected. With respect to carbon dioxide, detection in nearest monitoring wells to TKO 137 (P7 – P9, GP12 & GP15) remain low (<0.5%) and present no evidence of consistent carbon dioxide migration.

14.6.15 As the landfill gas monitoring data confirms occasional elevated above background concentrations of methane and carbon dioxide and correspondingly depleted oxygen concentrations, the SENT and SENTX is considered as a medium category source, as there is potential for gas generation over time, but comprehensive and proven control measures are installed.

Categorisation of Natural and Manmade Pathways

14.6.16 Natural pathways are assessed with reference to the geology of SENT and SENTX and TKO 137 and ground conditions through which landfill gas must pass in order to reach the development. Potential pathways for migration of landfill gas from the SENT and SENTX in TKO 137 comprise only natural features and reclamation fill.

14.6.17 With reference to the *South East New Territories Landfill Extension – Feasibility Study:* Environmental Impact Assessment Report (Agreement No CE10/2005 (EP), it is likely that almost all groundwater flow will be occurring within the TKO 137 fill rather than in the underlying saturated marine or alluvial deposits. Based on records of the ground investigation undertaken as part of the SENTX EIA, the groundwater table is approximately +2.8mPD, leaving an unsaturated thickness of 2.2m. Whilst landfill gas cannot migrate through saturated soil/rock, it is conservatively considered that this permeable fill layer is conducive to landfill gas migration.

14.6.18 The minimum separation between the landfill and the development boundary is 30m, which is the width of the Road L8 and associated pavements. Dependent on the actual separation between the landfill and each development, natural pathways are considered to be "very short / direct" (path length of less than 50m for unsaturated permeable strata), "moderately short/direct" (path length of 50 to 100m for unsaturated permeable soil) or "long/indirect" (path length of 100 to 250m for unsaturated permeable soils).

14.6.19 Manmade pathways are assessed with reference to existing utility connections that may provide a preferential gas migration route from SENT and SENTX to TKO 137.

14.6.20 No direct anthropogenic migration pathways (man-made underground utilities) have been identified connecting the SENT and SENTX to TKO 137 and there are currently no man-made underground utilities in TKO 137, except a box culvert connecting the existing SENT and its

berthing area in TKO 137. However, it is envisaged that utilities along Wan Po Road will be extended to TKO 137 for the future development.

Categorisation of Targets

14.6.21 Whilst foundation construction during development may entail deep excavation where risk of exposure of LFG can increase, construction works would be undertaken by trained workers with risk assessment, safety supervision and implementation of safe construction methodologies acting to minimise and control identified risks. Construction phase targets are classified as Medium Sensitivity.

14.6.22 With reference to the Recommended Outline development Plan (RODP) and **Figure 14.1**, planned land use within 250m of the landfill consultation zone includes the following:

- Government, Institution or Community (G/IC)
- Public Housing Site (RSc)
- Open Space (O)
- Education (E)
- Other Specified Uses (OU)

14.6.23 A detailed landfill gas hazard assessment report shall be prepared in accordance with the LFGHA Guidance Note and submitted to EPD for vetting and approval when the final design details/parameter are available.

14.6.24 Dependent on the actual design for indoor facilities (such as toilets) within Open Spaces (O), these will be likely be classified as Low Sensitivity.

14.6.25 Dependent upon the actual design and usage of buildings within other land uses including public housing, Government, Institution or Community, Amenity, Education and Other Specified Uses such as the Effluent Polishing Plant; these facilities are classified as either High or Medium Sensitivity.

Source-Pathway-Target Analysis

14.6.26 On the basis of the source, pathways and targets identified above, a source-pathway-target analysis has been undertaken and is presented according to EPD's assessment framework in **Table 14.6**.

14.6.27 The overall risk level for the **construction phase** of the Development ranges from **Low** to **Medium**. This classification for the operational phase is intended only as preliminary guidance on the nature of protective works anticipated for the Development, and a more detailed investigation and reassessment at the development stage will allow targeted and more accurate design of protective measures.

14.6.28 The overall risk level for the **operation phase** of the Development ranges from **Low** to **High** dependent on the actual design and usage of Government, Institution or Community, Public Housing Site and Education facilities. For Open Space, the overall risk level for the operational phase ranges from Very Low to Low.

14.6.29 For development categorised as **Medium** and **High** risk, engineering measures (some potentially significant) will be required to reduce risk associated with hazards arising from potential landfill gas migration.

14.6.30 Detailed LFGHA shall be conducted in accordance with the LFGHA Guidance Note during the detailed design stage of the development with appropriate control measures recommended based on the type of buildings/structures proposed, however potential hazard(s) posed by

landfill gas are considered to be surmountable and numerous feasible engineering options exists to mitigate risks identified to acceptable levels.

Table 14.6 Source-Pathway-Target Analysis

Source	Pathway	Target Sensitivity *	Risk Category *
SENT and SENTX : there is potential for gas generation over time, but comprehensive and proven control measures are installed. SENT and SENTX is considered as a **"Medium"** category source	The minimum separation between the landfills and the development is 30m, which is the width of planned Wan Po Road. Depending on the actual separation, pathways are considered to be **"Very short / direct"**, **"Moderately short/direct"** or **"Long/indirect"**.	Construction Phase – Foundation construction during development may entail deep excavation where risk of exposure of LFG can increase. However, construction works would be undertaken by trained workers with risk assessment, safety supervision and implementation of safe construction methodologies acting to mitigate identified risks. Construction Phase targets are classified as Medium Sensitivity.	Source Pathway Receptor linkages classify the overall risk during construction phase to be **"Low" or "Medium"**
		Operation Phase – Open Space (O): Depending on the actual design of indoor facilities (such as toilets), Open Spaces (O) will be classified as Low Sensitivity.	Source Pathway Receptor linkages classify the overall risk to be **"Very Low"** or "**Low"**
		Operation Phase – Government, Institution or Community (G/IC), Public Housing Site (RSc), Education (E): Depending on the actual design and usage of the buildings, all other proposed land use will be classified as either Highly Sensitive or Medium Sensitivity. However, the actual target sensitivity will be dependent on the actual building layout/design.	Source Pathway Receptor linkages classify the overall risk to be **"Low". "Medium" or "High",**
		Other Specified Uses – Effluent Polishing Plant. Target sensitivity will be dependent on the facility design but anticipated to be Medium - High sensitivity.	Source Pathway Receptor linkages classify the overall risk to be **"Medium" or "High"**

* This operation phase classification is intended only as preliminary guidance on the nature of protective works anticipated for the development, and a more detailed investigation and reassessment at the development stage will allow targeted and more accurate design of protective measures.

14.7 Recommended Protection Measures

Protection Measures during Construction

14.7.1 During the construction phase, the risk is classified as “Medium” or “Low”. Safety requirements stated in Chapter 8 - Hazards Arising During Construction of the LFGHA Guidance Note should be implemented properly during construction phase.

14.7.2 Hazards may arise which are related either to the flammability of landfill gas or to its potentially asphyxiating properties. According to the LFGHA Guidance Note, the following precautions should be followed:

Appointment of a Safety Officer

- A Safety Officer, trained in the use of gas detection equipment and landfill gas-related hazards, should be present on site throughout the ground-works 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:

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

Safety Measures

- 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 excavations. Safety notices should be posted warning of the potential hazards.
- Those staff who work in, or have responsibility for 'at risk' areas, including 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.
- An excavation procedure or code of practice to minimise landfill gas related risk should be devised and carried out by the project proponent.
- 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.
- 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 designated for smoking.
- Welding, flame-cutting or other hot works should be confined to open areas at least 15m from any trench or excavation.
- 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 authorised by the Safety Officer.
- 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 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 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.
- Ground level construction plant should be fitted with vertical exhausts at least 0.6m above ground level and with spark arrestors.

- Any electrical equipment, such as motors and extension cords, should be intrinsically safe.
- During piping assembly or conduiting construction, all valves/seals should be closed immediately after installation. As construction progresses, all valves/seals should be closed as installed to prevent the migration of gases through the pipeline/conduit. All piping/conduiting should be capped at the end of each working day.
- Mobile offices, equipment stores, mess rooms etc. should be located on an area which has been proven to be gas free (by survey with portable gas detectors) and ongoing monitoring should be carried out to ensure that these areas remain gas free. The use of permanent gas detectors may be appropriate in some circumstances where there is a relatively high risk but for many developments it will be sufficient to have regular monitoring undertaken manually by the safety officer. The particular arrangements to be adopted at a specific site will need to be determined during the risk assessment/design of protection measures.
- Alternatively, such buildings should be raised clear of the ground. If buildings are raised clear of the ground, a minimum, clear separation distance (as measured from the highest point on the ground surface to the underside of the lowest floor joist) should be 500mm.
- During construction, adequate fire extinguishing equipment, fire-resistant clothing and breathing apparatus (BA) sets should be made available on site.
- Fire drills should be organised at not less than six monthly intervals.
- The developer should formulate a health and safety policy, standards and instructions for site personnel to follow.

Monitoring

- 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 monitoring frequency and areas to be monitored should be set down prior to commencement of groundworks either by the Safety Officer or by an appropriately 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.

Monitoring of excavations

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

- 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 through the working day whilst workers are 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.

Actions In The Event Of Gas Being Detected

- Depending on the results of the measurements of landfill gas, actions required will vary and should be set down by the Safety Officer or other appropriately qualified person.

The actions required in the event of landfill gas being detected in excavated/ confined area are as follows;

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	Prohibit hot works Ventilate to restore methane to < 10% LEL
	> 20% LEL	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%

Specific Advice Relating to the Drilling of Boreholes within the Consultation Zone

- Drilling should only proceed with adequate care and precautions against the potential hazards which may be encountered.
- Before site works begin, the drilling contractor should devise a 'method-of-working' statement covering all normal and emergency procedures and the site supervisor and all operatives must be familiar with this statement.

The method-of-working statement should cover, inter alia:

- number of operatives;
- experience and special skills of operatives;
- normal method of operations;
- emergency procedures, including firefighting;
- supervisors' responsibilities;
- storage and use of safety equipment;
- safety procedures; and
- signs, barriers and guarding.

Safety Equipment and Clothing

An intrinsically safe, portable methane meter should be available at all times. Other safety equipment should include:

- no smoking signs, to be placed prominently adjacent to the drilling area;
- portable fire extinguisher;
- high visibility clothing to be worn by all drilling operatives; and
- additional protective clothing should include stout industrial boots (with steel toe cap
- and insole), plastic hard hats, heavy duty waterproof industrial gloves.

Working Procedures

- On arrival at site the drilling rig should be set-up up-wind of the borehole location, 'No smoking' signs set out and the working area should be roped or coned-off.
- At the end of the working day all vehicles, the drilling rig and any hand tools should be hosed down with clean water to remove deposits of excavated spoil.
- Suitable guards or barriers should be placed around the excavation or borehole to prevent access by unauthorised persons.

Safety Procedures

- One person should be present at all times during drilling operations, with the sole responsibility of assuring the observance of all safety procedures. This person should be trained in the use of all recommended safety equipment.
- Smoking should be prohibited within 15 metres of a boring or excavation at any locations within the Consultation Zone.
- For large diameter boreholes, a working platform should be placed over the hole which will prevent accidental entry into the hole by operatives.
- No worker should be allowed to work alone at any time near the edge of the well under construction. Another worker should always be present, beyond the area considered to be subject to the possible effects of landfill gas or cave-in.
- Periodically during the well construction, the work areas should be monitored for levels of methane.
- If the well construction is not completed by the end of the working day, the hole should be covered with a plate of sufficient overlap to prevent access to the hole and sufficient structural strength to support expected loads. The plate should be weighted down to discourage removal and, on landfill sites, the edges of the plate should be covered with sufficient depth of wet soil to prevent escape of gas.
- All pipes or casings should be capped at the end of each working day.
- Engine-driven rigs should have vertical exhaust stacks discharging not less than 1.5m above ground level and should have overspeed limits to prevent engine run away on ingested gas.
- Diesel engine air-intakes should also be located not less than 1.5m above ground level.
- Any electrical equipment should be intrinsically safe.
- Additional safety advice and guidance may be found in 'Investigation into Establishing an Effective Practical Safe Working Practice When Drilling in Landfill Sites and Adjacent Areas and Contaminated Ground and Adjacent Areas' compiled by the British Drilling Association (1993).

Utility Protection Design Measures (applicable to construction phase)

- For all service runs, the aim should be to provide a protective barrier at the point where the trenches pass through the perimeter of the consultation zone such that trench excavations do not form a route for gas migration to or from unprotected utilities beyond the Consultation Zone.
- For service runs within the consultation zone these may remain “unprotected” as the general public may not have access to such underground features, however ducts, manholes and chambers to utility services within the consultation zone should be sealed from the surrounding ground to prevent gas entry and provided with vented covers to allow any gas that enters to dissipate to atmosphere.
- The service run should be designated as a “special route” and utility companies should be informed to that effect so that they may implement precautionary measures. 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 (Labor Department, Hong Kong).
- Above ground (minor) termination features e.g. transformers, gas kiosks and telecom cabinets should be considered to be “buildings” and should be protected by e.g. membrane barriers to minimise the possibility of gas ingress.
- Any future works such as maintenance or extensions should be subject to the recommendations specified in the LFGHA Guidance Note.

Protection Measures during Operation

14.7.3 "Passive" and "Active" control measures should be considered for developments categorised as "Medium" or "High" Risk respectively. For developments of which the landfill gas risk is categorised as "Low", some precautionary measures may be required to ensure that the planned development is safe, however the measures which depend on the actual design of indoor facilities if any (such as toilets).

Passive Control Measures

14.7.4 In accordance with the LFGHA Guidance Note, "passive" control measures/systems to reduce the risk of gas ingress to proposed building structures with ground level or subsurface levels include:

- Gas-resistant polymeric membranes which can be incorporated into floor or wall construction as a continuous sealed layer. 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;
- Synthetic composite geotextiles which provide a free-venting cellular structure and provide preferential pathways for release of gas.

14.7.5 Passive control measures may be used in low and medium risk situations where gas emissions are expected to be at relatively low rates and concentrations and venting to atmosphere is unlikely to cause a hazard or nuisance due to the low concentration or high dilution which will occur. Passive control measures are generally preferable, if the rates of gas emission are not too high, because they do not require as much maintenance or monitoring as active control systems.

Active Control Measures

14.7.6 "Active" control/systems can also be considered to be employed as a precautionary measure, in situations where there is a sensitive target to protect. "Active" control measures/systems include the following:

- A void under the structure, which is continuously ventilated by mechanical fans, such that any emissions of gas from the ground are mixed and diluted in the air flow before discharge to atmosphere;
- Construction of a granular layer incorporating perforated collector pipes which is continuously ventilated by mechanical 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;
- Creation of a positive pressure zone below the building structure by injection of air from a blower into the granular layer; and
- Creation of positive air pressure zones within building structures to counteract possible leakage of gas into the building from the ground.

- For any newly built permanent building structures (e.g. basement plant rooms in buildings into which operators frequently enter) within the 250m Consultation Zone, forced ventilation should be installed in such rooms or buildings. Gas detection systems with audible alarm should also be installed in such area of the development in order to monitor internal spaces inside buildings. The gas detection systems should be calibrated and maintained at regular basis in according to the recommendation of manufacturer's instruction. The operators at the development should also make sure that the gas detection systems are always in functions during the operational phase of the development.

14.7.7 "Active" control should always be applied in conjunction with passive barriers such as membranes 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" controls are usually required for sites where gas has been measured in the ground at or close to the sites and buildings are close to the source of gas.

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

14.7.8 Any service voids, manholes or chambers which are 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 Safety Guide to Working in Confined Spaces should be followed to ensure compliance with the Regulation.

14.7.9 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. All the access to the confined spaces would be restricted only to authorised personnel who should be aware of the LFG hazard. No member of the general public should be permitted or allowed to access these confined spaces, manholes or inspection chambers. The safety measures recommended in Chapter 8 - Hazards Arising During Construction of the LFGHA Guidance Note should also be strictly followed.

Detailed Landfill Gas Hazard Assessment

14.7.10 Project proponents of future developments located within the 250m landfill gas consultation zone shall conduct a detailed LFGHA following the LFGHA Guidance Note issued by EPD at detailed design stage to re-confirm the landfill gas hazard risk and undertake detailed design of the mitigation measures, as appropriate.

14.7.11 Subjected to the detailed design, monitoring during operation phase, if required, shall follow the criteria established in the EM&A manual for ensuring continued performance of the implemented precautionary/ protection measures. The detailed LFGHA covering the design of specific protection measures; and the operational phase monitoring programme should be prepared to the satisfaction of EPD following the prevailing mechanism at detailed design stage.

14.7.12 Overall, no insurmountable landfill gas hazard is anticipated. Provided that the operation phase protection and control measures are properly designed and implemented, safety will be safeguard and landfill gas hazard risk could be mitigated to acceptable level.

14.8 Environmental Monitoring and Audit

14.8.1 For construction and operation within the landfill Consultation Zone, to ensure the continued performance of implemented precautionary / protection measures proposed; the maintenance programme/arrangement shall be detailed in the EM&A manual and follow the requirements specified in **Section 14.7** which will reflect in the detailed design.

14.9 Conclusion

14.9.1 A review of the Development Areas indicates landfill gas hazard assessment for TKO 132 is not required as the development resides beyond 250m of any landfill.

14.9.2 The northeastern quadrant of TKO 137 lies within the Consultation Zone for the SENT and SENTX, therefore landfill gas hazard assessment is required for those development areas of TKO 137 situated within the 250m landfill Consultation Zone.

14.9.3 The overall risk for the construction phase for the Development ranges from Low to Medium. Safety requirements stated in Chapter 8 - Hazards Arising During Construction of the LFGHA Guidance Note should be implemented properly during construction phase.

14.9.4 For the operational phase, depending on the actual design and usage of the buildings, the overall risk levels for operation phase for Open Space ranges from Very Low to Low and the overall risk levels for operation phase for Government, Institution or Community, Public Housing Site, Education and Other Specified Uses ranges from Low to High. “Passive” or “active” control measures should be considered for development area with “Medium” or “High” Risk respectively.

14.9.5 Detailed LFGHA, shall be conducted in accordance with the LFGHA Guidance Note, during the detailed design stage of the development with appropriate control measures recommended based on the type of buildings/structures proposed, however potential hazard(s) posed by landfill gas are considered to be surmountable and numerous feasible engineering options exists to mitigate any unacceptable risk identified to acceptable levels.

14.9.6 Provided that the construction and operational phase mitigation measures/ protection controls are appropriately designed and properly implemented, safety will be safeguarded and risk associated with landfill gas migration and potential hazard will be adequately controlled.