5.0 Landfill Gas Hazard assessment

5.1 Introduction

Background

The location of the Project Site is shown in Figure 5.1. As a portion of the Project Site falls within the 250m Consultation Zone of Sai Tso Wan Landfill, a qualitative landfill gas (LFG) hazard assessment is required in accordance with *ProPECC PN 3/96 - Landfill Gas Hazard Assessment for Development Adjacent to Landfill* and *Landfill Gas Hazard Assessment - Guidance Note (EPD/TR8/97)*.

For the purpose of this EIA report, a qualitative assessment of the potential hazard posed by landfill gas (generated from Sai Tso Wan Landfill) to the concerned area of the Project Site will be summarized.

5.2 Landfill Gas Generation

Infiltration of water into a landfill will cause gases to be generated as biochemical decomposition of organic materials occurs. When biodegradation starts, the oxygen is soon exhausted, and the landfill becomes anaerobic as the replenishment of free oxygen is not available.

Anaerobic decomposition of the organic waste can be simplified into two basic stages. In the first stage, the complex organic materials in the tipped waste are biodegraded into simpler organic materials which are typified by salts of acetic acid, propionic acid, pyruvic acid or other simple organic acids and alcohol. The second stage of anaerobic decomposition is methane formation or methanogenesis. Methanogenic bacteria utilize the end products from the first stage and yield methane and carbon dioxide. These two gases are the most abundant of LFG, which may also include gases such as hydrogen sulphide, hydrogen and nitrogen.

The generation of LFG is dependent on environmental conditions and waste characteristics, including temperature, pH, substrate availability, moisture content, and oxygen content. These factors are influenced by the configuration of the landfill site, the characteristics of the waste and the way in which the waste is placed, the restoration of the landfill, and the provision of landfill gas and leachate management systems.

A typical composition of LFG is about 60% (v/v) methane and 40% (v/v) carbon dioxide, although these percentages can vary widely depending on the site conditions. Also present are trace quantities of hydrogen sulphide, nitrogen and gaseous hydrocarbons such as hexane, octane and heptane.

5.3 Landfill Gas Hazard

Methane, colourless and odourless, has a low solubility in water and generally has little influence over groundwater quality. It occurs in gaseous form in the unsaturated zone. The gas, which is an asphyxiant, is highly flammable and can be explosive when all the following conditions exist at the same time:

1) its concentration in air is between 5% (v/v) (Lower Explosive Limit (LEL)) and 15% (v/v) (Upper Explosive Limit (UEL));

2) the gas is in a confined space; and

3) a source of ignition is present.

Control limits are usually set at levels that provide a margin of safety 10 - 20% of the LEL (i.e. 0.5 - 1% (v/v) methane).

Carbon dioxide is colourless, odourless, and non-combustible. This gas is also an asphyxiant. A concentration of 3% (v/v) in air can cause headaches and difficulty in breathing to human beings. Symptoms become severe at concentration above 5% (v/v) and unconsciousness can result at 10% (v/v). Concentrations above 15% (v/v) may be fatal. As for methane, control limits are often set at levels that provide a margin of safety. For instance, occupational limits for carbon dioxide in the UK are 0.5% (v/v) 8-hour time-weighted average, and 1.5% (v/v) 15-minute time-weighted average.

LFG migration can be a dangerous hazard because of the combustible and in some cases explosive nature of the methane; and also the asphyxiant nature of the carbon dioxide.

The principal cause of LFG migration is pressure gradients within the landfill which result in gas pressures within the fill being relieved by escape of the gas along paths of least resistance (i.e. greatest pressure loss). Diffusion is a minor mechanism of gas movement. Since movement under pressure is not dependent on concentration, gas concentrations do not necessarily fall in proportion to distance from the landfill. It is therefore possible for high concentrations of gas to be found several hundred metres away from a landfill where pathways of low resistance permit migration to occur.

Methane is less dense than air, and carbon dioxide is denser than air. A gas containing 54% methane and 46% carbon dioxide is nearly as dense as air. Therefore, LFG can be more or less as buoyant as air, depending on its composition. Consequently, it is dangerous to assume that LFG will always rise. When it is denser than air it can accumulate at low levels and persist unless forced to move through air movements or pressure build-up.

LFG has the potential to cause fire, explosion or asphyxiation if it migrates and accumulates in confined space such as building basements, underground car parks, lift shafts, pumping stations, and maintenance chambers. For the same reasons, temporary structures such as site huts and any other unventilated enclosures erected during construction stage are also subject to LFG 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.

The potential hazards that may arise during the construction phase of this project include fires and explosions, asphyxiation of personnel and toxicity effects.

5.4 Description of the Environment

Project Site Information

The portion of the Project Site that falls within the 250m Consultation Zone of the Sai Tso Wan Landfill includes the Lei Yue Mun Road/Kai Tin Road roundabout and the segment of Lei Yue Mun Road to the northwest of the roundabout.

The main works within the concerned areas of the Project Site include constructing a segment of the underpass, and a pedestrian footbridge (crossing the junction of Lei Yue Mun Road and Kai Tin Road). Of these two items, the segment of the underpass is in the closest proximity to the Sai Tso Wan Landfill.

Sai Tso Wan Landfill Information

Landfill Site Layout

Sai Tso Wan Landfill is a valley-infill type landfill and is situated at Cha Kwo Ling to the south of the Sceneway Garden residential development. The landfill has an area of about 14 hectares and is composed of a single large platform of triangular shape sloping down on all sides. The landfill has a frontage to Sin Fat Road to the west, north and northeast.

Landfill Site History

Sai Tso Wan Landfill was in operation from 1978 to 1981. In total, approximately 1.6 million tonnes of domestic and commercial waste was deposited in the relative proportions of 40% and 60%, respectively. The maximum thickness of waste in the landfill is about 70 m.

Prior to landfilling, the site was underlain with separate French drains for collection of groundwater and leachate. These drains were constructed above each other and are separated by a polyvinyl chloride (PVC) membrane. Side slopes were sealed with a bitumenised Chunam covering.

The 80mPD platform and its surrounding slopes were provided with a final cover layer with average depths of 7.5m and 3.5m, respectively. The final cover layer consisted of a fairly well graded brown silty sand with a trace of clay and a little fine gravel.

Improvement works for the landfill were undertaken in 1988. The works included the construction of a retaining wall on the earth bund at the western end of the landfill and the placement of further 3m compacted completely decomposed granite (CDG) fill on the slopes to prevent gas migration.

Restoration Works of Sai Tso Wan Landfill

The restoration works for Sai Tso Wan Landfill had commenced in April 1997 and completed in April 1998. The Defect Correction Period (DCP) then commenced in May 1998 and ended in April 1999. The Aftercare Period is from May 1999 onwards.

Prior to the restoration works for Sai Tso Wan Landfill, an active LFG abstraction system comprising of 29 active gas interception and collection wells and a blower/flare facility existed at the landfill site.

The restoration works for the landfill include landfill gas management, landfill gas utilization, groundwater management, surface water management, restoration infrastructure, restoration capping system, landscape restoration and slope stability study.

Some aspects related to LFG hazard are highlighted below.

Landfill Gas Management System

A gas extraction system and a passive gas barrier trench have been in place at the landfill prior to the hand over of the landfill by Hong Kong Landfills Restoration Group. Improvements were made to this original system.

These improvements include the addition of 2 extraction wells, 1 condensate dripleg and 3 control valves. These were added to the original system of 25 extraction wells and 4 condensate driplegs, located within the waste boundary.

The original gas extraction system also included 4 active gas extraction wells and 1 condensate dripleg located outside the barrier trench. Gases from both systems have been routed to an existing on-site flare and gas extraction facility.

Leachate Management System

Prior to the restoration works, the original leachate collection system at Sai Tso Wan Landfill comprised a PVC liner installed on cut-and-fill platforms. A system of sub-surface drains installed above the liner drained leachate from the base of the landfill and discharged to the government foul sewers.

After the restoration works, the leachate is extracted by pumping from extraction wells to a leachate storage/transfer tank installed adjacent to the existing LFG processing plant.

Leachate is collected from the existing collection system for transport by tanker lorry to Jordan Valley Landfill. A centralized leachate treatment plant has been constructed at Jordan Valley Landfill to treat leachate generated at Jordan Valley, Mau Yau Tong Central, Ma Yau Tong West and Sai Tso Wan Landfills. Treated leachate is then discharged to the foul sewer system at Jordan Valley Landfill.

Regular monitoring is conducted at a series of leachate monitoring wells, comprising existing and new wells to monitor compliance levels and leachate quality within the landfill waste. Leachate quality and flow are also monitored at all discharge points.

Groundwater Management System

The groundwater management system consists of water table and quality monitoring at groundwater wells and groundwater discharge points.

Capping System

The existing capping system within Sai Tso Wan Landfill was retained during the restoration works. The capping system comprises varying thickness of final intermediate cover consisting of CDG having coefficient of permeability to water of 10^{-6} to 10^{-7} ms^{-1}.

5.5 Geology and Hydrogeology at Sai Tso Wan Landfill and Project Site

Geology at Sai Tso Wan Landfill and Project Site

According to the geological map *Hong Kong Geological Survey Sheet 11 - Hong Kong and Kowloon*[1], the geologic formation beneath the Lei Yue Mun Road is basalt (minor intrusive igneous rocks of Jurassic-Cretaceous Age) whereas the geological formation beneath the area in between the landfill and the Project Site is megacrystic fine- to medium-grained granite (major intrusive igneous rocks of Jurassic-Cretaceous Age) (Figure 5.2).

Figure 5.2 also reveals that there are two fault lines beneath the concerned areas. Both fault lines run in northwest-southeast direction. One fault line runs through the middle of the landfill and one fault line runs along the Lei Yue Mun Road. Neither of these fault lines runs across the area between the landfill and the Project Site.

Hydrogeology at Sai Tso Wan Landfill and Project Site

According to *Restoration of Urban Landfills – Contract Arrangements (Agreement No. CE 53/92) Technical Note – An Assessment of Environmental Impacts, Monitoring and Audit Requirements* (*June 1995*), the static water table was considered near the base of the landfill, while perched water tables fluctuate within the landfill during and after heavy rain. The perched water tables establish during heavy rainfall, after which they drain sub-horizontally along the intermediate cover seams within the landfill. Furthermore, the groundwater recharge at the landfill is essentially restricted to rainfall infiltration on the top platform and the side-slopes of the landfill.

The average water table at the groundwater monitoring wells installed along the perimeter of the landfill from November 1998 to November 1999 are tabulated in Table 5.1.

Table 5.1 Average water table at monitoring from November 1998 to November 1999

Monitoring well location	Average water table level (mPD)
North of landfill	About 44
Northeast of landfill	About 48
Southeast of landfill	About 55
South of landfill	About 31
Southwest of land	About 41
West of landfill	About 22
Northwest of landfill	About 11

1 Edition 1 (1986), Scale 1:20,000

On the other hand, the average leachate levels at the northwestern, southern and southwestern parts of the central platform of the landfill from November 1998 to November 1999 are approximately 32.5 mPD, 32.6 mPD and 39.8 mPD respectively. Therefore, it can be concluded that within the landfill site, the major groundwater flow is from the southeast to the northwest of the landfill, with minor seepage towards the south.

In view of the topography of the area in between the eastern part of the landfill and the Lei Yue Mun/Kai Tin Road roundabout, the slope of the landfill facing the Lei Yue Mun/Kai Tin Road roundabout is a groundwater divide between the landfill and the Lei Yue Mun Road.

Geological Cross-section between Sai Tso Wan Landfill and Project Site

The geological cross-section between the eastern part of Sai Tso Wan Landfill and the concerned area of the Project Site are provided on Figures 5.3 and 5.4.

5.6 Environmental Legislation, Policies, Standards and Criteria

Although there is no primary legislation covering hazards to development caused by LFG, the EPD have issued two guidance notes regarding LFG hazard assessment - *ProPECC PN 3/96 - Landfill Gas Hazard Assessment for Development Adjacent to Landfill* and *Landfill Gas Hazard Assessment - Guidance Note (EPD/TR8/97)*.

These two guidance notes set out the conditions under which a LFG hazard assessment should be carried out and provide guidance on LFG hazard assessment. These two notes recommend that in general, assessment of LFG hazard is to be required for proposed developments that lie within the 250m Consultation Zone of a landfill.

5.7 Description of Assessment Methodologies

This qualitative LFG hazard assessment was undertaken following the method recommended in *Landfill Gas Hazard Assessment - Guidance Note*. This method is based on the “Source – Pathway – Target” model. The meanings of these three components are as follows:

a) Source – location, nature and likely quantities/ concentrations of LFG which has the potential to affect the development.
b) Pathway – the ground and groundwater conditions, through which LFG must pass in order to reach the development.
c) Target – elements of the development that are sensitive to the effects of LFG.

The LFG source, identified pathway(s), and identified target(s) are then categorized in order to facilitate the assessment process.

5.8 Identification, Prediction and Evaluation of Landfill Gas Hazards

Landfill Gas

According to *Restoration of Urban Landfills – Contract Arrangements (Agreement No. CE 53/92) Technical Note – An Assessment of Environmental Impacts, Monitoring and Audit Requirements (June 1995)*, the landfill gas production rates in 1988, 1994 and 2000 have been calculated to be 3000 m^3h^{-1}, 1800-2300 m^3h^{-1} and 1200-1500 m^3h^{-1}, respectively.

As part of the restoration contract for Sai Tso Wan Landfill, a post-restoration monitoring programme has commenced since April 1997. Monitoring of LFG has been carrying out at the gas probes and monitoring wells installed on-site or close to the perimeter of the landfill. The locations of these gas probes and monitoring wells are shown in Figure 5.5.

The monitoring data of gas probes at DPR16, DPR18, DPR19, G3 and G4 and monitoring wells at GW2, GW3 and GW6 have been assessed. The available monitoring data between April 1997 to November 1999 for these probes/wells have been plotted on graphs in Appendix 5.1. It should be noted that the monitoring wells G3 and G4 are nested well system. Each of them has 3 separate well casings and the depths of well screen in the 3 casings are different.

The plots given in Appendix 5.1 reveal that exceedance of 1% (v/v) methane only occurred at gas probe DPR18 between the period from June 1997 to September 1997. It is understood that this situation had been rectified during the Defects Correction Period. Furthermore, there are currently 8 monitoring wells located along the boundary between Sai Tso Wan Landfill and the Project Site, namely GW2, G3, GW6, G4, DPR19, GW3, DPR18 and DPR16. During the last year (1999), exceedance in the CO_2 limit occurred only at 2 wells (3 exceedances for DPR18 (in September/October 1999) and 2 exceedances for GW6 (in May 1999). In fact, 3 out of the 5 exceedances were only marginal. Therefore, the source of LFG is considered not significant.

Leachate / Groundwater Quality

Under certain circumstances, landfill gas may be transported in solution by leachate or may be generated from the anaerobic degradation of organic compounds in the leachate.

According to the requirements of the Restoration Contract for Sai Tso Wan Landfill, the leachate level within the Sai Tso Wan Landfill shall not rise above 47.0 mPD during the Works and the Aftercare Period (including the Defects Correction Period). The monitoring data for leachate levels from October 1998 to October 1999 reveal that the leachate level at the three leachate monitoring wells within the platform of the landfill, namely CWM1, CWM2 and CWM3, ranged from 30.7 to 33.7 mPD, 32.0 to 33.6 mPD and 39.1 to 40.4 mPD, respectively (Appendix 5.2). In fact, there has been no exceedance in leachate level since the beginning of the Aftercare Period.

During the Aftercare Period (including the Defects Correction Period), the discharge of groundwater and any leachate abstracted from the landfill discharging into foul sewers leading directly into Government sewers or sewage treatment plants shall not exceed the target limits of 2,000 mg/l COD and 200 mg/l Total Kjeldahl Nitrogen as part of the Contract requirements. The respective target limits for discharging into inland and coastal waters are 80 mg/l COD and 20 mg/l Total Kjeldahl Nitrogen.

Leachate quality is currently monitored at the above-mentioned 3 leachate monitoring wells and at a leachate monitoring manhole (MH1) located to the northwest of the landfill. The monitoring data from November 1998 to November 1999 are tabulated in Table 5.2.

Table 5.2 Leachate monitoring data from November 1998 to November 1999

Date	COD (mg/l)				Total Kjeldahl Nitrogen (mg/l)			
	CWM1	CWM2	CWM3	MH1	CWM1	CWM2	CWM3	MH1
Nov 98	---	4200	---	1100-1500	---	4100	---	1100-1300
Dec 98	---	2100	---	1400-1700	---	2400	---	1200-4000
Jan 99	---	---	2400	1300-1400	---	---	1800	1300-1400
Feb 99	---	---	1800	1000-1300	---	---	1800	1400-1500
Mar 99	---	---	2700	1200-1800	---	---	1800	1500-1900
Apr 99	---	---	1800	1300-1600	---	---	1800	1500-1800
May 99	---	---	---	1300-1900	---	---	---	1500-1600
Jun 99	---	---	---	1400-1700	---	---	---	1300-1600
July 99	---	2500	---	100-1700	---	2500	---	160-1500
Aug 99	---	---	---	42-1600	---	---	---	29-1200
Sep 99	---	---	---	43-64	---	---	---	16-59
Oct 99	---	3000	---	69-610	---	2400	---	47-1200
Nov 99	---	---	---	1400-1500	---	---	---	800-1300

The above leachate monitoring data indicate that although the COD level of the raw leachate within the waste exceeded the discharge limit for foul sewage or sewer treatment plants on many occasions, the COD level of the leachate that migrated off-site did not exceed the limit. On the other hand, the Total Kjeldahl Nitrogen (TKN) levels of the leachate within the waste and the leachate that migrated off-site exceeded the discharge limit for foul sewers or sewage treatment plants. Nevertheless, as MH1 is located to the northwest of the landfill and is down gradient of groundwater flow, it is anticipated that the levels of COD and TKN of any leachate that migrated to the east of the landfill would be lower than that at MH1.

Groundwater quality is also currently monitored at eight groundwater monitoring wells of which three are located along the eastern boundary of the landfill, namely GW2, GW3, and GW6. The available data of groundwater quality for these 3 wells are given in Appendix 5.3. The data reveal that the COD and TKN levels of the groundwater at these 3 wells have been below the discharge limits for the past year.

5.9 Migration Pathways

Natural Pathways

The geological formation beneath the landfill essentially comprises completely decomposed granite (immediately below the waste) and granite bedrock. The air permeability of granite is considered relatively low.

Although there is a fault line underlying the landfill site, the orientation of this fault line runs along the southeast-northwest direction, and it neither intersects the Project Site nor extends beyond the landfill site. Therefore, this fault line will not form a natural pathway for landfill gas migration.

Monitoring of off-site LFG migration is currently undertaken at six off-site gas vents installed around the Cha Kwo Ling Tennis Court (CKLTC) at Sin Fat Road (Figure 5.6). Furthermore, monitoring of off-site confined spaces is currently undertaken at three off-site buildings, namely, a storeroom at CKLTC (OSB1), a storeroom at Lam Tin Alliance Church Social Centre for the elderly (OSB2) and the main switch room at CKLTC (OSB3). The locations of these off-site locations are shown in Figure 5.7.

Due to the fact that most of these gas vents and confined spaces are located between the landfill and the Project Site, the available monitoring data at these gas vents are considered appropriate to assess the potential LFG impact at the Project Site. The monitoring data for September 1998 to September 1999 (Appendix 5.4) reveal that no measurable quantities of methane and carbon dioxide have been detected at any these off-site monitoring locations. It is therefore considered that there would not be any significant natural pathways for off-site migration of LFG.

It is known that under certain conditions LFG may dissolve in, and be transported by, groundwater/leachate, and may then be released downstream. However, as mentioned above, the flow direction of groundwater/leachate within the waste of the landfill is towards the northwest of the landfill, rather than towards the Project Site. Therefore, it is considered that there is no pathway (attributed to groundwater/leachate flow) for off-site migration of LFG towards the Project Site.

Man-made Pathways (Utilities)

The plans of utility services for the area between the Sai Tso Wan Landfill and the concerned area of the Project Site are shown in Figure 5.8. It is shown from these figures that there is a segment of gas main (about 50 m long) located near the toe of the slope between the landfill and the northeastern part of the Project Site. In addition, it appears that there are some underground cables connecting the street light poles on Lei Yue Mun Road. However, the orientations of both this gas main segment and the cables run parallel to the alignment of Lei Yue Mun Road, thus do not act as pathways for migration of LFG from the landfill to the concerned area of the Project Site. Therefore, it is considered that there are no man-made pathways link between the landfill and the concerned area of the Project Site.

5.10 Targets

Construction Phase

During the construction phase of the proposed project, excavation will be carried out for the construction of the underpass and utilities. The excavation is considered to be a target with high potential of LFG migration. However, as the deepest excavation will be undertaken at about 15 m below the existing level, it is anticipated that structures such as retaining walls would be constructed around the designed excavated area to prevent the ingress of groundwater into the excavations during the course of the construction of the underpass.

Operation Phase

The underpass to be constructed will be located below the existing level, with the top and bottom of the underpass locating at about 4.5m and 15m below the existing levels respectively. Therefore, it is likely that the underpass would be located at saturated zone, thus, the potential of LFG migration into the interior of the underpass would be low. Furthermore, due to the fact that the underpass will not be an enclosed confined space and the traffic flow will agitate and help to dissipate any gas ingress into the underpass, the risk level of LFG hazard posed to the underpass is considered to be low.

It is anticipated that some service ducts/chambers would be constructed beneath the underpass. However, the access to these confined spaces will be restricted to authorized personnel who should be aware of the LFG hazard, the risk level of these target components is considered to be medium.

5.11 Summary of Qualitative Source-Pathway-Target Analysis

Based upon the available information, a source-pathway-target analysis has been undertaken for the different combinations of source, pathway, and target discussed above, and is summarized in Table 5.3.

Table 5.3 Summary of qualitative source-pathway-target analysis

Source	Pathway	Target	Risk
Landfill gas yield predicted from modelling is relatively low, estimated at 1200-1500 m^3hr^{-1} in 2000. A comprehensive restoration work for Sai Tso Wan Landfill has been undertaken. Gas monitoring data indicate that there were only few exceedances in the CO_2 limit but no exceedance in the 1.0 % methane during the last year (1999). The leachate level within the landfill site is generally low. (*Minor source*)	**Natural pathway** Average distance about 100 m. Geological formation beneath the waste is granite (completely decomposed to bedrock) which has relatively low air permeability. Groundwater flow path towards opposite direction. (*Moderately short / direct pathway*)	**Excavations during construction** Excavations for underpass construction and service ducts. (*High sensitivity target*)	Medium
		Underpass to be constructed The underpass is likely to be lined with waterproof material and submerged by groundwater. (*Low sensitivity target*)	Very low
		Service ducts/chambers to be constructed Service ducts to be constructed beneath the underpass. (*Medium sensitivity target*)	Low
	Man-made pathway (utilities) There are no utilities linking the landfill and the concerned area of the Project Site directly. (*Moderately short / indirect pathway*)	**Excavations during construction** Excavations for underpass construction and service ducts. (*High sensitivity target*)	Medium
		Underpass to be constructed The underpass is likely to be lined with waterproof material and submerged by groundwater. (*Low sensitivity target*)	Very low
		Service ducts/chambers to be constructed Service ducts to be constructed beneath the underpass. (*Medium sensitivity target*)	Low

Table 5.3 Summary of qualitative source-pathway-target analysis (Cont'd)

Source	Pathway	Target	Risk
Leachate from landfill (contaminated groundwater that has the potential to give off flammable gas). (*Minor source*)	Flow beyond vent trench, then outgassing to produce methane in unsaturated soil zone. Leachate should outgas partially, at or before vent trench. (*Moderately long/ indirect pathway*)	**Excavations during construction** Excavations for underpass construction and service ducts. (*High sensitivity target*)	Medium
		Underpass to be constructed The underpass is likely to be lined with waterproof material and submerged by groundwater. (*Low sensitivity target*)	Very Low
		Service ducts/chambers to be constructed Service ducts to be constructed beneath the underpass. (*Medium sensitivity target*)	Low

5.12 Site Categorization

According to *Landfill Gas Hazard Assessment - Guidance Note*, the category is based on the highest level of risk nominated for any of the potential impacts identified. For example, a subject site with four low risks and one medium risk will fall into the category of medium level of risk; and a site with four low risks, two medium risks, and one high risk will fall into the category of high level of risk. However, if four or more different impacts arise in a particular risk category, then the overall risk classification may be considered to be one category higher. For instance, a site with three low risks and four medium risks will fall into the category of high level of risk.

In this assessment, there are three "medium", three "low", and three "very low". Therefore, the overall risk level of the development site is considered to be **Medium**.

As suggested in the guidance note, some protection measures will be required to protect a proposed development of medium level of risk. Recommendations for protection measures to minimize the LFG hazard at the concerned area of the Project Site are proposed and presented in the following section.

5.13 Recommendations for Protection Measures

Construction Phase

All relevant workers should be briefed with LFG hazard and be aware of the potential presence of LFG in excavations.

Smoking, naked flames and other sources of ignition should be prohibited within 15m of any excavations. Signs such as 'No Smoking' and 'No Naked Flame' should be in place in the vicinity of excavations.

Hot works such as welding and flame-cutting should only be carried out at open areas that are at 15m or more away from any excavations unless these are controlled by a 'Permit to Work' procedure which is authorized by a Safety Officer.

All electrical equipment to be used in excavations should be intrinsically safe.

Adequate fire extinguisher, fire-resistant clothing and breathing apparatus should be provided on site.

For working in excavations deeper than 300 mm, monitoring of methane, carbon dioxide and oxygen should be undertaken by a Safety Officer using suitable calibrated gas detector(s). The monitoring schedule is presented in Table 5.4.

Table 5.4 Monitoring schedule for working in excavations

Depth of excavation	Monitoring schedule
Between 300 mm and 1 m	1) Directly upon completion of excavation; 2) Prior to each entry to excavation; and 3) Periodically throughout the working period while workers are in the excavation (the frequency to be determined by the Safety Officer).
More than 1 m	1) At ground surface prior to excavation work; 2) Directly upon completion of excavation; 3) Prior to each entry to excavation; and 4) Periodically throughout the working period while workers are in the excavation (the frequency to be determined by the Safety Officer).

Appropriate action(s) should be taken according to the Action Plan presented in Table 5.5.

Table 5.5 Action Plan for monitoring for working in excavations

Parameter	Monitoring results	Appropriate action
Methane	> 0.5 % (v/v) (i.e. >10 % LEL)	• Prohibit all hot works inside excavation; and • Ventilate to restore methane to < 0.5 % (v/v).
	> 1.0 % (v/v) (i.e. >20 % LEL)	• Prohibit entry to excavation or evacuate personnel and stop work; • Increase ventilation to restore methane to < 0.5 % (v/v); and • Ordinary breathing apparatus should be used when entering the excavation.
Carbon dioxide	> 0.5 %	Ventilate to restore carbon dioxide to < 0.5 %.
	> 1.5 %	• Prohibit entry to excavation or evacuate personnel and stop work; • Increase ventilation to restore carbon dioxide to < 0.5 %; and • Ordinary breathing apparatus should be used when entering the excavation.
Oxygen	< 19 %	Ventilate to restore oxygen to > 19 %.
	< 18 %	• Prohibit entry to excavation or evacuate personnel and stop work; • Increase ventilation to restore oxygen to > 19 %; and • Ordinary breathing apparatus should be used when entering the excavation.

The above mentioned protection measures including the monitoring schedule and action plan must be incorporated into Contract Documentation.

Operation Phase

As mentioned above, the LFG hazard posed to the underpass is low, therefore, recommendations on protection measures are only made with regard to the maintenance works to be undertaken at the service ducts/chambers constructed/installed beneath the underpass. These measures are presented below.

Personnel (including workers) of relevant service departments/companies should be advised of the potential presence of LFG in subsurface and should take appropriate precautionary measures in accordance with the practice of their departments/companies.

Smoking, naked flames and other sources of ignition should be prohibited within 15 m of any service ducts/chambers. Signs such as ‘No Smoking’ and ‘No Naked Flame’ should be in place in the vicinity of the service ducts/chambers.

Hot works such as welding and flame-cutting should only be carried out at open areas that are at 15 m or more away from any service ducts/chambers unless these are controlled by a ‘Permit to Work’ procedure which is authorized by a Safety Officer or an authorized qualified person.

All electrical equipment to be used in service ducts/chambers should be intrinsically safe.

Monitoring of methane, carbon dioxide and oxygen should be undertaken by a Safety Officer or an authorized qualified person using suitable calibrated gas detector(s) prior to each entry to any service ducts/chambers and periodically throughout the working period while workers are in the service ducts/chambers. The frequency of the periodic monitoring is to be determined by a Safety Officer or an authorized qualified person.

Appropriate action(s) should be taken according to the Action Plan presented in Table 5.6.

Table 5.6 Action plan for monitoring for maintenance works at service ducts/chambers

Parameter	Monitoring results	Appropriate action
Methane	> 0.5 % (v/v) (i.e. > 10 % LEL)	• Prohibit all hot works inside service ducts/chambers; and • Ventilate to restore methane to < 0.5 % (v/v).
	> 1.0 % (v/v) (i.e. > 20 % LEL)	• Prohibit entry to service ducts/chambers or evacuate personnel and stop work; and • Increase ventilation to restore methane to < 0.5 % (v/v).
Carbon dioxide	> 0.5 %	Ventilate to restore carbon dioxide to < 0.5 %.
	> 1.5 %	• Prohibit entry to service ducts/chambers or evacuate personnel and stop work; and • Increase ventilation to restore carbon dioxide to < 0.5 %.
Oxygen	< 19 %	Ventilate to restore oxygen to > 19 %.
	< 18 %	• Prohibit entry to service ducts/chambers or evacuate personnel and stop work; and • Increase ventilation to restore oxygen to > 19 %.

The above mentioned protection measures including the monitoring schedule and action plan must be incorporated into relevant documents (e.g. Letter of Assurance).