

Introduction

7.1 In describing the planning stage (Stage 1), in [Section 4](#) of this Guidance Note, a series of generic protection measures were described for each of the five different categories of development site. Whilst these generic groups will be helpful in forming an early indication of the nature of protection required for the development, they should not be seen to be absolute requirements. On the basis of detailed site investigation and revised risk assessment, specific protection measures can then be designed which are directly related to the targets identified as being at risk in the assessment. A flow chart for procedures at this stage is given on [Figure 7.1](#).

Design Objectives

7.2 It is important when designing gas protection measures to establish a set of objectives which must be achieved by the final design. The gas protection measures may be located on the boundary of the development site closest to the landfill (to prevent gas migration into the area of the development), at the buildings or at both locations.

7.3 Control of landfill gas and leachate within landfills is the subject of detailed advice already available in, for example, Waste Management Paper 27 (UK HM Inspectorate of Pollution, 1991) and Guidelines for the Safe Control and Utilisation of Landfill Gas (UK Department of Trade and Industry et al 1993). The reader is referred to these documents for information and may consider the relevance of the guidance to the circumstances at their development.

7.4 A reasonable set of objectives for design of building protection may be:

- In terms of methane and carbon dioxide hazards, to exclude completely landfill gas from all buildings, services, ducts and enclosed spaces.
- To design sufficient gas control methods to facilitate successful operation of the development throughout the remaining gas producing lifetime of the landfill site.
- To use a set of control systems which are simplest and require the least maintenance to

achieve the above objectives.

Multiple System Design

7.5 In order to meet the general design objectives and to provide "sufficient gas control methods", it will generally be necessary to have more than one system of control to ensure that landfill gas does not affect the development. This is the basis of the concept of "multiple system" design. The number and type of "systems" provided is related to the perceived degree of risk from landfill gas to the development. The risk will depend on the nature of the development itself and will be different for, for example, buildings, car parks and landscaped areas. The design of the "systems" is carried out on the basis of each being able to stand in its own right as a means of controlling gas.

Site Specific Design Measures

7.6 It is inappropriate for this Guidance Note to be prescriptive regarding the detail of gas protection measures. However, the types of measures which can be adopted are described below in relation to the generic terms set out in [Section 4](#) and *Table 4.2*. Selection of protection measures must be based upon the actual risk identified and should be designed to reduce the risk to a normally acceptable (or background) level.

7.7 Sketches showing the general concepts of the various types of gas protection measures and drawings of typical design details are provided in *Figures 7.2 to 7.9*. Drawings of typical design details for protection of services, are included in [Annex B](#).

General Protection Measures

7.8 One approach to the protection of buildings against landfill gas ingress is to provide measures which prevent gas entering the ground on which the buildings are to be constructed. This approach has the advantage that it is largely independent of the design of the buildings, or their foundations, and also protects services running through the same area of land as the development.

Passive Systems (Gas Barriers and Vents)

7.9 The most common way of preventing gas from entering an area of ground is to set a

'gas barrier' into the ground which is either keyed into low permeability strata or extends at least 1 metre below the lowest groundwater level.

7.10 Any gas barriers used for this purpose should be engineered to be effectively impermeable to gas transport and, as such, for natural material barriers (for example soil bentonite mixes) the permeability (hydraulic conductivity) should be 10^{-9} ms^{-1} or lower and for membrane liners the hydraulic conductivity should be 10^{-12} ms^{-1} or lower. The difference in these values reflects the relative thickness of a soil-bentonite filled trench compared with a membrane lined trench, which is generally three orders of magnitude.

7.11 Barriers using membranes, often called 'Flexible Membrane Liners' (FMLs), may utilise polyethylene (low or medium density), asphaltic composites or other polymeric materials which can be demonstrated to possess a long-term stability which will guarantee a lifetime of at least 30 years.

7.12 The presence of a gas barrier to the movement of gas may lead to a gradual build up of gas on the landfill side of the barrier if the gas migration pathway is covered by low permeability materials. To relieve the potential build up of gas, it may be necessary to install additional measures for venting the gas such as trenches filled with no-fines, granular material, such as gravel, connected to venting pipes which will provide a preferential pathway for the release of gas to atmosphere. An outline of this type of protection measure is shown on [Figure 7.2](#) and a more detailed cross-section of a typical design is presented on [Figure 7.3](#).

7.13 The current level of understanding of gas transport in soils around landfill sites does not allow rigorous analysis and consequently there are no 'design equations' for cut-off barrier specifications. **It is therefore essential to seek expert advice before finalising the design detail of any cut-off barrier.**

Active Systems

7.14 Active systems for preventing gas entering an area of land usually comprise a series of vertical wells arranged in a line across the route of gas migration. By applying suction to the wells gas is drawn out of the ground and gas which is migrating horizontally towards the development site is intercepted. In practice, such systems are generally not employed, unless there are substantial volumes of gas migrating through the ground, because there are a number of potential drawbacks to the method as follows:

- By applying suction to the ground at the development site, gas will tend to be drawn away from the landfill site and encouraged to migrate laterally into the ground outside the landfill. This goes against the general philosophy of landfill gas control which is to contain the gas within the landfill site. (Installation of wells within the waste, however, is a commonly and successfully used technique for controlling the gas at source - see UK HM Inspectorate of Pollution 1991, UK Department of Trade and Industry et al 1993).
- Such systems have to be carefully controlled on an ongoing basis (eg. amount of suction applied to each well). As well as being expensive to install they are therefore expensive to maintain.
- Being mechanical systems they are prone to failure.

7.15 The alternative active control scheme of injecting an inert gas into the ground to create a positive pressure in order to reduce migration and cause dilution of the landfill gas is unproven and generally not used. The technique suffers most of the same problems as active extraction with the added complication, cost and uncertainties of introducing the inert gas into the ground.

7.16 Outlines of these two types of active protection measure are shown on [Figure 7.4](#).

Gas Monitoring

7.17 With either the passive or active systems described above it is usual to install monitoring wells into the ground on the development side of the barrier or extraction wells. These are used to measure the concentrations of methane and carbon dioxide within the ground and hence determine the effectiveness of the measures in preventing landfill gas migration.

Building Protection Design Measures

7.18 Building design measures can be both passive, meaning they rely on natural air movement to prevent gas build-up, or active, meaning they require energy input to mechanically move air to protect against gas build-up.

Passive Systems

7.19 Passive control measures for buildings include the following:

- 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.

7.20 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.

7.21 The general principle of passive sub-floor venting is shown on [Figure 7.5\(a\)](#) and typical design details for flexible membrane protection measures are shown on [Figure 7.6](#).

Active Systems

7.22 Active control measures are employed where the rates of gas emission are too high to rely on passive ventilation or in particular circumstances where, for example, there is a sensitive target to protect. Active control measures include the following.

- A void under the structure, as discussed for passive control, but which is continuously ventilated by a fan, such that any emissions of gas from the ground are mixed and diluted in the air flow before discharge to atmosphere. The rate of ventilation is

usually expressed in terms of the number of air changes (volume of the void) per hour and is designed to ensure that, based on the estimated rate at which gas will enter the void, the landfill gas will be diluted to safe concentrations. Discharge to atmosphere usually takes place above the eaves level of the building or, in the case of high rise structures, at a minimum height of 10 metres above ground and away from air intakes to the building.

- Construction of a granular layer incorporating perforated collector pipes which is continually ventilated by a fan, such that any emissions of gas from the ground are drawn towards the end of the pipes and diluted in the air flow before discharge to atmosphere above the eaves level of the building, or in the case of high rise structures, at a minimum height of 10 metres above ground and away from air intakes to the building.
- Creation of a positive pressure zone below the building structure by injection of air from a blower into the granular layer.
- Creation of positive air pressure zones within building structures to counteract possible leakage of gas into the building from the ground.

7.23 The general principle of active sub-floor ventilation is shown in [Figure 7.5\(b\)](#).

7.24 Active control measures should always be used 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 systems are normally required for high risk sites where gas has been measured in the ground at or close to the development site, and buildings are close to the source of gas.

Gas Detection System

7.25 Gas detection systems include the following:

- A series of sensors located in appropriate positions within a structure where gas has the potential to accumulate eg. near to service entries, in unventilated basements, cupboards or ducts. The sensors detect flammable gas by the catalytic oxidation or infra-red principles, and pass data back to a control panel by electrical cabling. The control panel can be set to have two triggers activating alarms, and may also be linked

by telemetry to off-site offices. A schematic of a typical gas detection system is presented in [Figure 7.7](#). The sensors can also be used to activate fans, or increase speed of fans, in active gas control schemes.

- A series of sampling tubes which are located in appropriate positions (see above) and run back to a single measurement station operating on infra-red measurement principles. A pump automatically draws samples of air/gas along each tube in a pre-set pattern such that measurements of flammable and/or other gases (such as carbon dioxide) can be taken at regular and frequent intervals. Triggers, alarms and telemetry systems can be incorporated.
- Manual monitoring can be undertaken using a range of portable instruments. Instruments used in areas where flammable gas may be present should be intrinsically safe.

7.26 Gas detection systems should only be proposed where there is an organisation involved in the long-term use of the development which can be relied upon to maintain and calibrate the system on a regular basis. The systems can be used in three ways:

- as a means of monitoring the amount of gas being extracted from below a building and initiating actions such as an increase in ventilation in the event of rising gas concentrations;
- as a final line of defence in detecting gas which has, by whatever means, by-passed other protective measures; and
- as a means of demonstrating the effectiveness of gas protection measures.

7.27 Where a detection system is used as a final defence, it must be ensured that appropriate emergency actions, to be taken in the event of the trigger levels being exceeded, are specified. These should include procedures for evacuation if necessary.

Maintenance of Control Measures

7.28 Fundamental to the success of gas protection measures is the means by which they are monitored, managed and maintained, and thus all designs must be accompanied by a statement or set of procedures showing how the measures proposed can be confidently expected to operate satisfactorily for the duration of the potential gas-producing lifetime of

the landfill.

Design Measures for Sub-Surface Building Services

7.29 Whilst the design of the development is the responsibility of the project proponent, there will be an interface with the utility companies, and the Professional Person should liaise with them about the gas protection measures being implemented for the development, particularly with respect to service entries and excavations for cable/pipe laying. The utility company should also ensure that their works, both feeding to the development site and in roads passing by, are protected from landfill gas and that their trench excavations do not form a route for gas migration.

General

7.30 Protection measures applied to service conduits should not be considered in isolation and it is essential that an integrated approach is adopted in which gas protection of the building (or development) is formulated in conjunction with the service conduits. However, there are a number of generic protection measures which may be applied to service conduits. The choice and exact details of any particular measures used for services must be considered in conjunction with the primary building protection strategy as discussed above.

7.31 The Professional Person's attention is drawn to the need to consult with Government and relevant utility companies prior to specification of the gas protection measures; including, but not limited to:

- Electricity supply utilities;
- Hong Kong and China Gas Co;
- Water Supplies Department; and
- Drainage Services Department.

7.32 Attention is also drawn to developments which may be located outside the consultation zone but which have service runs which pass through the zone. Under these conditions, whilst the building development itself falls outside the requirements of the Guidance Note, the service runs and any construction work which involves excavation deeper than 300mm which is located in the Consultation Zone should have some form of protection measures.

7.33 Therefore, the advice which follows applies equally to both service installations for

developments within the Consultation Zone and also to service conduits and runs which are located within the Consultation Zone but which feed building developments located outside the Consultation Zone. Additional recommendations, specific to the case of service conduits which pass through the Consultation Zone, are also presented.

7.34 Basically, there are three generic measures which may be employed, as follows:

- barriers;
- vents; and
- location of the service utilities outside the potential gas migration pathway.

7.35 A general discussion on each of these types of protection measure is presented below and more detailed information is provided in [Annex B](#).

Generic Protection Measures

Gas Barriers

7.36 As for barriers used to prevent movement of gas through the ground, use may be made of clay (or clay-rich soils), bentonite or polymeric membranes (such as HDPE). A gas barrier used to prevent movement of gas through services may form part of a more extensive barrier to prevent general migration towards the development (see above). The design detail at the point where the service penetrates the membrane is important and, in the case of HDPE membranes, pre-formed shrouds are often available.

7.37 A schematic of a natural material cutoff barrier, including sealing of a service trench is shown in [Figure 7.8](#) and a schematic for an HDPE flexible membrane cut-off is shown in [Figure 7.9](#).

7.38 In the case of water pipes and sewers which are not always fully filled, water traps, such as U-bends, should be provided to effectively seal off the conduit and prevent gas-phase transport. Further discussion on the measures which may be applied to water pipes and those which may be used to prevent the ingress of gas into a building via the interface between a pipe and the backfilled soil are discussed in [Annex B](#).

Gas Vents

7.39 Vent pipes or gridded manhole covers may be used to avoid build-up of gas in

underground utilities manholes. Venting stacks may be built into inspection chambers or connected to collection pipes within high permeability drainage layers adjacent to gas barriers. The various types of venting arrangement are discussed further in [Annex B](#).

7.40 Under all circumstances, due to the possible accumulation of gas, care will be needed in accessing any manhole chambers, especially those which are not fitted with vents and the safety procedures detailed below must be rigidly followed.

Location of Service Entry Points Above Ground

7.41 In some cases it is possible to route service entries into a building above ground level, thereby providing a discontinuity in the gas migration pathway and thus eliminating the risk of gas entry to the building interior. Further details, including means of overcoming potential architectural constraints of this approach, are presented in [Annex B](#).

Service Conduits Which Pass Through the Consultation Zone

7.42 In addition to the general guidance given above, the following recommendations apply to service conduits which pass through the Consultation Zone with connections to developments outside the Zone:

- For all such service runs, the aim should be to provide a protection barrier located at the point (or points) where the trench passes through the perimeter of the Consultation Zone.
- The service runs through the Consultation Zone may remain 'unprotected' since the risks will be minimised by the protection measures installed at the perimeter of the Consultation Zone and because the general public do not have access to such underground features.
- The service run should be designated as a 'special route' and the utility companies should be informed to that effect so that they may implement precautionary measures (see below).
- Any future works such as maintenance or extension should be subject to the recommendations specified in this Guidance Note.
- Any above ground (minor) termination features, such as telecom cabinets, should be

considered to be 'buildings' and should be protected by, for example, membrane barriers to minimise the possibility of gas ingress.

7.43 Typical details of the measures required for services which pass through a Consultation Zone are shown in [Annex B](#).

Guidance for Entry Into Manholes and Chambers

7.44 Any chamber, manhole or culvert which is large enough to permit access to personnel should be subject to entry safety procedures. Such work in confined spaces is controlled by the Factories and Industrial Undertakings (Confined Spaces) Regulations of the Factories and Industrial Undertakings Ordinance. Following the *Safety Guide to Working in Confined Spaces* ensures compliance with the above regulations.

7.45 The key issues with regards to confined spaces which are at risk of landfill gas build-up are set out below.

- The entry or access point should be clearly marked with a warning notice (in English and Chinese) which states that there is the possibility of flammable and asphyxiating gases accumulating within.
- The warning notice should also give the telephone number of an appropriate competent person who can advise on the safety precautions to be followed before entry and during occupation of the manhole.
- Personnel should be made aware of the dangers of entering confined spaces potentially containing hazardous gases and, where appropriate, should be trained in the use of gas detection equipment.
- Prior to entry, the atmosphere within the chamber should be checked for oxygen, methane and carbon dioxide concentrations. The chamber may then only be entered if oxygen is greater than 18% by volume, methane is less than 10% of the Lower Explosive Limit (LEL), which is equivalent to 0.5% by volume (approximately), and carbon dioxide is less than 0.5% by volume.
- If either carbon dioxide or methane are higher, or oxygen lower, than the values given above, then entry to the chamber should be prohibited and expert advice sought.

- Even if conditions are safe for entry, no worker should be permitted to enter the chamber without having another worker present at the surface. The worker who enters the chamber should wear an appropriate safety/recovery harness and, preferably, should carry a portable methane, carbon dioxide and oxygen meter.

7.46 In general, when work is being undertaken in confined spaces sufficient approved resuscitation equipment, breathing apparatus and safety torches should be available. Persons involved in or supervising such work should be trained and practised 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 consistently employed.