Ground Gas Information Sheets

Multiple lines of evidence approach using continuous monitoring data
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In 2019 Card et al published *Risk and Reliability in Gas Protection Design – 20 Years on* in Ground Engineering. This provides a screening approach to ground gas risk that can be applied when continuous monitoring data (including flow rates) is available. It is increasingly being used by informed consultants as part of ground gas risk assessments. The approach maximises the value of continuous monitoring data, allowing more robust assessments and often reducing or eliminating the need for gas protection. In the drive to reduce the embodied carbon in building construction, avoiding unnecessary installation of gas protection is an important aim. Multiple lines of evidence requires the assessment of the ground gas risk based on each individual information or data source on its own. The individual results are then assessed for consistency and an overall level of risk determined from consideration of all lines of evidence. This paper describes how to use the 2019 screening method as one line of evidence in a multiple lines of evidence approach. Importantly it explains the limitations and requirements for use of the method that are stated in the Ground Engineering paper.

Introduction

Detailed analysis of continuous monitoring data using the approach described by Card et al (2019) (the "2019 Ground Engineering paper") can often realise a significant reduction in the scope of gas protection measures required for developments. It is often possible to remove the need for gas membranes or venting layers. Using continuous monitoring data also allows an approach to gas risk assessment that is more robust than the screening methods presented in CIRIA Report C665 (Wilson et al, 2007) and BS8485 (BSI, 2019). Continuous monitoring techniques generally allow shorter monitoring periods. Achieving a more robust, less conservative, gas protection solution is important in making continuous monitoring cost effective. This paper describes how to combine the Ground Engineering method with a multiple lines of evidence approach that is

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described in CIRIA Report C795 (Wilson et al, 2020). Ground gas risk assessment has developed over the years since 1999 when the first assessment method using flow rates was published (Wilson and Card 1999). Since that time the Wilson and Card method has been refined and the requirements for determining a gas screening value (GSV) and Characteristic Situation have changed as shown in Figure 1.

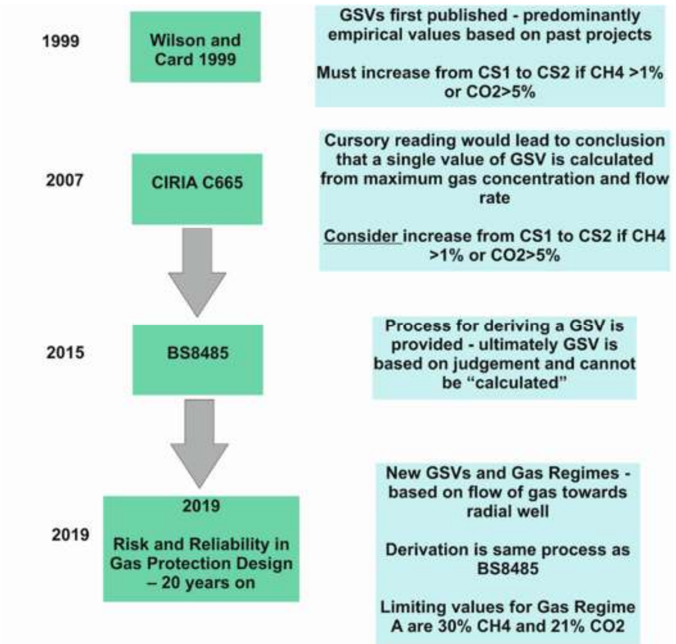

Figure 1 Development of ground gas risk screening

The 2019 Ground Engineering approach can fit into the current framework for gas risk assessment and protection design in BS8485, as shown in Figure 2. It can be used as the first part of more detailed quantitative assessment methods, which are covered by Clause 6.2.2 of BS8485, as a screening method where continuous monitoring data is available.

Although the screening values in the paper are to be used with continuous monitoring data, the background information in Part 1 of the paper can also be used to help interpret spot monitoring data when using BS8485.

Relevant and authoritative guidance

Papers published by Ground Engineering are peer reviewed before publication. In addition, the authors of the 2019 Ground Engineering paper asked respected professionals who work in the field of ground gas risk to review it before submission as a technical paper. Advice in Ground Engineering Technical Papers is used to inform geotechnical design in many other fields.

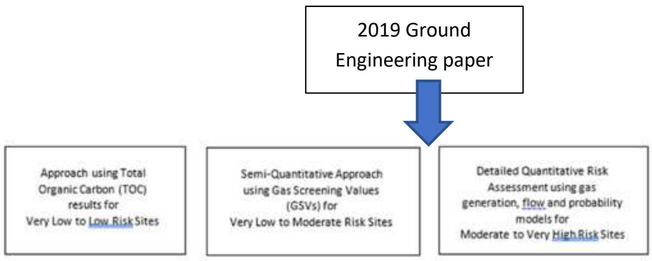

Figure 2 2019 Ground Engineering paper and BS8485

Who is competent?

The 2019 Ground Engineering paper requires that any gas protection design elements are completed by a Chartered Engineer, however anyone with relevant experience and with chartered membership of an appropriate professional body would be acceptable (eg Chartered Geologist).

Professionals using the risk assessment method should be experienced in geo-environmental site investigation and risk assessment.   They should possess a good understanding of ground gas generation, migration and quantitative risk assessment. It requires far more than just multiplying a gas concentration and flow rate together to obtain a GSV (as does the method in BS8485). It is therefore recommended that regulators should require risk assessors using the method to be suitably qualified and experienced as required under the definition of 'competent persons' in the National Planning Policy Framework (NPPF) in England and equivalents in the devolved governments. Land Contamination: Risk Management (LCRM) also requires that for '*land contamination and planning you must use and meet the National Planning Policy Framework definition of a competent person'.* This is the same condition provided in the CL:AIRE guide to mine gas risk assessment (CL:AIRE, 2021), being 'a person with a recognised relevant qualification, sufficient experience in dealing with the type(s) of pollution or land instability, and membership of a relevant professional organisation'.

Risk assessors and designers using the paper should ideally be Chartered professional members of an appropriate organisation (or be able to demonstrate equivalence) and have: competence in geology; understanding of ground gas generation processes, how it can migrate in the ground, to the surface and into buildings; as well as gas risk assessment techniques.

Additional accreditation (e.g. SoBRA[1] fully accredited risk assessor for permanent gases or a similar level of qualification such as SiLC[2] or RoGEP[3]) is one way of demonstrating professional competence.

When can it be used?

The 2019 Ground Engineering paper includes some important limitations regarding its use.

- The permeability of the ground around the well is known or can be estimated, for example using the plot in Figure B1 from the paper (reproduced as Figure 3 below). Permeability can be estimated from permeability tests, infiltration tests or using good soil descriptions and Figure 3.
- The response zone of the monitoring well is analogous to a fully penetrating well (i.e. it extends to an impermeable layer such as just above the groundwater table or to a clay layer).
- The permeability of the ground through which gas can flow to a receptor is < 1 x 10^{-4} m/s. Most soils in the UK will achieve this criterion, but it may preclude the use of the method in clean gravel or fractured rock (see point 7).
- Gas sampling in between flow rate monitoring is undertaken for at least 4 minutes and the exhaust gases are vented to atmosphere. In practice this requirement is not essential, and experience has now shown it will not affect the result of a risk assessment using the method.
- No preferential pathways have been identified that gas can flow to and along (e.g. vibro stone columns or underground services that are deep enough to form a pathway between source and receptor and have permeable backfill). Regular shallow services (gas, electric and water) are not likely to constitute a preferential pathway but this can be easily demonstrated by flow analysis. An explanation of preferential pathways is provided in Appendix A.
- The gas is present at 1m depth or greater below the building floor slab. This is most often the case because of the presence of piling mats and oxygen ingress through the ground surface over the top 1m.
- The ground in which the gas is migrating through should be soil material. This method is not applicable where gas is migrating through a fractured rock environment (which in any event may have a permeability > 1 x 10^{-4}m/s – see bullet point 3 above).

[1] The Society of Brownfield Risk Assessment (SoBRA) has developed this registration scheme in order to recognise and reward the technical skills associated with land contamination risk assessment. The SoBRA scheme does not demonstrate that an individual is an expert but it shows that the individual possesses the critical technical, scientific and communications skills required to design, perform and/or critically evaluate land contamination risk assessments.

[2] A registered SiLC is a senior practitioner who has a broad awareness, knowledge and understanding of land condition issues, providing impartial and professional advice in their field of expertise.

[3] The Register of Ground Engineering Professionals (RoGEP) provides external stakeholders, including clients and other professionals, with a means to identify individuals who are suitably qualified and competent in ground engineering

The gas monitoring data must be "continuous data". Typically continuous data is collected at hourly intervals although it may be shorter or longer than this. When the frequency of monitoring exceeds the frequency of change of the measured parameter, the monitoring can be considered to be continuous. It must also cover a period of worst case conditions as defined by CL:AIRE (2018).

Other limitations are stated in Table 1 of Part 2 of the paper. The limiting values of methane and carbon dioxide concentrations for Gas Regime A should not be used where the source of gas is one of the following:

- Municipal solid waste landfill sites (domestic waste); and
- Mine workings.

In practice such sites are highly likely to require detailed quantitative risk assessment rather than use of gas screening values.

The paper also requires the gas screening value to be determined using the approach described in BS8485 (BSI, 2019). This is described in the next section.

The requirements for using the 2019 Ground Engineering approach are summarised in Box 1.

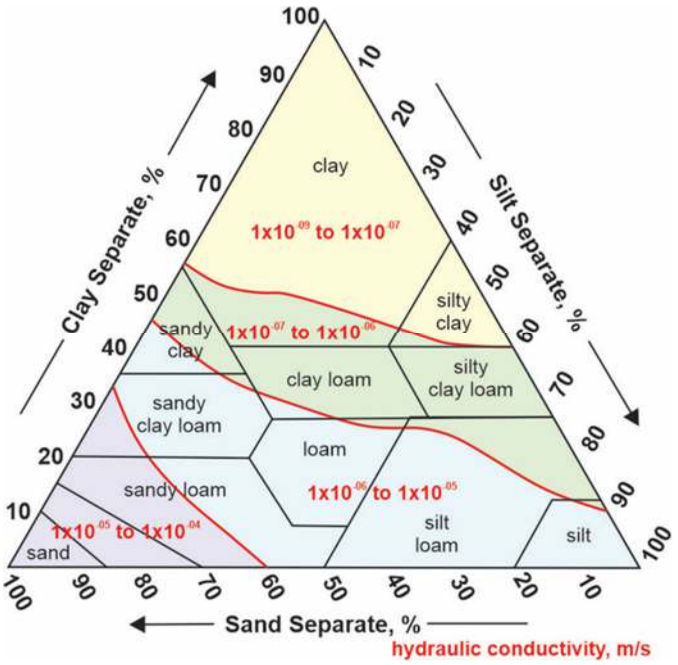

Figure 3 USDA soil classification with intrinsic permeability (USDA, 2003)

Derivation of the GSV

The derivation of the Gas Screening Values (GSV) for a site should follow the guidance in British Standard BS 8485:2015+A1:2019. This requires a thorough understanding of the conceptual site model in order to inform the semi-quantitative risk assessment. The flow and gas concentrations used for the assessment should be appropriately robust and justifiable based on a thorough understanding of the ground model.

The correct application of the guidance in British Standard BS 8485:2015+A1:2019 is described in Clause 6.3.1. BS8485 uses the concept of the borehole hazardous gas flow rate (HGFR). This is obtained by multiplying the gas concentration by the flow rate of all gases from a well. It is calculated for each monitoring event in each well. Where flow or concentration is not detectable the limit of detection of the instrument is used in the calculations.

The individual values of HGFR obtained from several monitoring locations over several visits are considered collectively to establish a Gas Screening Value (GSV) for the site as a whole (or potentially zoning the site) This requires consideration of the results in relation to the conceptual site model.

The process for developing a GSV for a site is summarised as follows:

- Borehole HGFRs are calculated **for each borehole standpipe for each monitoring event**.
- The reliability of the measured gas flow rates and concentrations is assessed, considering borehole construction, geology and groundwater levels. One key issue is that flow rates from flooded wells should not be used in the assessment.
- Decisions are made as to whether to use peak gas flow rates or steady state rates in each calculation (Note: British Standard BS 8485:2015+A1:2019 states that steady state values are to be normally used, as does BS8576: 2013). During spot monitoring the engineer/technician should ensure that steady state values are achieved (this can take ten minutes or more).

Box 1 Key requirements to use the 2019 Ground Engineering approach

1. Competent professional as defined in NPPF and LCRM
2. Not to be used where source of gas is domestic waste or mine workings
3. Gas monitoring data must be "continuous data" and also cover a period of worst case conditions as defined by CL:AIRE (2018).
4. Permeability of the ground around the well is known or can be estimated
5. Permeability of the ground is < 1 x 10-4 m/s
6. Response zone of monitoring well extends to an impermeable layer such as just above the groundwater table or to a clay layer
7. There are no preferential pathways for gas migration
8. Gas is present at 1m depth or greater below the building floor slab
9. The method is not applicable to a fractured rock environment

- Decisions are made about how to deal with any temporal or spatial shortages in the data (note application of the screening values in Table 8 of the 2019 Ground Engineering Paper require continuous flow monitoring over a period that includes worst case atmospheric pressure as defined in CLAIRE TB17 (Wilson et al, 2018)).
- Judgements are made about what GSV to use for design purposes taking all relevant information into account. This requires an assessment of the continued gas generation rate of the source, (e.g. consider TOC content and the nature of the organic matter) and the permeability of ground around the monitoring wells. Only data taken from wells with an exposed response zone in the unsaturated zone should be used.

BS8485 has additional requirements to be **considered,** and which are which are therefore not mandatory. In the Ground Engineering paper there is also a requirement to consider increasing from Gas Regime A to B based on carbon dioxide concentrations above 21% and methane above 30%.

The "worst-case" approach in BS8485 can be used if data is limited (Cl 6.3.7.3 of BS8485). This determines the GSV by combining the maximum flow rate and maximum gas concentration **from wells in the same stratum**. It was included as a way of dealing with possible uncertainty when using spot monitoring data. Clause 7.7.3.4 of BS8485 states that the worst-case value should only be adopted as the GSV if it is prudent and reasonable, and does not results in unnecessarily over conservative protection measures.

Therefore, it is very unlikely to be appropriate to use the worst-case approach from BS8485 where continuous monitoring data, including continuous flow rates, is available. The continuous data should be sufficient to allow a more robust assessment of ground gas risk.

Multiple lines of evidence

CIRIA Report C795 (Wilson et al, 2020) describes a multiple lines of evidence approach to ground gas risk assessment. CLAIRE Technical Bulletin TB18 (Talbot and Card, 2018) provides some information on using continuous monitoring data in a multiple lines of evidence of approach and the relationships that may be observed in results.

Each line of evidence uses a different information or data to assess the gas risk. For example, for permanent gases (e.g. methane and carbon dioxide) the following are considered separate lines of evidence:

1. Desk study identifying age and nature of gas source and therefore whether it is likely to be producing elevated concentrations and/or large volumes of gas;

2. Desk study identifying how long receptors have been exposed to source and whether there have been any reported issues (odours, drowsiness, etc);

3. Site investigation data including detailed descriptions and visual assessment of gas source

(see AGS Guidance on Description of Anthropogenic Materials, AGS, 2018);

4. Total organic carbon (TOC) tests and gas generation modelling;
5. Gas monitoring data and its analysis (spot and continuous data are both gas monitoring and are part of the same line of evidence including any statistical analysis of the data such as ternary plots, pie charts, concentration-duration curves, etc);
6. Analysis of water samples and determination of potential dissolved methane in groundwater;
7. Investigation of soil and groundwater sources of VOCs;
8. Flow modelling of gas migration through the ground and into buildings;
9. Confirmation that gas migration is occurring or not by gas monitoring in relevant migration pathways in the ground;
10. Flux chamber testing (for permanent gases) of surface emissions or surface emissions tests;
11. Confirmation of shallow gas regime below floor by sub-slab monitoring; and
12. Confirmation of gas ingress into buildings or sub slab voids by internal or void gas monitoring.

Each separate line of evidence is assessed on its own merits considering the reliability and uncertainty of each. The conceptual model for gas migration pollutant linkages is refined based on the evidence. The consistency between lines of evidence is then considered (and resolved if necessary) before an overall assessment is made, based on a consistent conceptual model, taking into account uncertainty.

An example application of this approach is provided in Appendix B. This also includes a checklist that can be used to show all the requirements are met that allow use of the 2019 Ground Engineering.

Conclusions

The screening method proposed by Card et al (2019) published in Ground Engineering can be used as part of a multiple lines of evidence approach to ground gas risk assessment. Before doing so the requirements and limitations in the paper should be checked to make sure it is being applied by appropriately qualified professionals and it is appropriate for a particular site.

The method is compatible with the guidance in BS8485 and can be used as the first screening stage in a DQRA, where continuous gas monitoring is available.

Use of the method requires the GSV for a site to be determined following the guidance in BS8485. However, some parts of the guidance (for example the worst-case check using maximum flow rate x maximum gas concentration) are not appropriate when continuous monitoring data is available.

References

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Wilson S, Sopp G and Mallett H (2020) Retrofitting hazardous ground gas protection measures in existing or refurbished buildings. Report C795.

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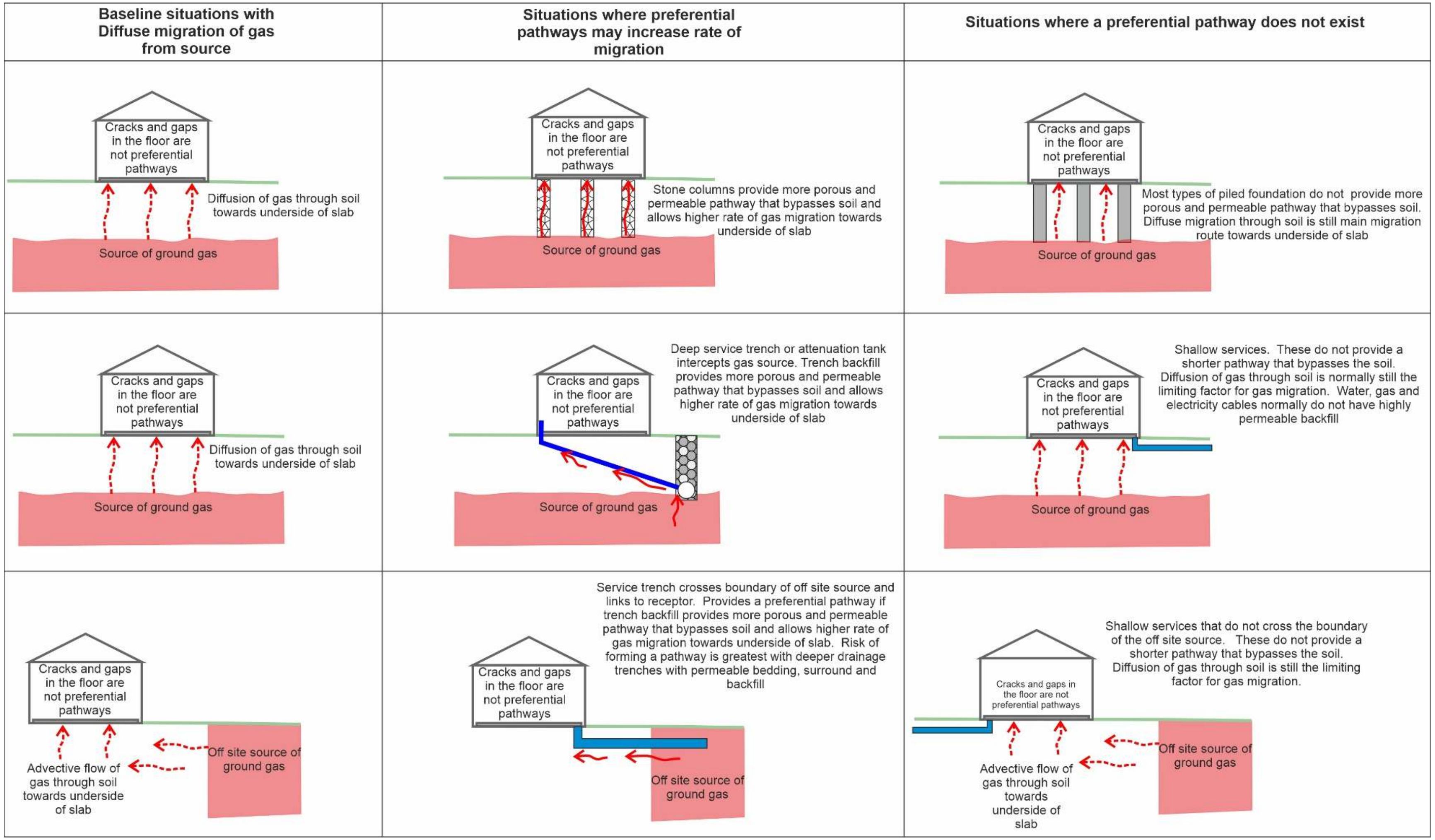
Appendix A Preferential Pathways

Advice on preferential pathways for vapour intrusion is provided by the US Department of Defence (USDoD, 2020). This can also be applied to ground gas.



Definition of Preferential Pathway

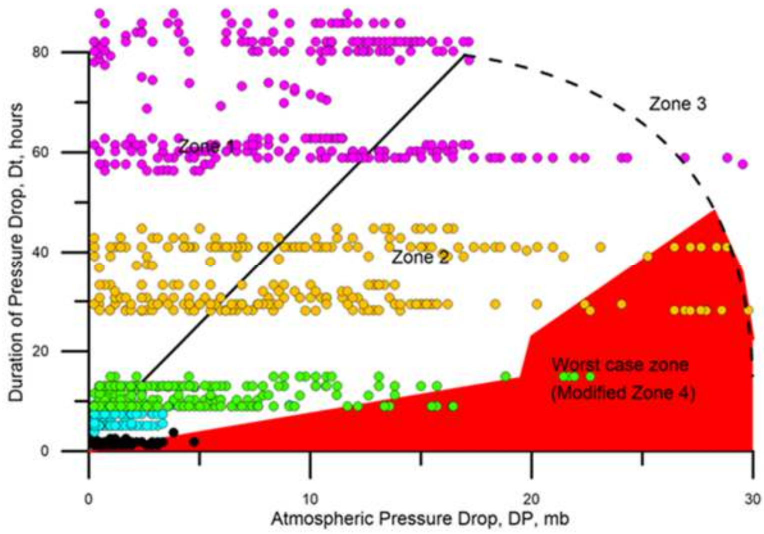
A vapor (or gas) intrusion preferential pathway (VIPP) is typically defined as a high permeability conduit that can serve as a high-capacity transport pathway for vapors from a subsurface volatile organic compound (VOC) source area to or into a building. For example, a sewer line can serve as a preferential pathway connecting an area of contaminated groundwater to a building.

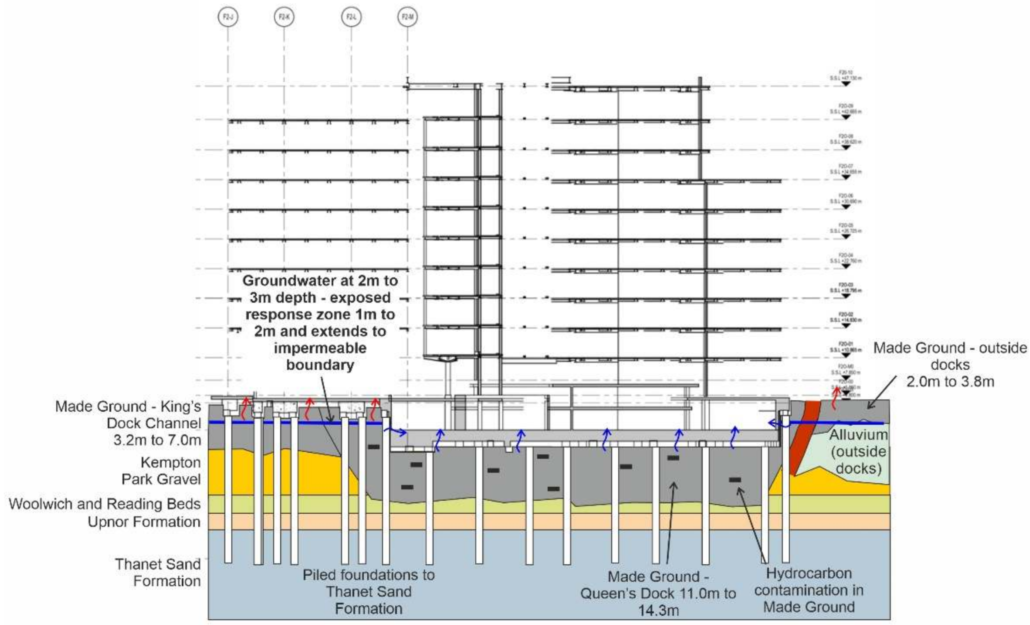
Foundation cracks and other building features are not considered preferential pathways for migration of gas from the source towards the underside of a building. This is because the influence of these does not extend very far beyond the building foundation. They should be considered when assessing gas flow across the floor slab.

Appendix B Example Application of the 2019 Ground Engineering Method in a Multiple Lines of Evidence Approach

The multiple lines of evidence approach has been applied to a site as shown below.

1. Is the 2019 Ground Engineering paper method applicable?

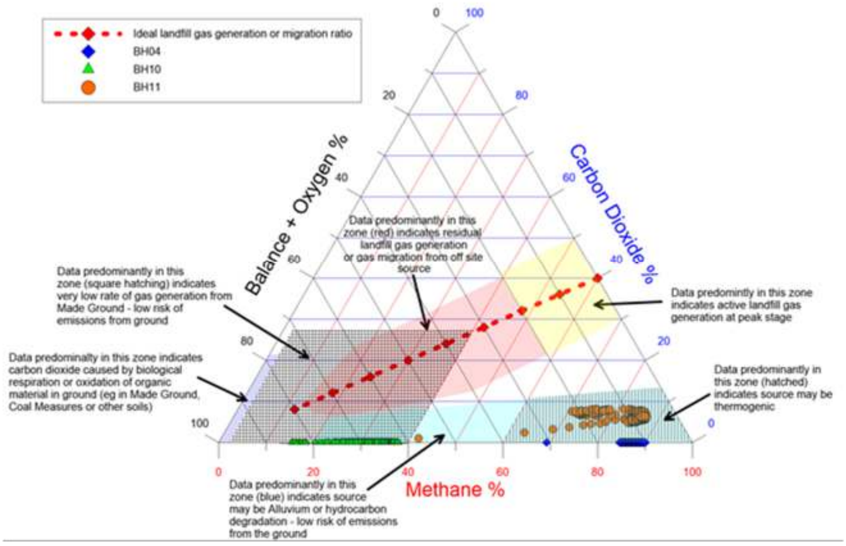
Requirement	**Achieved on this site?**	**Evidence**
Competent risk assessor	Yes	Risk assessor is SoBRA accredited risk assessor for permanent gas with 30 years+ experience and also Registered Ground Engineering Adviser
Source of gas is not domestic waste or mine workings	Yes	Site is former dock infilled with soil based materials and contaminated with hydrocarbons. Degradation of hydrocarbons is the main source of gas
Continuous monitoring data is available and covers worst case in TB17	Yes	Monitoring has been completed for 6 weeks . An assessment of barometric pressure drops during the monitoring has been completed following CLAIRE TB17 (see graph below). The assessment shows the monitoring covers sufficient periods of falling barometric pressure that meet worst case conditions. 
Permeability of the ground around the well is known or can be estimated	Yes	Good quality soil descriptions are available together with particle size distribution analyses.
Permeability of the ground is < 1 x 10^{-4} m/s	Yes	Ground gas migration pathway is from the water table to the ground surface through Made Ground. The Made Ground is predominantly cohesive or clayey gravel. Infiltration tests show the infiltration rate (and hence assumed permeability) is < 1 x 10^{-5}m/s)

<table>
<tr><th>Requirement</th><th>Achieved on this site?</th><th>Evidence</th></tr>
<tr><td>The response zone of the monitoring well extends to an impermeable layer such as just above the groundwater table or to a clay layer</td><td>Yes</td><td>

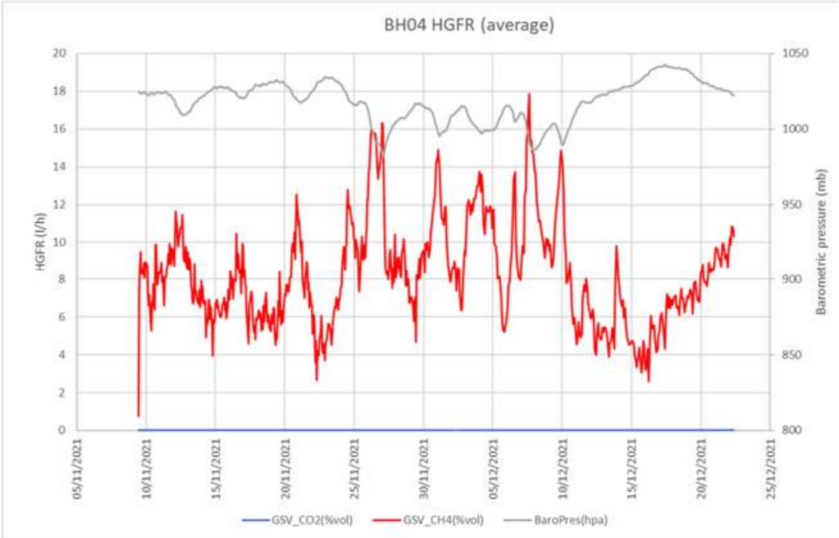
Existing monitoring wells are to be used for continuous monitoring on this site. Spot monitoring has already been completed and the continuous monitoring was targeted at two wells with high methane that are not flooded and one with fluctuating gas concentrations that is not flooded.
Ambisense GasfluX units have been installed in these three wells.</td></tr>
<tr><td>There are no preferential pathways for gas migration</td><td></td><td>The limiting factor will be flow of gas through the Made Ground towards the floor slab. The same applies to any services and piled foundations– they will not significantly increase flow rate from the source at depth. For information on piled foundations and preferential pathways see Wilson and Mortimer (2021).</td></tr>
<tr><td>Gas is present at 1m depth or greater below the building floor slab</td><td></td><td>The hydrocarbon degradation is causing elevated dissolved methane in the groundwater. This in turn comes out of solution into the soil pores of the unsaturated zone and slowly diffuses towards the ground surface. Groundwater (and thus source of gas) is at around 2m to 3m depth below the ground surface (and any floor slab) which is conservative</td></tr>
<tr><td>The method is not applicable to a fractured rock environment</td><td>Yes</td><td>Fractured rock is not present in the migration pathway (which is Made Ground).</td></tr>
</table>

Summary of multiple lines of evidence

<table>
<tr><th>Line of Evidence</th><th>Site specific comment</th><th>Risk of hazardous emissions based on the line of evidence</th></tr>
<tr><td>1. Use the desk study to develop a robust visual CSM that identifies the credible sources of gas below a site. This will also identify the age and nature of the gas source(s) and whether it can generate large volumes of gas that could pose a hazard at the surface</td><td>The CSM in in the preceding section provides a scaled geological cross section through the site with scaled and realistic foundation details on it, showing the proposed development and groundwater level.
The significant sources of gas in this site based on site history are:
Dock infill – Given the age of the infill (filled between 1965 and 1975) it is not likely to be generating large volumes of gas at the present time. From the site history details it is likely to be predominantly soil. The risk of hazardous emissions into buildings is very low.
Hydrocarbon contamination – degradation of hydrocarbons gives low volumes of methane but at very high concentrations. The concentration of hydrocarbons in groundwater and soil is low, but sufficient to cause high methane concentrations in monitoring wells. The risk of hazardous emissions into buildings is very low.
Alluvium – the gas in Alluvium is trapped and essentially not mobile. Gas is not being actively generated at the present time. It does not pose a risk of hazardous emissions into buildings.</td><td>Very low</td></tr>
<tr><td>2. Site investigation to give visual assessment of gas source</td><td>Made Ground is predominantly soil with some wood and fabric. There is nothing to suggest high gas generation rates will occur and no evidence of highly degradable material. Alluvium is organic clay – low permeability with no significant current gas generation. The total organic carbon (TOC) and dissolved organic carbon (DOC) from waste acceptance criteria (WAC) testing results indicate negligible degradable carbon content.
Hydrocarbon odours noted throughout – hydrocarbons will degrade and produce methane but at very slow rates such that hazardous rates of emissions are not likely in the long term. Gas ratios suggest that the methane is present due to degradation and is not interference with the meter.
The gas from hydrocarbon degradation can become trapped below impermeable layers over time and if below the water table the pockets can become pressurised. These are no a significant risk in the long term (because the volumes of gas are typically small). However they can present a short term health and safety hazard during construction if they are penetrated. Normally on most sites if the pocket is punctured the gas pressure will dissipate over a few days.
All the above indicate the risk of hazardous emissions into buildings is very low.</td><td>Low</td></tr>
<tr><td>3. Assess gas monitoring data</td><td>Spot monitoring data
Assess current data quality (flooded wells, etc) and plot data as ternary plots (CH4, CO2 and N2 + O2) to assess gas source. See Ground Gas Information Sheet No 1 (Wilson et al 2018) for information on ternary plots. The ternary plot shows that there is no difference between wells in different areas of the site and that the source of the elevated methane is predominantly degradation of hydrocarbons.
The Characteristic Situation using the screening approach in BS8485 is CS3. This is not consistent with the description of the source soils or the site history as it indicates moderate risk. It is a short term effect caused by the trapped gas from hydrocarbon degradation.



</td><td>Moderate</td></tr>
</table>

Line of Evidence	**Site specific comment**	**Risk of hazardous emissions based on the line of evidence**
	Assessment of continuous data using the approach described in Ground Engineering (2019) by Card et al The assessment indicates the low end of Gas Regime C as shown in the example graph of HGFR below. Peak is 18l/h and several peaks occur above 10l/h. Interpretation of the data indicates that the gas is being generated by degradation of hydrocarbons. Although the generation rate is low it is trapped in the ground below more impermeable layers in the Made Ground. This causes elevated flows from monitoring wells in the short term giving a moderate rather than very low risk category from the gas data. The assessment could be further refined by collecting additional data such as extended gas monitoring showing a decline in flow rates or membrane interface probe tests with an FID and surface emissions tests but the construction programme precludes this.  	
4. Flow modelling of gas migration through the ground and into buildings considering site specific construction	The model uses the same approach as used in vapour intrusion studies and shows that the risk of gas migration through the floor slab of the completed development is low.	Low
5. Confirmation of surface gas emissions by surface emissions survey using ppm level detection instruments	Not required on this site	N/A
6. Flux chamber testing (for permanent gases) of surface emissions or surface emissions tests	Not required on this site	N/A
7. Confirmation of likely shallow gas regime below future floor by vapour pin monitoring through existing hardstanding	Not required on this site	N/A
8. Confirmation of gas venting performance by GasfluX monitoring in sub-floor void and/or internal monitoring	Not required on this site	N/A
9. OVERALL RISK	There is some discrepancy between the gas monitoring data and the other information (site history and soil descriptions). This is likely because methane generated from hydrocarbon degradation is becoming trapped below impermeable layers in the Made Ground. This is trapped and does not migrate to the surface quickly (otherwise it would not be trapped). Flow is only occurring because the gas wells have penetrated the confining layer. The gas reservoir should slowly dissipate but can take up to a year or more. There is not sufficient time in the construction programme to undertake longer term monitoring to show this. There are sufficient peaks in the Gas Regime C zone in the continuous data that it is prudent with eh current data to classify the site as overall Gas Regime C – moderate risk of emissions	**Moderate – Gas Regime C**