A pragmatic approach to ground gas risk assessment for the 21st Century

CIRIA/Environmental Protection UK Ground gas seminar – 22nd June 2011 and 13th September 2011

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Abstract

This paper proposes an alternative framework for the investigation and assessment of low risk gassing sites using information and data that allows the gas generation potential of a source to be estimated. On many sites it will allow gas well installation and monitoring to be avoided where appropriate (eg where only natural soils are present with a low gas generation risk). It can also be used in conjunction with gas monitoring to reduce the period of monitoring required or to avoid extra gas monitoring where anomalous results, particularly high borehole flow rates, are recorded.

Introduction

Ground gases such as methane and carbon dioxide are found widely in soils and rocks as they are in integral component of the geochemistry cycle of the Earth. Risks arising from the presence of these gases is usually due to :

1. An accumulation of large volumes of gas
2. A sudden release of gas into a confined space
3. A combination of the above.

These conditions generally require the physical presence of cracks or fissures in the Earth's surface that can act as high permeability conduits for the release of ground gases, Examples are faults in the earth's surface and volcanic activity, e.g Italy and Baku.

Soils with high content of degradable organic material can also be problematical. Ground gas forms in the pore space of soils. Since the pressure of a gas bubble is inversely proportional to its radius ground gas can remain in a stable condition in a discrete pore space at relatively high pressures up to a critical value. Above this critical value rupture of the soil skeleton surrounding the pore space will occur and a gas migration network will form (Ref: CIEH 2008). Initial high pressures due to coalescence of pores into a network will cause large volume release of gas giving rise to potential risk to building development. . However in many instances (Alluvium, old Made Ground, etc) the gas has been generated in the past and is now effectively trapped in the pore spaces of the soil or it is being generated at very low rates.

In many soils, however, the pore space is made of small discrete voids such that the presence of ground gas represents a relatively small volume. In reality this does not generally pose a significant risk to buildings or development constructed over such soils.

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Examples where ground gas is present and does not generally pose a risk include soils or rocks with low gas production:

1. Low organic content and degradation potential to form methane and carbon dioxide, such as Made Ground and Recycled soils
2. Carbonate soils in alkaline or near neutral environments with low production of carbon dioxide which, in addition, can be quickly reabsorbed as part of the natural carbon cycle (eg chalk or limestone).

Experience of gas monitoring on many city centre redevelopment sites has shown that Made Ground/recycled soils with a low organic content are present below many older urban areas of the UK and there are low levels of gas in them. There are also areas with high natural methane content such as the Somerset levels. These sites have had housing or other buildings over them for many years without any evidence that gas poses a significant hazard (Sladen et al 2001). The presence of methane and carbon dioxide in these soils was not really recognised until the past 15 to 20 years, because prior to that gas monitoring was not a routine undertaking on development sites, whereas now it is (Boyle and Witherington, 2007).

Now that gas monitoring wells are being installed on the majority of development sites ground gas is being found in many situations where it would not in the past have been considered an issue. This can cause problems when it accumulates in gas monitoring wells at elevated concentrations (eg from experience carbon dioxide can often be between 5% and 15% in natural soils). This can lead to gas protection measures being specified on both greenfield and brownfield sites where small volumes/relatively low concentrations of gas do not pose a hazard.

Radon is another ground gas that is present below many areas of the UK requiring similar protection measures to those used to prevent the ingress of methane and carbon dioxide to buildings. If Radon protection is provided the development will also have a very good resistance to ground gas ingress and the need to obtain gas monitoring data will be removed in many cases.

Recent changes to the Building Regulations with regard to energy efficient structures also mean that air tightness requirements for buildings are becoming more stringent. This leads to more air tight (and thus gas tight) floor slab construction and less background air ventilation within the building. The detail shown in Figure 1 shows details to achieve an air tight floor slab (NHBC Foundation, 2009) that will also give good resistance to ground gas ingress.

Figure 9 Good sealing between the soil vent pipe and the floor structure.

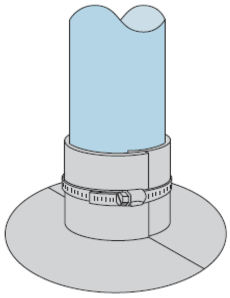

Figure 10 An example of a top hat detail. A seal is achieved around the pipe and the flange is sealed to the air barrier.

Figure 1 Sealing dpm around services to achieve air tightness (NHBC Foundation 2009)

Gas monitoring on low risk sites where small volumes of gas are likely to be present in the soil pores, or where radon protection or air tightness is already required, is not always necessary. There are other simpler and more reliable methods of identifying and managing the risk posed by the possible presence of ground gas in these situations (eg where limited depths of inert Made Ground are present). This paper proposes an alternative framework for the investigation and assessment of such sites to allow gas well installation and monitoring to be avoided where appropriate. It can also be used in conjunction with gas monitoring to reduce the period of monitoring required or to avoid extra gas monitoring where anomalous results, particularly high borehole flow rates, are recorded.

The approach is based on principles described in the Local authority guide to ground gas published by the Chartered Institute of Environmental Health (CIEH, 2008) and is compatible with the guidance in CIRIA Report C665 and British Standard BS 8485: 2007. It seeks to separate out high risk situations such as large relatively recent domestic landfill sites from low risk sites where there is a thin layer of inert Made Ground or natural sources of ground gas.

Gas monitoring wells

Gas wells are an artificial construction in the ground that can in some specific instances (that are discussed below) cause high flow rates or gas concentrations that are not necessarily representative of sustained surface gas emissions from low risk sources. The experience of practitioners is increasingly demonstrating that careful interpretation of results is required to ensure that appropriate conclusions are drawn from them in respect of the volumes of gas that are likely to migrate into a building from low risk sources.

It is normal practice in the UK to install simple standpipes with a single response zone to monitor ground gas. To fully understand ground gas regimes in the soil pore space and migration patterns multi point gas well installations are required at each location with small discrete response zones at various depths.

The head space of a gas monitoring well is usually only a very small volume (for each 1m of 50mm diameter standpipe there is approximately 2 litres of headspace). Thus relatively small volumes of ground gas can be recorded as apparent high concentrations in terms of percentage by volume and potentially short lived moderate flow rates. Figure 2 shows how a number of variables can affect flow rates, whilst gas concentrations can be affected by a number of factors including:

- The presence of organic material in groundwater that is standing in the well. This can degrade and produce methane and carbon dioxide.
- Organic material in silt collecting in the base of a well, that can degrade and produce methane and carbon dioxide.
- The presence of dissolved methane anmd carbon dioxide in groundwater that can come out of solution if changes in groundwater levels cause a drop in pressure in the headspace (Figure 2)
- The presence of hydrocarbons collecting in the well that can degrade and produce methane and carbon dioxide.
- The accumulation of methane and carbon dioxide displacing air due to buoyancy effects.
- The presence of the monitoring well has created an artificial mechanism by which gas can enter the headspace of the well (eg where the response zone intersects a layer of peat that is confined with more impermeable layers above and below it).

All these factors can, on some sites, give high concentrations in the headspace of a monitoring well that are not representative of the gas concentration pattern in the pore spaces of the surrounding ground or of likely gas emissions from the ground. The gas concentration due to degradation of organic material in the soil may be much lower than indicated by monitoring results that are affected by the preceding factors. This is often not recognised by different parties leading to disagreements that can prolong the time it takes to obtain planning permission or agreement to discharge planning conditions. A common response to anomalous results is to recommend ever more and frequent monitoring that does not solve the underlying problem.

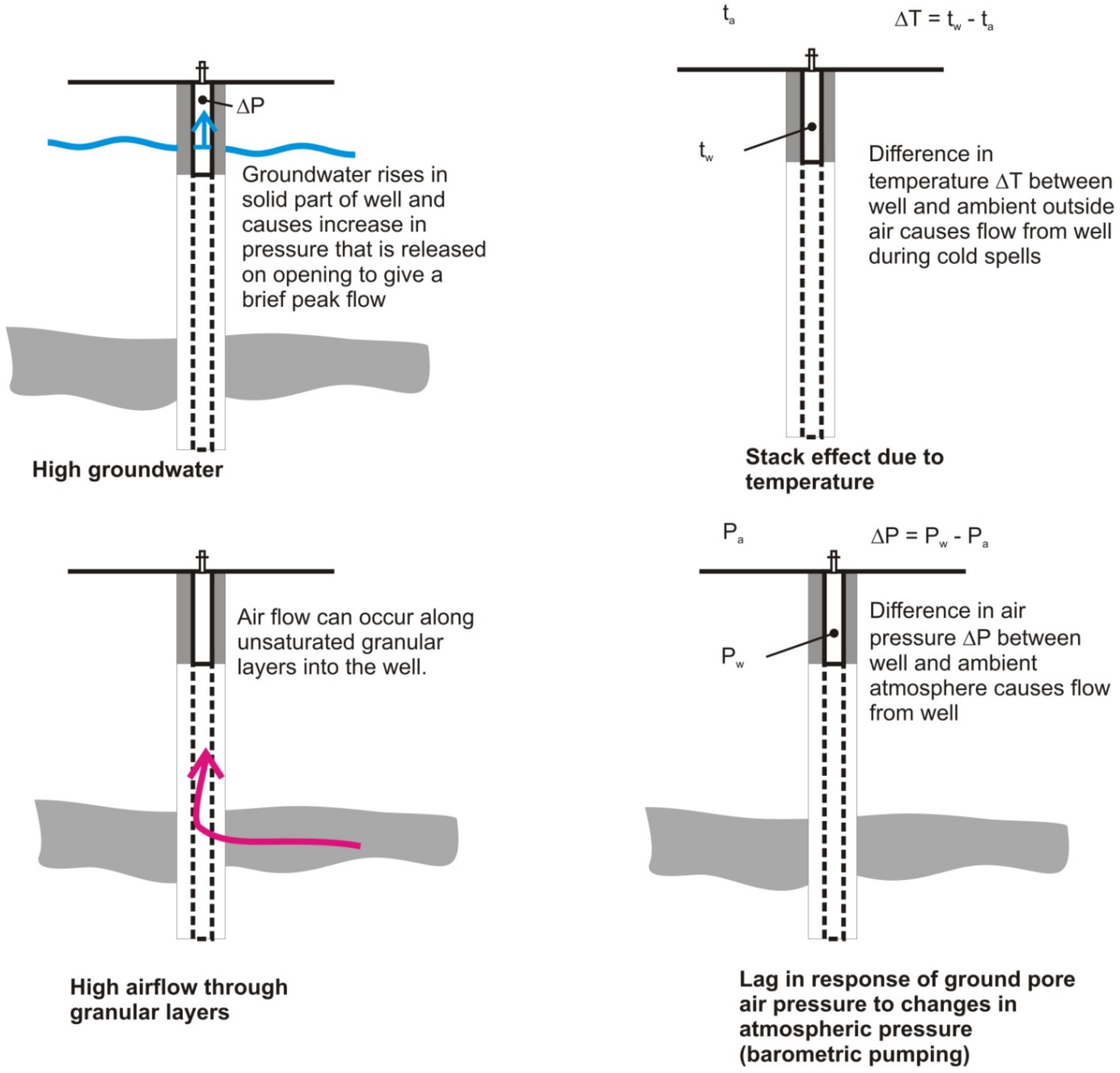

Figure 2 Factors that can affect flow rate measurements

It is important that risk assessors recognise these issues and allow for them when interpreting results from gas monitoring data because the screening process that is at the heart of UK guidance on ground gas risk is based on limits that are derived using borehole concentration and flow rate. The Gas Screening Value (GSV) is the product of the borehole flow rate and gas concentration.

Requirements for gas protection

Many areas of the UK require radon protection measures to be installed in accordance with BRE guide BR211 (2007) without any data from site specific monitoring. The main form of protection for new buildings is to provide a radon barrier in the floor slab construction and ventilation below it. In commercial buildings positive pressurisation and a membrane may be used. These are the same methods used to protect against the ingress of other ground gases such as methane or carbon dioxide (Wilson et al, 2007 and Boyle and Witherington, 2007). Therefore it seems unreasonable to mandate gas monitoring in such situations, where gas protection is already to be provided and the results will not increase the design requirements or result in any cost reduction.

The requirements or Part L of the building regulations relating to the air tightness of buildings also leads to the need for a well sealed damp proof membrane (dpm) either above or below a floor slab (NHBC, A practical guide to building air tight dwellings). As standards become more stringent there will be an increasing need for all the penetrations through floor slabs to be well sealed, both between pipes and the floor structure and the dpm using top hat details. Again these are the same measures required for protection against the ingress of ground gases.

Many housing developments have block and beam suspended floor slabs with a ventilated underfloor void (these are the preferred type of construction for geotechnical and/or cost reasons in many areas). The void gives very good protection against ground gas ingress and when designed and constructed correctly it dilutes any gas being emitted from the ground to acceptable levels. The minimum level of ventilation required to deal with condensation is capable of dealing with quite onerous ground gas regimes. For a typical residential property up to 8m wide the minimum ventilation to the void of 1500mm^2/metre of wall will provide adequate dilution of gas (equilibrium concentration of 0.25% v/v) up to a Gas Screening Value of 3.5l/h (Wilson and Card - Characteristic Situation 3 or NHBC - Amber 2). This has been demonstrated by monitoring of voids below completed buildings for many years (Wilson and Card, 1999 and Pecksen, 1986). Good construction also requires the cavity below ground level to be filled with concrete, again limiting the potential for gas ingress. Thus many buildings will already have an inherent level of gas protection provided in their construction and this can be taken into account when determining whether gas monitoring is likely to be required during a site investigation.

Alternative approach to gas monitoring on low risk sites

Given the uncertainty in the measurement of gas concentrations and flow rates in monitoring wells that can sometimes occur on low risk sites an alternative approach is proposed. Low risk sites are defined as those where the conceptual model has not identified any significant sources of ground gas including:

1. Natural soils with a high carbonate content, such as Chalk, some Glacial Tills, etc
2. Natural soils that are known to contain methane, such as Alluvium, Peat, et
3. Made Ground with a low organic content (ie predominantly soil, ash or clinker with occasional pieces of wood, etc). The maximum depth for applying this approach has been chosen as 5m. This value is used because there is a greater risk of unidentified degradable material with deeper deposits and the soil atmosphere is more likely to be predominantly anaerobic below this depth.
4. Areas of flooded mine workings or mine workings that were abandoned by the early 20th Century (gas emissions from these types of mine workings are not likely to pose a significant risk). The exception may be where buildings are within 20m of a mine opening (shaft or adit).

This effectively means that gas monitoring is only required for:

1. High risk sites where gas can be emitted from the ground in large volumes (domestic or industrial landfill sites with a high degradable content, Made Ground with a higher degradable content, mine workings where there is still a large gas reservoir and a vent to the ground surface such as a shaft or fractured rock).
2. Sites with Made Ground where maximum depth is greater than 5m or average depth greater than 3m.
3. Sites where migration from an off-site source with a credible migration pathway needs to be assessed.

Gas monitoring may also be chosen where it is thought the costs will be outweighed by cost reductions in the gas protection design (in this case wells may be installed as a precautionary measure during the site investigation and only monitored if the TOC testing indicates it is necessary. Often groundwater monitoring wells will be suitable for this, although care needs to be taken in choosing appropriate wells as not all groundwater wells are suitable for gas monitoring). Gas monitoring will still often be required on sites being investigated under Part IIA of the Environmental Protection Act. This is because generally Part II A sites involve investigating gas migration across site boundaries outside higher risk former landfill sites. In built resistance to gas in older housing stock cannot be assumed either. However the principle of gas generation modelling does form an important element of these assessments.

Identification of low risk sites requires a good understanding of the nature of the source material. It takes account of the following:

- the gas regimes that occur where Chalk or other carbonate material is present.
- the gas generation that occurs in natural soils such as Alluvium and peat
- The results of total organic carbon tests and forensic description of soils (Appendix A) to estimate the likely rate of gas generation below a site from Made Ground. The basic approach to modelling gas generation is described in the Local Authority Guide to Ground Gas (CIEH, 2008).

The data required is quick and easy to obtain during an intrusive site investigation (TOC testing and forensic description). It is less sensitive than gas monitoring to external influences and thus temporal variations will be removed from the assessment. Spatial coverage of the data used in the assessment should also be greater because a greater number of tests can be achieved than is normally obtained using gas monitoring wells. This alternative approach is based on an understanding of soil chemistry and gas generation processes and the volumes of gas produced from carbonate or organic degradable material that are cycled naturally in the environment.

Such an understanding on low risk sites can remove the need to install costly monitoring wells. It can also be used in conjunction with gas monitoring to reduce the period of gas monitoring specified in CIRIA C665 (Wilson et al, 2007) or avoid extended monitoring when anomalous results are recorded, especially high borehole flow rates.

Data requirements

One of the key elements of this approach is the collection of robust desk study information combined with rigorous interpretation of that data. This allows the development of a sound conceptual site model that includes cross sections in and outside the site to natural scales if practicable (ie the vertical scale is not exaggerated). This is possible on most sites even if only rudimentary data is available from ordnance survey maps and observations made during a walkover survey. At this stage potential credible gas sources and pathways should be identified for the specific site being considered.

The data requirements to allow the new approach to be used are summarised in Table1.

Table 1 Requirement for site investigation

Element of site investigation	Requirements
Desk study	Comprehensive desk study including historical maps, geological maps and memoirs, regulators data on landfill sites. Topographical maps Consideration of likely sources of gas both on and off site. Check Radon requirement in BR211 (2007), Radon: guidance on protective measures for new buildings.
Ground investigation	Where possible the site investigation should include trial pits that extend beyond any Made Ground. Forensic description of soil required (detailed quantitative assessment of the organic content of soil by sorting and weighing different fractions: fine soil (organic and inorganic), coarse soil (such as clinker, gavel, concrete, etc), wood, vegetable matter, cloth/leather, other non degradable materials (metal, glass, ceramics, etc), paper and card, other degradable material). See Appendix A. Care should be taken when relying on information from small diameter window sampler holes. The requirement for more robust methods of investigation will be determined by the preliminary conceptual model and risk assessment and on ground conditions encountered.
Laboratory testing	Total organic carbon content (carried out on the soil fraction only). Test in accordance with Environment Agency Guidance for waste destined for disposal in landfills, EA, 2006 and Guidance on sampling and testing of wastes to meet landfill waste acceptance procedures, EA, 2005) Dissolved organic carbon in leachate. Optional - Cellulose, hemi cellulose and lignin content of clearly degradable fraction (eg wood, cloth, paper, vegetable matter, etc), loss on ignition.

Basis of method

Where only natural soils are present and there is no credible pathway for gas to migrate onto a site from external sources gas monitoring is not considered to be required. An example would be where a site is underlain only by London Clay without any nearby landfills or similar. Sites where only Chalk is present that will give rise to small volumes of carbon dioxide would also fall into this classification. A summary of the more common ground conditions where this would apply is given at the end of the paper (Table 4).

Alluvial soils and peat can quite often give high concentrations of methane and carbon dioxide in monitoring wells, often methane concentrations can reach up to 90%. This is because the gas has been generated historically and is trapped in the pores. There is no or very little current gas generation and the carbon dioxide has dissolved out of the gas trapped in the soil pores. Experience on many dockland and similar sites has shown that sites on Alluvial soils do not generate sufficient hazardous gas flows to exceed Characteristic Situation 2 as defined in BS8485: 2007. Therefore if gas monitoring is not undertaken it is acceptable to simply install Characteristic Situation 2 protection on sites where Alluvial soils are present. A similar approach is acceptable on sites with soils containing lignite or layers of peat. In all these situations experience has shown that provision of passive venting or positive pressurisation below the floor slab combined with a gas resistant membrane (installed correctly and independently verified) is sufficient to mitigate the risk posed by the presence of gas in the ground. A table summarising some of the more common situations is provided in Table 4 at the end of this paper.

The site investigation will require sufficient coverage to give a robust indication of the nature of any potential gas source. It is recommended that forensic description (sorting and weighing of different fractions – see Appendix A) of Made Ground is carried out on at least one bulk (15kg) sample from each trial pit. The sample should be representative of the source material. Often more than one sample will be required, for example where there are significantly different soil horizons. The forensic description should be combined with total organic carbon tests on the soil fraction from the Made Ground.

Natural soils in the UK can contain up to 1% organic material and pose no hazard with respect to ground gas generation. For example siliciclastic mudrocks can contain 1% organic matter (Reeves et al, 2006). Even bentonite used to form seals in monitoring wells can contain 4% to 6% organic matter (Herzog et al, 1991) which may contribute to ground gas in wells if it is not in a cement:bentonite mixture (the cement will increase the pH of the mixture and inhibit any degradation).

When organic matter has been present in the soil for years (decades or even longer) the remaining organic matter comprises large complex compounds that few microbes present can degrade (University of Minnesota, 2011). Other compounds become bound inside the soil structure where they cannot be reached by microbes. When drilling boreholes the exposure of soils to atmospheric aerobic conditions can allow microbes to reach this material and is possibly one reason why initially high concentrations of methane can often be detected in wells installed in low generation potential material shortly after installation. After a period of time the concentrations subsequently decrease to negligible values (CIEH, 2008) as shown typically in Figure 3. The figure shows that initial high frequency data using a portable hand held gas monitor identified the reduction in gas concentration that has subsequently been confirmed by spot monitoring. Another reason for these initial peaks may be the release of small volumes of methane trapped in the soil pore spaces that is not replaced.

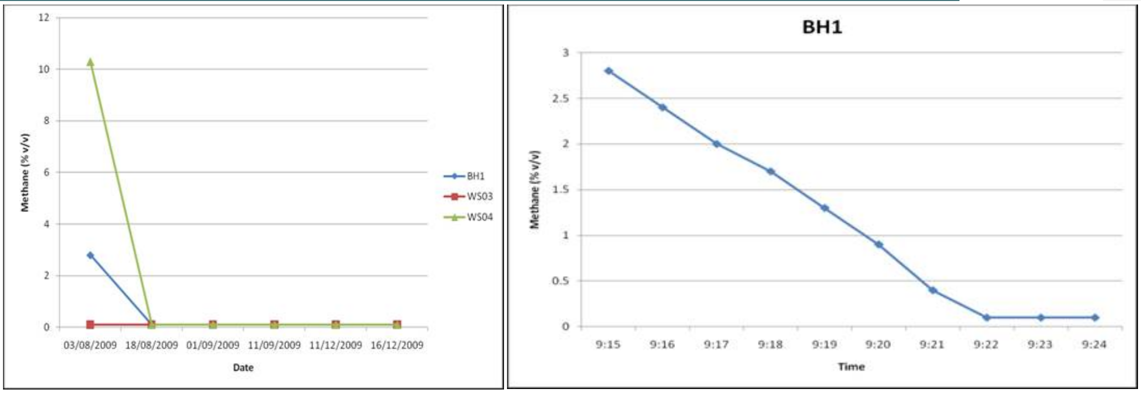

Figure 3 Initial peak methane results in gas well installed into Made Ground

The material that is hard to decompose is called stabilised organic matter and can comprise between one third and half of the total organic matter in soil (University of Minnesota, 2011).

Therefore the assumption made in the new classification system is that soils with a soil organic matter content less than 1% do not require gas protection measures (ie they meet the requirements of characteristic situation 1). Cresser et al (1993) indicate that arable soils can typically generate 90 litres of methane/m^2/year (0.01l/h/m^2). This is equivalent to a borehole flow rates of 0.1 l/h (if the Pecksen correlation between flow rate and surface emission is used) which is the same order of magnitude as the limiting GSV for characteristic situation 1 in CIRIA C665 (0.07l/h). Gas generation modelling would give slightly more conservative values of total organic carbon (TOC) and degradable organic carbon (DOC) for characteristic situation 1. However given the conservative nature of the modelling it is considered acceptable to base the limit for characteristic situation 1 on the typical values of soil organic matter found in natural soils.

The analysis of gas generation has been undertaken using the equations from the Environment Agency report Guidance on the Management of Landfill Gas, LFTGN 03. The rate of gas generation at any time after deposition is given by:

$$\alpha_t = \Sigma 1.0846.A.C_i.k.e^{-k.t}$$

Where:

α_t = gas formation rate at time t (m^3/year)

A = mass of waste (tonnes)

C_i = DOC content (kg/tonne), degradable organic carbon content. This is related to total organic carbon (TOC) by the approximate equation

DOC = TOC ÷ 1.33

and to soil organic matter (SOM) by

DOC = SOM ÷ 2.29

k = rate constant ($year^{-1}$)

t = time elapsed since deposit (years) – For Fresh Made Ground this is taken as one year and for Made Ground older than 20 years is taken as 21 years. This can be a very conservative assumption depending on the site.

The estimated gas generation is then converted to a surface emission rate. As the gas migrates through the soils to the surface there will be some oxidation or other changes in the upper layers of the soil. In most low generation sites there is significant oxidation of methane in the upper 1m of Made Ground. To be conservative this has been ignored although it is likely to occur on most sites. The surface emission rate is converted to an equivalent borehole flow rate using the Pecksen correlation (multiply surface emission rate by a factor of 10). Finally the values are rounded up to the nearest 0.5% to reflect the nature of the analysis (in reality this will make no difference to the risk on any site because the calculated surface emission rate would not vary significantly from this rounding up).

The analysis has been undertaken based on the estimated degradable carbon content of the ground gas source at the time of the site investigation (from correlations with total organic carbon identified earlier). It is assumed that 65% of the organic material in Made Ground is readily available for degradation. This is reasonable because the main type of degradable material in Made Ground will be wood, textiles, newspapers, etc that do not fully degrade (Environment Agency, 2004). It is also assumed that all gas generated can reach the surface. In reality this is not the case, for the reasons discussed above and the fact that some gas becomes trapped in pore spaces. The gas generation estimates are the peak values that will occur in the first few years after placement of the material. They will often reduce significantly in later years where the conditions are suitable (where there is sufficient moisture etc) Thus the analysis gives a worst case scenario and rounding up the values obtained from the modelling to give the defining values in Table 1 is reasonable. In addition where the gas source is less than 5m deep a large proportion of the material may be much more aerobic. Thus decomposition will generate more carbon dioxide in the aerobic zones and overall methane generation will be lower or may be absent altogether.

As a check the gas generation rate estimated using the procedures described above is used to determine the equilibrium gas concentration in a house built over the source. A limiting value of 0.05% is used as an acceptable value for CS2 and CS3. Again this is a conservative approach as any resistance to gas flow provided by the ground or floor construction (that will include a membrane or robust floor slab) is ignored in the assessment.

Experience over the past 10 years suggests that the majority of sites where the main source of gas is Made Ground with a low degradable content will be classified as characteristic situation 2 or 3. Therefore the approach is currently limited to a maximum of CS3. If the requirements in Table 2 for characteristic situation 3 are exceeded gas monitoring will be required to define the protection measures for a site.

Gas generation modelling described earlier has been carried out to determine equivalent ground gas flow rates from boreholes for a range of degradable organic carbon contents. These results have been used to define limiting values of degradable organic carbon (DOC) and total organic carbon (TOC) in Made Ground for Characteristic Situations CS2 and CS3 defined in CIRIA Report C665 and BS8485 (BSI, 2007). Total organic carbon is used as the defining parameter as this is a standard test requirement for waste acceptance classification (WAC testing) and therefore it can readily be carried out by commercial laboratories. There are various methods of testing for total organic carbon, each with its own advantages and disadvantages. The method adopted for consistency and practicality is that specified by the Environment Agency in their guidance on WAC testing (Environment Agency 2005).

The alternative method

A flow chart showing the new approach and detailed requirements is provided in Figure 4.

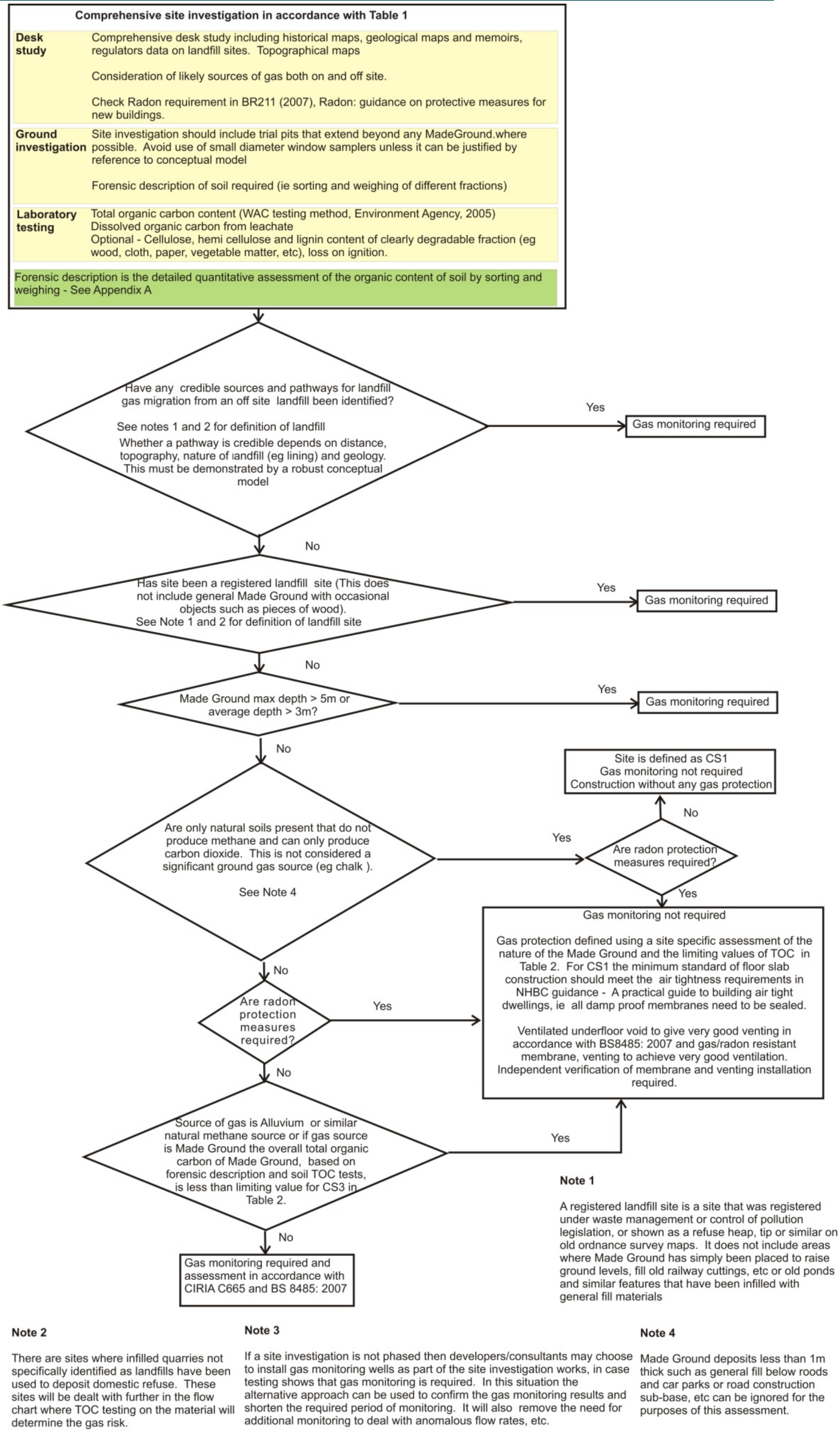

Figure 4 Alternative approach to ground gas assessment on low risk sites

The limiting values of TOC in Table 2 should be determined from a combination of forensic description and laboratory testing on the soil fraction of the Made Ground. For example if Made Ground contains 30% organic material at 20% TOC and the remaining 70% of the soil fraction has a TOC of 0.5% the overall TOC will be 6.4%. Care is needed where Made Ground is predominantly ash, clinker and coal as this can give high TOC results that do not represent the risk of gas emissions from such material (it is generally not degradable so cannot produce methane or carbon dioxide). In this case the assessor must estimate what proportion of the TOC will be degradable and apply a reduction factor to the results. This can be done by considering the proportion of cellulose and hemi cellulose in the sample.

Table 2 Limiting values of organic content in Made Ground

Characteristic situation (BS 8485 and CIRIA C665)	**Depth of Made Ground (m)**	**Maximum total organic carbon content of Made Ground – TOC (%)** see note 1 and 2		**Comments**
		New Made Ground	Made Ground in place for > 20 years	
CS1	Maximum 5m Average < 3m	≤1.0	≤1.0	Limiting values based on reported soil organic matter (SOM) content of natural soils up to about 1%
CS2	Maximum 5m Average < 3m	≤1.5	≤3	Limiting values based on gas generation modelling assuming slow degradation Equilibrium methane concentration in building above <0.01%
CS3	Maximum 5m Average < 3m	≤4	≤6	Limiting values based on gas generation modelling assuming slow degradation Equilibrium methane concentration in building above <0.01%
This method can only be used to define characteristic situations up to 3.	Gas monitoring required where TOC is greater than 6%. Gas monitoring results will show whether the high TOC is available and conditions are suitable to generate ground gas.			

Note 1: TOC = DOC x 1.33 (Hesse, 1971)

Note 2: TOC tested in accordance with the method described in Guidance on sampling and testing of wastes to meet landfill waste acceptance procedures, Environment Agency , 2005)

Examples

The approach has been used on many development sites and sites being assessed under Part 2a of the Environmental Protection Act 1990 in the past few years to confirm the Gas Screening Values obtained from gas monitoring results. Summaries from a selection of these projects are provided in Table 3.

Table 3 Summary of application to various developments

Development	Nature of gas source	Gas concentrations and flow rates used to calculate GSV	GSV / Characteristic situation - gas monitoring data and BS8485	Estimated GSV from site specific gas generation modelling / Characteristic situation	TOC content / Characteristic situation from Table 1	Comments
Housing in SE Manchester	Made Ground average depth 4.4m	54% CH_4 14% CO_2 0.6l/h	0.3l/h / CS2 but with occasional higher values in one well up to 0.5l/h	0.1l/h / CS2	1.7% / CS3	Recently placed Made Ground
School in SE Manchester	Made Ground average depth 0.5m	0.1% CH_4 12% CO_2 15l/h	2.2l/h / CS3 due to occasional high flow rates, typically 0.01l/h/CS2 (due to concentration)	0.2l/h / CS2	1.3% / CS2	Made Ground placed over 50 years ago
Warehouse development in Liverpool	Made Ground average depth 2.5m	69% CH_4 12% CO_2 0.4l/h	0.3l/h / CS2	0.7l/h / CS2	1.3% / CS2	Made Ground placed over 10 years ago
Apartments, west London	Made Ground average depth 1.2m	0.1% CH_4 3.2% CO_2 1.4l/h	0.04l/h / CS1	0.2l/h / CS2	0.5% / CS1	Made Ground placed over 90 years ago
Housing in Northwest England	Made Ground average depth 2m	1.6 % CH_4 8.9% CO_2 0.8l/h	0.07l/h / CS1	0.1l/h / CS2 (close to limiting value for CS1/CS2)	0.7% / CS1	Made Ground placed over 40 years ago

The summaries show that in general the approach gives a similar assessment of gas risk to existing approaches when the anomalous or natural background readings of gas concentrations from gas monitoring are discounted. Thus it is more reliable and robust.

Conclusion

The alternative approach to ground gas assessment will provide a rapid and more reliable indicator of ground gas risk on appropriate development sites. It will remove the need for gas protection on sites located over natural ground where low levels of carbon dioxide are ubiquitous. It will also reduce the need for gas monitoring wells on low gassing sites and should give a more reliable and rapid indicator of the ground gas risk than current approaches that rely on periods of gas monitoring.

Where the assessment shows that gas protection is required developers and their consultants may still choose to install gas monitoring wells if they consider it will reduce the characteristic situation and there is a cost benefit. However on many smaller sites this will not be the case.

The approach can also be used alongside gas monitoring as a separate line of evidence in the risk assessment. This would allow the period of monitoring to be reduced from that specified in CIRIA C665 or help to avoid extended monitoring where anomalous results are obtained that are not consistent with the site conceptual model.

Where chemical test data indicates a TOC greater than the limiting value for CS3 in Table 1, or there is a credible gas migration risk from off site, gas monitoring in accordance with CIRIA C665 and BS8485: 2007 will be required to verify the gas regime and characteristic situation.

The approach and its application to various common scenarios is summarised in Table 4.

Table 4 Application of approach to common scenarios

Scenario and source of ground gas	Gas monitoring ?	Gas protection?
Natural soils with no Made Ground. Eg London Clay, Mercia Mudstone, Lias Clay, Chalk, Gault Clay, Glacial Till	✗	✗
Natural soils with No Made Ground – in an area where radon protection is required.	✗	✓ Gas/radon protection required
Natural soils with low organic content – less than 1m of Made Ground that comprises general infill and car park construction materials. Eg Made Ground over London Clay, Mercia Mudstone, Lias Clay, Chalk, Gault Clay, Glacial Till	✗	✗
Natural soils with high organic content and less than 1m of Made Ground that comprises general infill and car park construction. Eg Alluvium, Peat over natural soils such as London Clay, Mercia Mudstone, Lias Clay, Chalk, Gault Clay or Glacial Till	✗	✓ CS3 gas protection provided
Natural soils with low organic content and1m to 5m of Made Ground that comprises general infill and car park construction materials TOC less than 6%. Eg Made Ground over London Clay, Mercia Mudstone, Lias Clay, Chalk, Gault Clay, Glacial Till	✗	? Determine gas protection using TOC content of Made Ground and Table 2
Old landfill with 6m of older refuse material. Identified as old landfill on historical maps	✓ Determine TOC content and use gas generation modelling to assist with interpretation of results	? To be determined from gas monitoring data
Old mineworkings that were abandoned before the early 20th Century	? To be determined based on preliminary conceptual model using desk study data	?
Glacial Drift deposits over Coal Measures strata with no former mine workings.	✗	✗

Note: In all cases where gas monitoring/and or gas protection is not required it must be demonstrated that there are no nearby landfills or mine workings that are a credible source of gas migration the site being assessed.

Acknowledgements

The following people have made valuable comments and contributions that have helped to develop this paper:

Karen Thornton - NHBC, Richard Boyle - HCA, Simon Firth – Firth Consultants Ltd, Hugh Mallett – Buro Happold.

We would like to thank them for the time they have spent looking at the paper.

References

Boyle R and Witherington P (2007). **Guidance on evaluation of development proposals on sites where methane and carbon dioxide are present.** National House Building Council (NHBC), Edition 4, March 2007.

BR211 (2007). **Radon: guidance on protective measures for new buildings**. Building Research Establishment (BRE).

BSI (2007). **Code of practice for the characterization and remediation from ground gas in affected developments**. BS8485: 2007. British Standards.

CIEH (2008). **The local authority guide to ground gas**. Chartered Institute of Environmental Health. (Also available as the Ground gas handbook published by Whittles Publishing).

Cresser M, Killham K and Edwards T (1993). **Soil chemistry and its applications**. Cambridge University Press.

Environment Agency (2004). **Guidance on the management of landfill gas**. Landfill Technical Guidance Note 3.

Environment Agency (2005). **Guidance on sampling and testing of wastes to meet landfill waste acceptance procedures**. Version 1, April 2005.

Environment Agency (2006). **Guidance for waste destined for disposal in landfills**. Version 2, June 2006.

Herzog BL, Pennino JD and Nielsen GL (1991). **Groundwater sampling. In Practical handbook of groundwater sampling**. Lewis publishers, Michigan.

Hesse P R (1971). **A Textbook of Soil Chemical Analysis**. John Murray (Publishers) Ltd. London.

NHBC Foundation (2009). **A practical guide to building airtight dwellings**. June 2009.

Reeves GM, Sims I, Cripps JC (2006). **Clay materials used in construction**. Engineering Geology Special Publication No. 21, Geological Society, London.

Sladen JA, Parker A and Dorell GL (2001). **Quantifying risk due to ground gas on brownfield sites**. Land Contamination and Reclamation, 9 (2) 2001. EPP Publications.

University of Minnesota (2011). **Organic matter management**. Soil Scientist. http://www.extension.umn.edu/distribution/cropsystems/components/7402_02.html. Downloaded May 2011.

Wilson S and Card G (1999). **Reliability and risk in gas protection design**. Ground Engineering, February 1999 pp 32 to 36 and clarification article in the News Section of Ground Engineering, March 1999.

Wilson S, Oliver S, Mallett H, Hutchings H and Card G (2007). **Assessing risks posed by hazardous ground gases to buildings**. CIRIA Report C665.

Appendix A

Forensic description of Made Ground for purposes of gas generation estimation

1. Scope

This document specifes the test method for determining the amount of degradable material in Made Ground.

This is intended as a test from which the degradable organic content can be estimated for use in gas generation assessments that are used to the assess the risk from old landfill sites in accordance with the Local Authority Guide to Ground Gas.

2. Terms and definitions

For the purposes of this document the following terms and definitions apply.

Made Ground – soil or other material that has been placed in the ground by man.

3. Principle

A sample of Made Ground is taken and the main constituents are divided into separate batches. The batches are weighed to determine the proportion of each in the sample.

4. Apparatus

Weighing scales with a readability of 0.02% of maximum capacity (up to a maximum of 2g).

Weighing scales with a maximum capacity of at least 15kg.

5. Samples

Bulk sample Made Ground with minimum weight of 15kg.

6. Procedure

Take the bulk sample and spread it out on a suitable surface

Divide the sample into the following fractions:

- Fine soil less including gravel less than 10mm (divide this into organic and inorganic)
- Coarse inert particles including clinker, gravel, concrete, brick, etc greater than 10mm
- Wood, trees, branches, etc
- Vegetable matter, etc
- Cloth, leather
- Metal, glass, ceramics and other inert material
- Paper and card
- Other degradable material

Weigh each fraction and record the result.

Determine total organic carbon content of the fine soil fraction in accordance with the method described in *Guidance on sampling and testing of wastes to meet landfill waste acceptance procedures*, Environment Agency , 2005).

7. Test report

The test report shall include the following information.

- Site reference
- Sample reference
- Sample location and depth
- Date of sampling
- % by weight of each of the following fractions in the sample
    - Fine soil less including gravel less than 10mm
    - Coarse inert particles including gravel, concrete, brick, etc greater than 10mm
    - Wood, trees, branches, etc
    - Green vegetation, grass, food waste, etc
    - Cloth, leather
    - Metal, glass, ceramics and other inert material
    - Paper and card
    - Other degradable material
- TOC content of fine soil fraction