Ground Gas Site Investigation and Risk Assessment: Beyond GSVs

Alex Staton, SiLC, ASoBRA

Introduction

Loscoe 1986
Williams and Aitkenhead (1991)

Gorebridge 2013 – 14
Edinburgh Evening News 7 March 2016

Guidance

- Assessing Risks Posed by Hazardous Ground Gases to Buildings, CIRIA C665 (2007)
- Guidance on Evaluation of Development Proposals on Sites where Methane and Carbon Dioxide Are Present, NHBC (2007)
- Ground Gas Handbook (2009)
- The Utility of Continuous Monitoring in Detection and Prediction of 'Worst Case' Ground-Gas Concentrations. CL:AIRE Research Bulletin RB17 (2012)
- Guidance on Investigations for Ground Gas – Permanent Gases and Volatile Organic Compounds (VOCs). BS8576: 2013
- Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings. BS8485:2015 + A1:2019
- Ground Gas Monitoring and 'Worst Case' Conditions. CL:AIRE Technical Bulletin TB17 (2018)
- Continuous Ground Gas Monitoring and the Lines of Evidence Approach to Risk Assessment. CL:AIRE Technical Bulletin TB18 (2019)
- Risk and Reliability in Gas Protection and Design – 20 Years On. Technical Paper: Ground Engineering. Card et al (2019)

Conceptual Site Model

- Fundamental in every ground investigation and risk assessment. Applies to ground gas as much to contamination in general.
- Uses source-pathway-receptor linkage concept.
- Identify potential sources for assessment. Site history, walkover, previous SI, etc.
- Iterative.
- Do not treat ground gas investigation and assessment as a mere ‘add on’.

Ground Gas Sources

- Landfill gas. Unless ‘inert’ contains high proportion of biodegradable matter. Commonly 40:60 CH_4: CO_2. High generation potential ~1000s m^3/hr.
- Mine gas. Escapes from coal when extracted. Methane and/or carbon dioxide. Carbon dioxide from mine workings implicated in Gorebridge incident.
- Peat. High concentration of methane but very low generation rate. May be trapped in pockets. Also other organic sediments.
- ‘Typical’ made ground. Low gassing potential. Refer to CL:AIRE RB17.
- Less significant sources: petroleum hydrocarbons, sewage, carbonate rocks (chalk), degassing of mineralised groundwater.

Migration Mechanism

- Advection. Pressure driven flow, i.e. along a pressure gradient. Analogous to groundwater flow and described by Darcy's Law $Q = K\Delta PL$.
  - Significant only for open, high permeability (K) pathways, e.g. unsaturated sand or gravel, or fractured bedrock.
- Diffusion. Concentration driven flow, i.e. along a concentration gradient. Described by Fick's Law $F=D\Delta C/L$. Diffusivity depends on gas and substrate.
  - May be important where advection is absent (don't assume migration through clay cannot take place) although diffusive travel by itself unlikely to lead to hazardous gas concentrations.
  - Marked variations in head space gas concentration and flow between monitoring rounds common where flow is diffusive as a result of barometric pumping.

Migration Mechanisms

- **Expansion due to fall in pressure. Described by Boyle's Law, $p_1V_1 = p_2V_2$.**
  - Key mechanism as Loscoe and Gorebridge. At Gorebridge, gas accumulated in stone columns supporting the foundations by diffusion through thin till deposits and expanded into properties when atmospheric pressure dropped.
- **In solution in groundwater. CO_2 is relatively soluble in water (1.45 g/L at STP), methane much less so. Solubility decreases with decreasing pressure.**

Site Investigation

- Must reference CSM.
- Mixture of targeted and non-targeted wells varying laterally and spatially. Avoid ‘dual purpose’ wells.
- Use short well screens, typically <3m. Inappropriately screened wells can give misleading results, e.g. due to gas stratification or accumulation of gas in borehole head space.
- Record everything: carbon dioxide, methane, oxygen, carbon monoxide, hydrogen sulphide, flow rate, barometric pressure, differential pressure, depth to water.
- Purge tests can be useful.
- Sense check in the field. Refer back to CSM. Call in problems.

Initial Data Checks

- CSM!
- Plot boreholes and results on plans and cross-section to understand their spread.
- Check for possible errors in data reporting.
- Group data according to source unit. Do not carry out risk assessment on data that derive from different sources/ground conditions.
- What about flooded wells?
- Only zone if supported by the CSM. Never simply discount ‘outliers’. They must be accounted for.
- Are the data representative of a range of atmospheric conditions? Do we need more? Note falling pressure is more important than low barometric pressure.

Risk Assessment (1)

- Commonly based on Gas Screening Values (GSV). Multiply concentration by flow rate. Do not simply pick highest values from entire data set and use it to derive Characteristic Situation for the site. CSM!
- Having carried out data checks, should carry out sensitivity analysis to assess whether representative of reasonable worst case conditions. Refer to Annex F in BS8576.
- Sense check your calculations. Do they make sense in terms of the CSM?
- Data currently screened against thresholds in BS8485. Also included in CIRIA C665 and NHBC Guidance. 'Modified Wilson & Card Methodology'.
- It may be appropriate to avoid the use of GSVs in low risk sites where source is thin made ground with low organic content. Refer to CL:AIRE RB17.

Risk Assessment (1)

Characteristic Situation (CIRIA Report 149)	Risk Classification	GSV (CH_4 or CO_2) (l/hr) [1]	Additional factors	Typical source of generation
1	Very low risk	<0.07	Typically methane ≤1%v/v and/or carbon dioxide ≤5%v/v. Otherwise consider increase to Situation 2	Natural soils with low organic content. "Typical" Made Ground
2	Low risk	<0.7	Borehole flow rate not to exceed 70l/hr. Otherwise consider increase to Situation 3	Natural soil, high peat/organic content. "Typical" Made Ground
3	Moderate risk	<3.5		Old landfill, inert waste, mineworking flooded
4	Moderate to high risk	<15	Quantitative risk assessment required to evaluate scope of protective measures	Mineworking susceptible to flooding, completed landfill (WMP 26B criteria)
5	High risk	<70		Mineworking unflooded inactive with shallow workings near surface
6	Very high risk	>70		Recent landfill site

Notes:

1. Gas screening value: litres of gas/hour is calculated by multiplying the gas concentration (%) by the measured borehole flow rate (l/hr);
2. Site characterisation should be based on gas monitoring of concentrations and borehole flow rates for the minimum periods as defined within within CIRIA Report 659;
3. Source of gas and generation potential/performance must be identified;
4. Soil gas investigation to be in accordance with guidance contained within CIRIA Report 659;
5. If there is no detectable flow, use the limit of detection of the instrument;
6. The boundaries between the Partners in Technology classifications do not fit exactly with the boundaries for the above classification.

Guidance on the Evaluation of Development Proposals on Sites where Methane and Carbon Dioxide Are Present. NHBC 2007)

Risk Assessment (2)

TABLE 1: CHARACTERISTIC SITUATIONS AND RISK LEVEL

Gas Regime		Gas Screening Value[1]			Ground Permeability	Additional Factors		
		Methane (l/h)	Carbon dioxide (l/h)	Oxygen deficient gas[2] (nitrogen) (l/h)	Vertical k (m/s)	Maximum Borehole gauge pressure (Pa)	Limitations	Comment
Gas Regime A	Negligible to very low	<2 <1.5 <1.3	<12 <9 <7	<217 for all permeability[4]	$\leq 1 \times 10^{-7}$ $1 \times 10^{-7} < k < 1 \times 10^{-5}$ $\geq 1 \times 10^{-5}$	500 (based on ASTM (2016))	• <30% methane. • <21% carbon dioxide. • Not applicable where municipal solid waste landfills, mine workings or similar credible sources with credible pathways for migration are present. • Not applicable where potential ground gas reservoirs are connected to buildings (eg for gas regime B, stone columns or other open features).	No limit on oxygen depletion because it is widespread in natural soils and fill materials due to chemical and biological processes. Consider whether pressurisation could realistically occur and over what timescales (eg by rising groundwater) where potential ground gas reservoirs are connected to buildings (eg stone columns or other open features) Greater concentrations may be acceptable for ground gas from the degradation of hydrocarbons or alluvial soils (Including peat) on a case by case basis.
Gas Regime B	Low to moderate	≤10 ≤7.5 ≤6	<140 <100 <85	NL[3]	$\leq 1 \times 10^{-7}$ $1 \times 10^{-7} < k < 1 \times 10^{-5}$ $\geq 1 \times 10^{-5}$	NL[3]		
Gas Regime C	Moderate to high	≤100 ≤75 ≤60	NL[3]	NL[3]	$\leq 1 \times 10^{-7}$ $1 \times 10^{-7} < k < 1 \times 10^{-5}$ $\geq 1 \times 10^{-5}$	NL[3]	NL[3]	Where oxygen deficient ground gas or carbon dioxide is likely to be emitted from shafts, fractured rock or ground where $k > 1 \times 10^{-4}$ m/s undertake DQRA
Gas Regime D	Very high	N/A	N/A	N/A	-	-	-	DQRA required

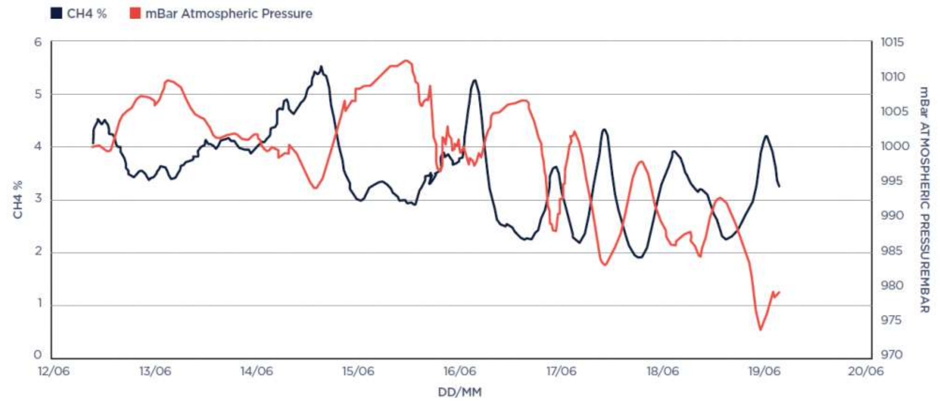
Card et al. Technical Paper: Risk and Reliability in Gas Protection Design. Ground Engineering (September 2019)

Risk Assessment (2)

- Separate limiting values for methane and carbon dioxide.
- Includes oxygen deficiency for lowest gas regime. Also borehole pressure.
- Includes consideration of vertical permeability. Should be sufficient to estimate. Apply sensitivity analysis.
- GSV calculated as before but using continuous data, not familiar orifice style sensor.
- Limiting GSVs are *much* higher than in Wilson & Card.
- DQRA for most aggressively gassing sites.
- Card et al also modified number of protection levels required.

Continuous Monitoring

- Continuous record of borehole head space concentrations. Also pressure, differential pressure and DTW.
- Can be installed and left. Modified borehole headworks.
- Not particularly new. CL:AIRE RB13 (2011). Likely to become commonplace.
- Provide much more realistic estimates of he rate at which gas is being generated than traditional ‘spot’ measurements.



Images from www.ionscience-india.com

Detailed Quantitative Risk Assessment

- Likely to be necessary only for the most aggressively gassing sites. Possibly for some Part 2A assessments.
- DQRA relies on site specific risk assessment parameters including concentrations, flow rates, properties of the substrate, effectiveness of any gas protection measures that might be present. DQRA can be used to provide a minimum specification for the effectiveness of gas protection.
- Commonly involves fault tree analysis where estimate probability of an undesirable 'top event' from estimates of the probabilities of individual events that lead to it. Some of these will be difficult to estimate, potentially limiting the circumstances under which DQRA useful.
- DQRA should become less common if Card et al (2019) approach is widely adopted.
- A DQRA is not an alternative to a poorly executed GQRA.

The Gorebridge Incident

- Coal Measures overlain by thin (~5m) boulder clay. Mine workings beneath the site contain mine gas (carbon dioxide).
- Advection is unlikely to contribute to movement of mine gas into the site. Diffusion may be signficant.
- Can use Fick's Law to estimate gas flux vertically through the till.
- Assume 100% CO2. Over 5m, concentration gradient is 0.2.
- Diffusion coefficient of CO2 in saturated clay is ~1E-6m2/d. In dry clay, ~1E-4m2/d.
- Assume living space has a footprint of 4 x 4m. Estimated mass flux through the floor is 16 x 0.2 x 1E-6 = 3.2E-6m3/d, or 0.003 litres/day.
- If the living space is 2m high, giving a volume of 32m3, it will take ~75,000 days to accumulate carbon dioxide at the critical concentration of 1.5% v/v. This ignores the effect of any structural slab, DPM or, crucially, ventilation. The calculation suggests that diffusion alone may not be a significant mechanism at the site.
- Nevertheless, note that if the soils are dry, the calculation yields a value of only 750 days. This could be of concern. It suggests there may be enough doubt in the risk assessment to warrant further investigation.

The Gorebridge Incident

- It is thought the Gorebridge incident was due to diffusion of carbon dioxide mine gas through thin clay into stone columns, where it accumulated. This reservoir of gas expanded into the living space when atmospheric pressure fell.
- Stone columns provided interconnected pore space where gas could accumulate. The diffusion coefficient for carbon dioxide in gravel is ~1E-4m2/d, i.e. similar to dry clay.
- Stones columns displaced the equivalent volume of clay and shortened the vertical migration pathway. The clay did not provide the level of protection it may have done had it been left undisturbed. This may not have been considered when the risk assessment was carried out. It has also been suggested that SI boreholes left ungrouted may have played a role.

Conclusions

- A thorough understanding of the CSM is crucial to any well designed site investigation and robust risk assessment. Too many ground gas investigations are tagged on almost as an afterthought.
- There are many tools to help from desk based information to a range of bespoke investigation approaches, not least continuous monitoring.
- Many risk assessments may be too conservative. This can be extremely costly for developers. We should be able to do better than a default 'CS3'. Work by Card et al supports this.
- DQRA will be essential for highly gassing sites but is limited by the quality of the data. DQRA is not an alternative to a poorly understood CSM and GQRA.
- It is crucial that risk assessors work with engineers. Modelling gas migration through clay is next to useless if the key migration pathway is something else entirely.