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Your Ref
Our Ref 3400/LR02-1/RJC

14th August 2017

Knights Construction Ltd

Hafod y Bwch
Middle Sontley
Wrexham
LL13 0YP

For the attention of Danny Bradshaw

Dear Danny,

Updated Ground Gas Risk Assessment for Investigations for a Proposed Agricultural Development, Rackery Lane, Llay, Wrexham.

1. Introduction & Background for Additional Works

TerraConsult Limited was commissioned by Knights Construction Group to carry out a site investigation for an area of land off Rackery Lane, Llay, Wrexham, LL12 0PB. The purpose of the report was to provide information on conditions at the site for a proposed agricultural development at the site comprising a series of turkey sheds and an auxiliary utility building/welfare).

The ground investigation work and subsequent assessment was presented in TerraConsult Phase 2 Site Investigation Report reference: 3400/01 Issue 1 of 28th June 2017. At the time of writing this report, three out of the six recommended rounds of groundwater and gas monitoring had been undertaken. This addendum letter report provides the further monitoring data and revises the ground gas risk assessment within the Phase 2 report. The full set of ground gas monitoring data is presented in Appendix A of this letter report.

2. Updated Groundwater Monitoring Results

During the monitoring period four of the wells were dry for the whole monitoring period with groundwater only encountered only in three out of the six wells. A summary of the groundwater monitoring is shown in Table 1. Groundwater was not encountered during the fieldwork. The monitoring of the installed wells has indicated some perched groundwater in WS02 (at between 1.06 m to 2.52m depth) and WS06 (at 3.91 m to 4.01m depth).

Table 1: Groundwater levels during monitoring							
Hole	Response Zone (m)	Groundwater Depth During Monitoring (m)					
		13/06/17	21/06/17	27/06/17	13/07/17	21/07/17	28/07/17
WS01	1.00-2.97	DRY	DRY	DRY	DRY	DRY	DRY
WS02	1.00-4.91	1.06	1.67	2.48	2.47	2.52	2.38
WS03	1.00-3.03	DRY	DRY	DRY	DRY	Wet at base	Wet at base
WS04	1.00-4.96	DRY	DRY	DRY	DRY	DRY	DRY
WS05	1.00-2.00	DRY	DRY	DRY	DRY	DRY	DRY
WS06	1.00-4.02	DRY	4.01	3.91	3.99	3.98	3.91
In WS03 water was monitored at a depth of 3.00 m on the last two occasions but with the well having the base at 3.03m the water monitored at 3.00 m is assessed as being water resting in the base cap of the well and this is not the groundwater level.							

3. Updated Ground Gas Monitoring and Risk Assessment

Summary of Original Measured Gas Concentrations

Three out of six rounds of gas monitoring carried were out by TerraConsult on the six gas monitoring wells at the site with atmospheric conditions varying from 988 to 1008 mbar between the 13th and 27th June 2017. One of the monitoring visits was carried out with atmospheric pressures less than 1000 mbar (pressures 988 mbar) with the other two sets of readings were all taken with air pressure greater than 1000 mbar.

The gas risk assessment in the Phase 2 report (Section 9.7) concluded that Characteristic Situation 1 (CS1) classification (Very Low risk conditions) at the site prevailed in the majority of the site and no ground gas protection measures would be required, but in the northern portion of the site, due to the methane and carbon dioxide concentrations monitored, primarily in WS04, result in this portion of the site to be designated as having a Characteristic Situation 3 (CS3) classification (moderate risk) and gas protection measures would be required in this area. However, the Turkey sheds are ventilated buildings and do not have small enclosed non-ventilated spaces therefore they are a completely different type of building to the 'normal' building types in the CIRIA guides and British Standards. Because they are always fully ventilated there is no requirement to have any specific ground gas protection measures.

This was based on the carbon dioxide concentrations recorded in one borehole –WS04 (<0.1 to 33.7 % v/v) coupled with gas flow rates measured between -9.9 to 9.0 l/hr in the same location.

Updated Measured Gas Concentrations

The final three monitoring rounds were undertaken between the 13th and 28th July 2017. Two of the monitoring visits were carried out with atmospheric pressures less than 1000 mbar (pressures 991 and 992 mbar) with the other set of readings taken with air pressure at 1010 mbar.

Overall this means that three out of six rounds were undertaken with pressure below 1000 mbar. It was also noted that the fifth round had low and falling pressure conditions. The other pressure conditions were as follows:

Rounds 1-4: Steady;
Round 5: falling conditions; and
Round 6: steady conditions.

The highest flow rates, methane and carbon dioxide concentrations, together with the lowest oxygen levels (i.e. a combination of the worst case temporal conditions recorded) from the monitoring visits are summarised in the Table 2 below and are presented in full in Appendix B of this report:

Table 2: Summary of Ground Gas Monitoring										
Borehole	Response Zone mbgl	Contamination evidence	No. of monitoring occasions	Steady State Flow (l/hr)	Methane (% v/v)	Carbon Dioxide (% v/v)	Oxygen (% v/v)	Carbon Monoxide (ppm)	Hydrogen sulphide (ppm)	Atmospheric pressure readings mb
WS01	1.00-2.97	No	6	0.1*	0.1*	1.4 – 2.7	18.6– 9.2	1*	1*	991-1008
WS02	1.00-4.91	No	6	0.1*	0.1* - 1.3	0.4 – 5.8	14.7– 20.0	1*	1*	991-1008
WS03	1.00-3.03	No	6	-9.1 - 0.1*	0.1* - 1.3	0.1 – 24.5	0.6– 20.5	1*	1*	991-1008
WS04	1.00-4.96	No	6	-9.9 – 20.5	0.1* - 33.7	0.1 – 26.6	1.0 – 20.9	1*	1*	991-1008
WS05	1.00-2.00	No	6	0.1* - 46.6	0.1* - 4.1	1.8 – 3.2	16.2– 19.4	1*	1*	991-1008
WS06	1.00-4.02	No	6	-4.4 – 4.0	0.1*	0.1* - 11.4	7.4– 20.8	1*	1*	991-1008
* Concentrations measured below the limits of detection (LOD) of the monitoring equipment. Assumed to be 0.1 for calculation purposes for all apart from CO and H2S, where the LOD is 1 ppm.										

Ground Gas Assessment

Background information relating to the origin and production of landfill and ground gases are presented in Appendix C, together with current guidance on the assessment of ground gases. In accordance with this approach and the above measured ground gas levels, it is considered that the worst case temporal conditions have been measured during the monitoring period. The gas flow rates measured for the majority of the monitoring were less than the instrument detection limit of 0.1 l/hr but positive gas flows were noted in:

WS03: 0.1 l/hr;
WS04: 9.0 l/hr;
WS05: 46.6 l/hr; and
WS06: 4.0 l/hr.

It was also noted that in the area of the backfilled pond, the hand dug inspection pit did not encounter any organic rich backfill material, it was Glacial Till with a low TOC.

Based on the measured concentrations of ground gas, the site will be zoned, with the north and eastern portion of the site (encompassing WS03 to WS06) being assessed separately compared to the remainder of the site. From Table 8.5 of CIRIA C665 the worst case Characteristic Situation for the site are as follows:

Table 3: Characteristic Gas Situations							
Borehole Number	Steady State Flow	CH₄			CO₂		
	l/h	% v/v	GSV (l/hr)	Characteristic Situation	% v/v	GSV (l/hr)	Characteristic Situation
Majority of site only – proposed shed area							
WS03	0.1	1.3	0.0013	1	24.5"	0.0245	2"
WS04	20.5	33.7	6.9085	4	26.6	5.453	4
WS05	46.6	4.1	1.9106	3	3.2	1.4912	3
WS06	4.0	0.1*	0.0004	1	11.4	0.4560	2
Southern area of site – including office building							
WS01	0.1*	0.1*	0.0001	1	2.7	0.0027	1
WS02	0.1*	1.3	0.0013	1	5.8	0.0058	1
* Concentrations measured below the limits of detection of the monitoring equipment or as negative values. Use 0.1 % for calculation of GSV. " Exceeds the normal upper limit of 5% for Characteristic Situation 1 so is assessed as Characteristic Situation 2.							

Based on the Ground Gas Assessment it can be seen that there is elevated carbon dioxide conditions across the northern and northeastern part of the site and also elevated methane concentrations in the north eastern wells WS04 plus WS05. The holes closest to the landfill to the northeast have the highest methane concentrations.

For the northern portion of the site, due to the methane and carbon dioxide concentrations monitored, primarily in WS04, results in this portion of the site to be designated as having a Characteristic Situation 4 (CS4) classification (moderate to high risk), whilst WS05 has a Characteristic Situation 3 (CS3) classification (moderate risk). Carbon dioxide concentrations in WS06 and WS03 mean that these have a Characteristic Situation 2 (CS2) classification (low risk). The remainder of the site would be classified as CS1 (Very low risk). Overall there is a reduction from CS4 in the north reducing to CS1 in the south as the boreholes become further away from the landfill. This is indicated in Figure 1 on the following page:

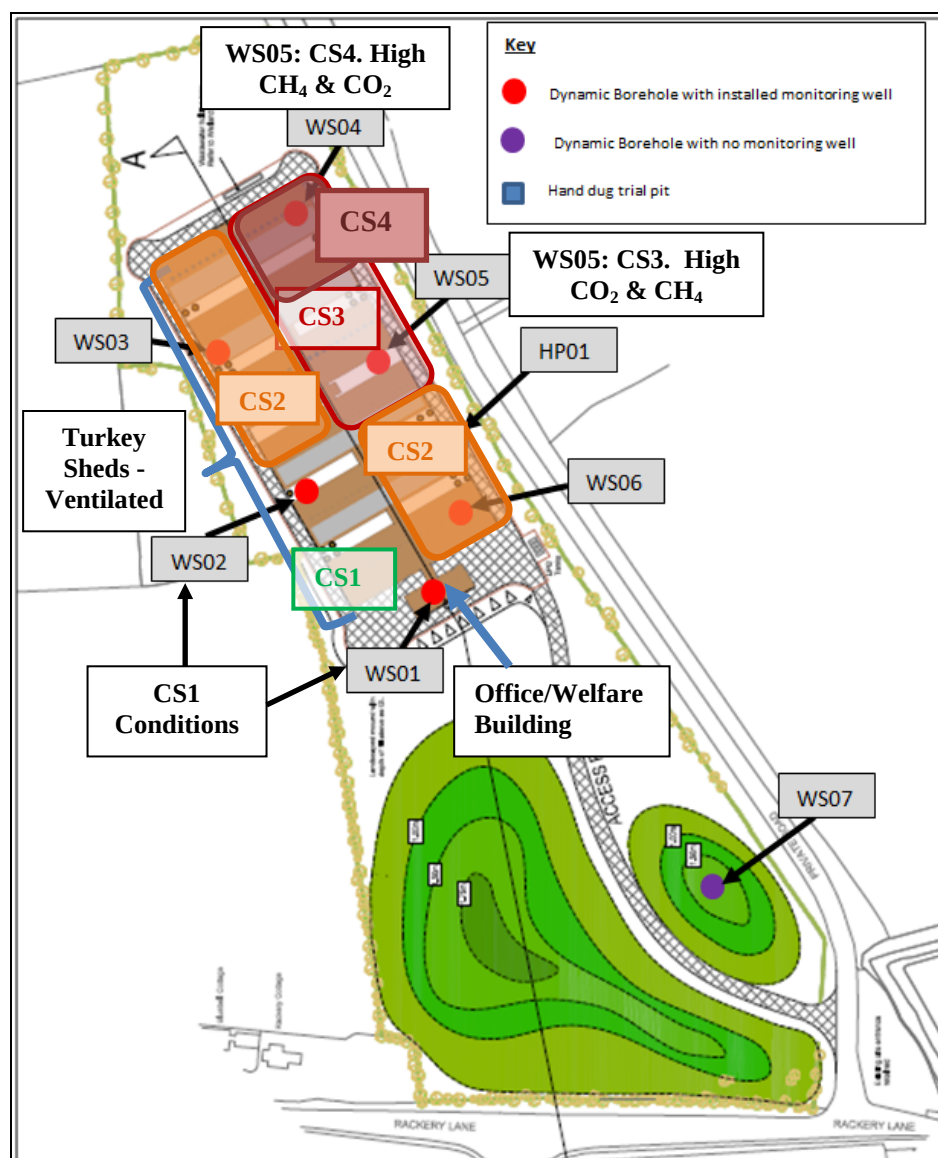


Figure 1: Summary of Ground Gas Conditions

In carrying out the ground gas risk assessment it should be noted that the turkey sheds are not standard type commercial buildings as they are naturally ventilated buildings and do not have small enclosed non-ventilated spaces. Therefore they are a completely different type of building to the 'normal' building types in the CIRIA guides and British Standards on ground gas risk assessment. Because they are always fully ventilated there is no requirement to have any specific ground gas protection measures.

The office/welfare building is a more conventional type of commercial building. Because this building is in an area where there ground gas situation is CS1 there is no requirement to have any specific ground gas protection measures.

Note that no precautions are required due to radon.

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We trust that the above assessment meets the requirements to discharge the relevant planning conditions at the site based on the robust assessment of the risk from ground gas and groundwater to the identified receptors.

Should you wish to discuss any matters in further detail, please do not hesitate to contact us.

Yours sincerely
for and on behalf of TerraConsult Ltd

A handwritten signature in black ink, reading 'R J Colin' in a cursive style.

R J Colin
Principal Geologist

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APPENDIX A

Groundwater and Ground Gas Monitoring Data

No: 3400

GROUNDWATER AND GROUND GAS MONITORING

TerraConsult

Site: Rackery Lane, Llay

Location	Date	Monitored by	Well Details		Groundwater		Gas												Weather	
			Standpipe diameter (mm)	Depth to Base (m bgl)	Water Depth (m bgl)	Water Sample Taken?	Atmospheric Pressure (mbar)	Atmospheric Pressure Comment	Relative Pressure (mb)	Flow (l/h)	CH ₄ (% v/v)	GSV CH ₄ (l/hr)	CO ₂ (% v/v)	GSV CO ₂ (l/hr)	O ₂ (% v/v)	CO (ppm)	H ₂ S (ppm)	VOC (ppm)	Conditions	Ambient Temp °C
WS01	13/06/17	GB	51	2.97	Dry	N	1008	Steady	0.01	0.1	0.1	0.0001	1.7	0.0017	19.2	1	1	NM	Sunny	20
	21/06/17	GB	51	2.97	Dry	N	1003	Steady	0.01	0.1	0.1	0.0001	2.2	0.0022	19.1	1	1	NM	Cloudy	19
	27/06/17	LG	51	2.97	Dry	N	988	Steady	0.01	0.1	0.1	0.0001	1.4	0.0014	18.9	1	1	NM	Rain	15
	13/07/17	GB	51	2.97	Dry	N	1010	Steady	0.01	0.1	0.1	0.0001	2.7	0.0027	18.6	1	1	NM	Cloudy/Sunny spells	21
	21/07/17	GB	51	2.97	Dry	N	991	Falling	0.01	0.1	0.1	0.0001	2.6	0.0026	18.8	1	1	0.1	Raining	16
	28/07/17	HP	51	2.97	Dry	N	992	Steady	0.01	0.1	0.1	0.0001	2.4	0.0024	18.7	1	1	NM	Raining	16
WS02	13/06/17	GB	51	4.91	1.06	Y	1008	Steady	0.01	0.1	0.1	0.0001	0.4	0.0004	20.0	1	1	NM	Sunny	20
	21/06/17	GB	51	4.91	1.67	N	1003	Steady	0.01	0.1	0.1	0.0001	1.0	0.0010	19.8	1	1	NM	Cloudy	19
	27/06/17	LG	51	4.91	2.48	N	988	Steady	0.01	0.1	0.1	0.0001	1.4	0.0014	19.0	1	1	NM	Rain	15
	13/07/17	GB	51	4.91	2.47	N	1010	Steady	0.01	0.1	0.1	0.0001	5.8	0.0058	14.7	1	1	NM	Cloudy/Sunny spells	21
	21/07/17	GB	51	4.91	2.52	N	991	Falling	0.01	0.1	0.1	0.0001	3.3	0.0033	17.7	1	1	0.1	Raining	16
	28/07/17	HP	51	4.91	2.38	N	992	Steady	0.01	0.1	1.3	0.0013	3.1	0.0031	17.4	1	1	NM	Raining	16
WS03	13/06/17	GB	51	3.03	Dry	N	1008	Steady	-0.11	-9.1	0.1	-0.0091	0.1	-0.0091	20.8	1	1	NM	Sunny	20
	21/06/17	GB	51	3.03	Dry	N	1003	Steady	0.01	0.1	0.9	0.0009	22.1	0.0221	0.7	1	1	NM	Cloudy	19
	27/06/17	LG	51	3.03	Dry	N	988	Steady	-0.01	0.1	1.3	0.0013	24.5	0.0245	0.8	1	1	NM	Rain	15
	13/07/17	GB	51	3.03	Dry	N	1010	Steady	-2.01	0.1	0.1	0.0001	0.5	0.0005	20.5	1	1	NM	Cloudy/Sunny spells	21
	21/07/17	GB	51	3.03	3.00	N	991	Falling	0.01	0.1	0.1	0.0001	23.6	0.0236	0.6	1	1	0.1	Raining	16
	28/07/17	HP	51	3.03	3.00	N	992	Steady	0.01	0.1	0.1	0.0001	16	0.0160	6.6	1	1	NM	Raining	16
WS04	13/06/17	GB	51	4.96	Dry	N	1008	Steady	-0.12	-9.9	0.1	-0.0099	0.1	-0.0099	20.9	1	1	NM	Sunny	20
	21/06/17	GB	51	4.96	Dry	N	1003	Steady	0.86	9.0	33.7	3.0330	24.0	2.1600	1.6	1	1	NM	Cloudy	19
	27/06/17	LG	51	4.96	Dry	N	988	Steady	0.04	0.3	33.1	0.0993	26.6	0.0798	1.0	1	1	NM	Rain	15
	13/07/17	GB	51	4.96	Dry	N	1011	Steady	-0.17	-3.4	0.1	-0.0034	0.2	-0.0068	20.7	1	1	NM	Cloudy/Sunny spells	21
	21/07/17	GB	51	4.96	Dry	N	991	Falling	2.19	20.5	33.4	6.8470	26.4	5.4120	1.1	1	1	0.1	Raining	16
	28/07/17	HP	51	4.96	Dry	N	992	Steady	0.01	0.1	26.3	0.0263	21.3	0.0213	4	1	1	NM	Raining	16
WS05	13/06/17	GB	51	2.00	Dry	N	1008	Steady	0.01	0.1	0.1	0.0001	1.8	0.0018	19.0	1	1	NM	Sunny	20
	21/06/17	GB	51	2.00	Dry	N	1003	Steady	0.01	0.1	0.1	0.0001	2.1	0.0021	18.5	1	1	NM	Cloudy	19
	27/06/17	LG	51	2.00	Dry	N	988	Steady	0.01	0.1	0.1	0.0001	3.2	0.0032	19.4	1	1	NM	Rain	15
	13/07/17	GB	51	2.00	Dry	N	1011	Steady	0.01	0.1	0.1	0.0001	3.0	0.0030	18.5	1	1	NM	Cloudy/Sunny spells	21
	21/07/17	GB	51	2.00	Dry	N	991	Falling	0.01	0.1	0.1	0.0001	3.2	0.0032	18.5	1	1	0.1	Raining	16
	28/07/17	HP	51	2.00	Dry	N	992	Steady	699	46.6	4.1	1.9106	2	0.9320	16.2	1	1	NM	Raining	16
WS06	13/06/17	GB	51	4.02	Dry	N	1008	Steady	-0.39	-4.4	0.1	-0.0044	0.1	-0.0044	20.8	1	1	NM	Sunny	20
	21/06/17	GB	51	4.02	4.01	N	1003	Steady	0.11	2.2	0.1	0.0022	0.9	0.0198	17.2	1	1	NM	Cloudy	19
	27/06/17	LG	51	4.02	3.91	N	988	Steady	0.01	0.1	0.1	0.0001	0.4	0.0004	18.1	1	1	NM	Rain	15
	13/07/17	GB	51	4.02	3.99	N	1010	Steady	-0.19	-3.5	0.1	-0.0035	0.8	-0.0280	20.2	1	1	NM	Cloudy/Sunny spells	21
	21/07/17	GB	51	4.02	3.98	N	991	Falling	0.29	4.0	0.1	0.0040	11.4	0.4560	7.4	1	1	0.1	Raining	16
	28/07/17	HP	51	4.02	3.91	N	992	Steady	0.01	0.1	0.1	0.0001	1.0	0.0010	19.9	1	1	NM	Raining	16

NOTES:

NM = Not Measured.

(x) = Peak value recorded.

[grey] = Below detection limit.

$$\text{GSV (l/HR)} = \frac{[\text{gas concentration (\%v/v)}]}{100} \times [\text{gas well flow rate (l/hr)}]$$

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APPENDIX B

Current Guidance for Ground Gas Risk Assessment

Current Guidance for Ground Gas Risk Assessment

Origin of Ground and Landfill Gases

When carrying out a ground gas risk assessment for permanent ground gases (e.g. methane and carbon dioxide), the origin or source of the gases is important as potential risks will vary depending on the source. This Appendix relates to the risk of the two main ground gases of concern: methane and carbon dioxide, and does not apply to other ground gases (e.g. radon or vapours from hydrocarbon spills). Methane and carbon dioxide are major constituents of landfill gas but can also occur from a variety of anthropogenic and natural sources, as summarised in Table G1 below:

Table G1. Potential Sources of Ground Gases		
Gas	Source	Comments
Landfill Gas	Anaerobic decomposition of degradable waste within landfill sites. Typically 60% methane and 40% carbon dioxide during methanogenic phase.	Composition varies over time, particularly in early stages. Contains a range of minor constituents (particularly carbon monoxide and hydrogen sulphide).
Landfill Associated Gases	- Anaerobic degradation of leachate external to the site; - Degassing of dissolved gases in groundwater; - Evolution of gases following interaction between leachate and groundwater	Can result in secondary (external) production of methane or carbon dioxide.
Made Ground	Anaerobic degradation of organic components	Very variable depending on source
Sewer Gas, Cess Pits	Anaerobic degradation of organic components of sewage producing methane and carbon dioxide.	Often characterised by hydrogen sulphide odour.
Mains Gas	Leakage from underground pipework or storage tanks. Mainly methane but often contains higher alkanes.	An odouriser is added to permit detection of leaks. Typically 90% CH ₄ , but 1 to 27% C ₂ -C ₄ alkanes, May also contain other trace gases e.g. CO, helium and CO ₂ (from degradation of CH ₄ in the ground).
Other Anthropogenic Sources	- Degradation of leaked or spilled hydrocarbons or other industrial chemicals; - Anaerobic degradation of organic contaminants in groundwaters (e.g. silage liquor); - Reactions between monitoring well construction components and environment; - Burial grounds/cemeteries.	Hydrocarbon spillages often have an 'oily' odour. Fuel spillages common – Petrol or Diesel and can contain a wide range of VOC's. Can degrade to produce methane / carbon dioxide.
Alluvium / Marsh / Peat Gas	Anaerobic microbial degradation of organic material (usually waterlogged vegetation / peat). Often associated with the presence of alluvial deposits or dredgings.	
Geogenic Gas	Natural seepages of carbon dioxide and hydrocarbon gases derived from geologic sources such as coal seams and deep oil / gas source formations. Can be present in solution in groundwaters.	Methane most common but can contain carbon dioxide and higher alkanes.
Mine Gases	Various types. Most common is "fire damp" with high methane, produced by the desorption of gas trapped in coal. "Black damp" (Stythe gas) with high carbon dioxide and denser than air. "White damp" is high in carbon monoxide.	Methane most common. Can contain higher alkanes, carbon dioxide and carbon monoxide. Often low in oxygen.
Natural Shallow Ground Gas	Various types - high carbon dioxide formed by subsurface aerobic activity leading to depleted oxygen and elevated carbon dioxide; - chemical degradation of rocks (e.g. carbonates) producing carbon dioxide; - carbon dioxide production in root zone of soils by plants.	Gases can be emitted from ground under falling barometric pressure conditions.

This Appendix concentrates on the assessment of risk from methane and carbon dioxide. This Appendix does not provide guidance for the assessment of risk when other gases are present due to 'Other Sources' from the above table (particularly organic compounds such as BTEX and VOC's or for the risk from radon or hydrogen sulphide).

To determine the origin of the gas a range of factors must be considered together, including;

1. Proximity of likely sources;
2. Ground conditions (geology, hydrogeology, anthropogenic pathways etc);
3. Properties of gases present including:
 - Chemical composition;
 - Physical properties;
 - Ratios of components e.g. methane : carbon dioxide.
4. Timeframe of activities such as infilling periods, capping works, installation of gas control systems etc.

Identification of the originating source may be problematic given that there may be more than one source present and trace gas analysis may be required. Identification of the sources of the gases encountered during monitoring is usually carried out through a process of eliminating the most unlikely potential sources (given the site setting) and selecting those which are the more likely candidates.

Hazards Associated with Presence of Ground Gases

Methane gas is combustible and potentially explosive. When the concentration of methane in air is between the limits of 5.0%v/v and 15.0%v/v an explosive mixture is formed. The Lower Explosive Limit (LEL) of methane is 5.0%v/v, which is equivalent to 100% LEL. The 15.0%v/v limit is known as the Upper Explosive Limit (UEL), but concentrations above this level cannot be assumed to represent safe concentrations. Further, the LEL and UEL will vary (up and down) depending upon the proportion of other gases (including oxygen). However, the fact that methane is a colourless, odourless gas means that there is no simple indicator of the presence of the gas until such a time as explosive limits are reached and an incident occurs. Methane is lighter than air and has a low toxicity. However, at high concentrations it can result in asphyxiation due to oxygen displacement.

Carbon dioxide is a colourless, odourless gas, which, although non-flammable, is both toxic and an asphyxiant. As carbon dioxide is denser than air, it will collect in low points and depressions. The UK Health & Safety Executive (HSE) has published information relating to concentrations of carbon dioxide that humans may be exposed to, which uses concentrations contained in the Control of Substances Hazardous to Health Regulations 2002 (as amended). These are the Long Term Occupational Exposure Limit (LTOEL, 8 hour period) and the Short Term Occupational Exposure Limit (STOEL, 15 minute period), which are 0.5% and 1.5% carbon dioxide, respectively.

Parameters Influencing the Rate of Ground Gas Production

Figure G2 is taken from EA guidance document LFTGN 03 illustrates typical ground gas generation curves from biodegradable materials:

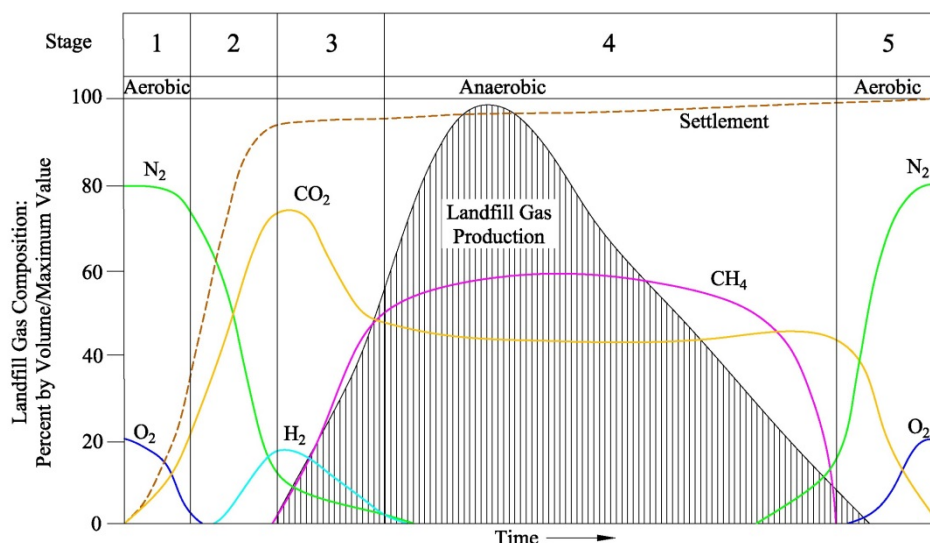


Figure G2. Idealised Representation of Landfill Gas Generation.

The production of methane and carbon dioxide at a landfill site may be expected to be considerable and ongoing. Concentrations of methane will eventually decrease, followed by concentrations of carbon dioxide, but the duration and rate of gas production can vary markedly between sites. Five distinct phases of gas production occur during the process which are, in order of event (as marked on Figure G2), as follows:

1. An aerobic phase involving oxygen depletion and temperature increase through aerobic respiration;
2. The establishment of anaerobic conditions and the evolution of carbon dioxide and hydrogen through acidogenic activity;
3. Commencement of methanogenic activity; the establishment of populations of methanogenic bacteria;
4. A phase of stable methanogenic activity, which may go on for many tens of years;
5. A phase of decreasing methanogenic activity, representing depletion of the organic material and a return to aerobic conditions.

The time scale for the return to the normal ground gas concentrations will be highly variable, depending upon the types and quantities of materials present. In addition, the optimum parameters influencing the rate of decomposition and ground gas production within the ground at a site are as follows:

- High water content with adequate rainfall and water infiltration to provide moisture content between approximately 20 to 26%;
- Conditions that either are or are very close to anaerobic;
- High proportion of biodegradable materials;
- A pH between 6.5 and 8.5, ideally verging slightly on the acidic between pH 6 to 7;
- Temperature between 25°C and 55°C;
- The ratio of the biochemical and chemical oxygen demands (BOD:COD);
- High permeability;
- Small particle size, as finer subsurface materials possess a greater surface area to provide a growing 'face' for the micro-organisms but high fines levels reduces permeability and reduces decomposition rate.

For this reason, it is vital that sources of methane and carbon dioxide are identified prior to the commencement of any work on a construction site, and that the ground gas regime is characterised at the worst temporal conditions a site may experience. From this, a risk assessment is carried out to identify the risk at the site from ground gases so that suitable protection measures can be designed and incorporated into a development to prevent a dangerous build-up of gas occurring.

Factors Influencing the Migration and Behaviour of Ground Gases

There are many factors that influence the migration of ground gases which can affect the risk from a gassing source:

- driving force – pressure differential along a pathway, diffusion and dissolved in solution;
- meteorological conditions – short term and seasonal conditions including atmospheric pressure changes (e.g. rapidly falling pressure causes gas to expand increasing emission rates), rainfall, frozen ground and thawing, temperature;
- geological and groundwater conditions – these can have the over-riding influence on the direction/pathways and quantity of migrating gas;
- anthropogenic influences – man-made pathways include mine shafts, service runs/drains, foundation piles, underground voids/pits/basements, foundation/building design/construction

Guidance Documents

Currently in the UK, there are no statutory threshold limits for hazardous gases in the ground as site specific variables mean that standard threshold values cannot be applied. The published guidance relating to development of sites where methane and carbon dioxide are present has been produced in response to building projects on or close to landfill sites, as both gases are principal constituents of landfill gas. Much of the historic guidance that has been produced on gas risk assessment focused on landfill sites and as a result there has previously been a lack of clarity when relating the process to gas conditions on non-landfill sites.

Statutory guidance regarding methane in the ground has previously taken a limiting concentration of 1.0 % by volume methane (equal to 20% of the lower explosive limit of methane in air) above which necessary actions will be appropriate. For carbon dioxide the limiting recommended trigger was 1.5 % by volume (the Long Term Exposure Limit for carbon dioxide). Above these concentrations the Building Regulations Approved Document C (1992) stated that consideration should be given to whether actions may be appropriate, whilst more specific solutions would be likely to be necessary at concentrations greater than 5% by volume of carbon dioxide (Building Regulations Approved Document C, 1992). However, the latest fully revised version of Approved Document C (DoE, 2004) no longer endorses this approach and instead requires the use of a risk-based approach in interpreting the findings of a gas monitoring survey. Further, the latest EA documentation on landfill gas (LFTGN 03, 2004) continues to sanction the use of a risk-based approach through a structured approach to the assessment of ground gases and links with the risk assessment process outlined within CLR 11 for soil contaminants.

With the above in mind, recent guidance has been produced in 2006 and 2007 with the aim of providing up to date advice in relation to residential and commercial development. The guidance does not address issues associated with gas derived from landfills, for this refer to “*Guidance on the Management of Landfill Gas*” (Environment Agency 2004) for an overview.

Recent guidance relevant to gas assessments for residential and commercial development includes;

- **Wilson *et al.* (CIRIA C665, December 2007) “Assessing Risks Posed by Hazardous Ground Gases for Buildings.”**

This document provides up to date advice on all aspects of ground gas risk assessment such as investigation, monitoring programmes, data collection and interpretation. The guidance presents separate methodologies for the characterisation of:

- **All development types except low rise housing with gardens and for Low Rise Buildings without a 150mm void (Situation A) (Table 8.5 CIRIA C665)**
and;

Idealised Frequency and Period of Monitoring (after Table 5.5a and 5.5b, CIRIA C665)						
		Generation Potential of Source				
		Very Low	Low	Moderate	High	Very High
Sensitivity of Development	Low (Commercial)	4/1	6/2	6/3	12/6	12/12
	Moderate (Flats)	6/2	6/3	9/6	12/12	24/24
	High (Residential with Gardens)	6/3	9/6	12/6	24/12	24/24

Notes

1. First number is the number of readings and the second is the minimum period in months (e.g. 6/2 – six sets of readings over two months).
2. At least two sets of readings must be at low (preferably under 1,000 mb) and falling pressure.
3. High sensitivity end use on high or very high hazard site will not normally be acceptable unless the source is treated to reduce gassing potential.

Before the latest guidance, good practice for site characterisation had been based upon the method proposed by Wilson and Card (1999). CIRIA C665 (2007) effectively supersedes Wilson and Card (1999) and includes a modified version of the Wilson and Card method (Tables 8.5, 8.6 and Box 8.1). Gas concentrations and flow rates for either methane and/or carbon dioxide measured at a site to 'Characteristic Situations.' Appropriate protection measures are selected from Table 8.6 (if using modified Wilson & Card method) and from Box 8.4 from CIRIA C665 (if using the NHBC traffic lights method). Throughout the risk assessment process, strong regard must be given to the nature of the gassing source, the flow rates and the estimated surface emissions. Note that certain protection measures are stated in CIRIA Report 149 that are now considered wholly inappropriate to certain developments and consequently should not be used without modification. Throughout the process, it is important to remember that these tables are not intended to be used as a definitive design tool and have been prepared to show the typical scope of measures for gas control.

Both the NHBC (2007) and CIRIA (2007) guidance documents and BS 8485 (2015) propose that both ground gas concentrations and flow rates are used to calculate the limiting gas well gas volume flow rates for methane and carbon dioxide, based on the ground gas conditions monitored for during the worse-case temporal conditions. This limiting gas well volume flow rate is termed the Gas Screening Value (GSV, note that this was termed borehole gas volume flow), and is calculated as follows:

$$\text{GSV (l/hr)} = \frac{[\text{gas well gas concentration (\%v/v)}] \times [\text{gas well flow rate (l/hr)}]}{100}$$

These GSVs are then compared to generic 'Traffic Lights' contained within the NHBC guidance, which present typical maximum gas concentrations and limiting GSV's, for 'Situation B Development' (Low rise housing with gardens).

Table 8.7 NHBC Traffic light system for 150 mm void				
Traffic Light	Methane ¹		Carbon Dioxide ²	
	Typical max concentration ³ (% by volume)	Gas Screening Value ^{2,4} (litres/hour)	Typical max concentration ³ (% by volume)	Gas Screening Value ^{2,4} (litres/hour)
Green	1	0.13	5	0.78
Amber 1	5	0.63	10	1.6
Amber 2	20	1.60	30	3.10
Red				
Notes: 1. The worst-case ground gas regime identified on the site, either methane or carbon dioxide, at the worst-case temporal conditions that the site may be expected to encounter will be the decider as to what Traffic Light is allocated; 2. Borehole Gas Volume Flow Rate, in litres per hour as defined in Wilson and Card (1999), is the borehole flow rate multiplied by the concentration in the air stream of the particular gas being considered; 3. The Typical Maximum Concentrations can be exceeded in certain circumstances should the Conceptual Site Model indicate it is safe to do so; 4. The Gas Screening Value thresholds should not generally be exceeded without the completion of a detailed ground gas risk assessment taking into account site-specific conditions.				

Box 8.4 of CIRIA C665 Gas protection measures for low-rise housing development based upon allocated NHBC Traffic light (Boyle and Witherington, 2007)	
Traffic Light Classification	Protection Measures Required
Green	Negligible gas regime identified and gas protection measures are not considered necessary.
Amber 1	Low to intermediate gas regime identified, which requires low-level gas protection measures, comprising a membrane and ventilated sub-floor void to create a permeability contrast to limit the ingress of gas into buildings. Gas protection measures should be as prescribed in BRE Report 414. Ventilation of the sub-floor void should facilitate a minimum of one complete volume change per 24 hours.
Amber 2	Intermediate to high gas regime identified, which requires high-level gas protection measures, comprising a membrane and ventilated sub-floor void to create a permeability contrast to prevent the ingress of gas into buildings. Gas protection measures should be as prescribed in BRE Report 414. Membranes should always be fitted by a specialist Contractor. As with Amber 1, ventilation of the sub-floor void should facilitate a minimum of one complete volume change per 24 hours. Certification that these passive protection measures have been installed correctly should be provided.
Red	High gas regime identified. It is considered that standard residential housing would not normally be acceptable without a further Gas Risk Assessment and/or possible remedial mitigation measures to reduce and/or remove the source of gas.

For a ‘Situation A Development’ (All development except low rise housing with gardens), the GSV value is used to derive the appropriate Characteristic Situation from Table 8.5 of CIRIA C665 (below):

Table 8.5 from CIRIA C665 Modified Wilson and Card Classification					
Characteristic Situation (CIRIA R149)	Comparable Partners in Technology gas Regime (see Box 8.2)	Risk Classification	Gas Screening Value (CH₄ or CO₂) (l/hr)¹	Additional Factors	Typical Source of Generation
1	A	Very low risk	<0.07	Typically methane ≤ 1% and/or carbon dioxide ≤ 5%. Otherwise consider increase to Situation 2	Natural soils with low organic content “Typical” made ground
2	B	Low risk	<0.7	Borehole air flow rate not to exceed 70l/hr. Otherwise consider increase to characteristic Situation 3	Natural soil, high peat/organic content. “Typical” made ground
3	C	Moderate risk	<3.5		Old landfill, inert waste, mine working flooded
4	D	Moderate to high risk	<15	Quantitative risk assessment required to evaluate scope of protective measures.	Mine working susceptible to flooding, completed landfill (WMP 26B criteria)
5	E	High risk	<70		Mine working unflooded inactive with shallow workings near surface
6	F	Very high risk	>70		Recent landfill site

It was intended in CIRIA C665 that the characteristic situation allocated to the development from the table above would then be used in Table 8.6 of CIRIA C665 in order to determine the level of gas protection the development requires. However, BS8485:2015 superseded this document and a different set of mitigation standards were put forward.

The recommended minimum gas protection score (points) be selected based on the building type (Table 3 which defines four building types) and the ground gas Characteristic Situation as detailed in Table 4 of BS8485:2015 (see below).

The first step in the decision making process is to obtain the level of gas protection necessary in the range 0 to 7.5 from Table 4. Then a combination of structural barriers (Table 5) ventilation protection measures (Table 6) and/or gas resistant membranes (Table 8) should be chosen to meet that requirement. The level of gas protection necessary should take into account the characteristic gas situation and a number of other factors. The whole decision making process should be made transparent, where all parties can see the approach being taken, can understand the various steps and decisions made and be confident that a risk-assessed solution has been designed and installed commensurate with the construction and site constraints.

Where the gas Characteristic Situation is 4 or more (and for NHBC Red situations according to CIRIA C665), the site requires a comprehensive risk assessment to confirm the scope of protection measures. These are higher risk sites and reliance on Table 4 alone is not sufficient.

BS8485:2015 Table 3 Building Types				
	Type A	Type B	Type C	Type D
Ownership	Private	Private or commercial/ public, possible multiple	Commercial / public	Commercial / industrial
Control (change of use, structural alterations, ventilation)	None	Some but not all	Full	Full
Room sizes	Small	Small / medium	Small to large	Large industrial / retail park style

BS8485:2015 Table 4 Gas Protection Score by CS and Type of Building				
CS	Required Gas Protection			
	High risk	Medium risk		Low risk
	Type A	Type B	Type C	Type D
1	0	0	0	0
2	3.5	3.5	2.5	1.5
3	4.5	4	3	2.5
4	6 ^(A)	5.5 ^(A)	4.5	3.5
5	(B)	6.5 ^(A)	5.5	4.5
6	(B)		7.5	6.5
a)	Residential building should not be built on CS4 or higher sites unless the type of construction or site circumstances allow additional levels of protection to be incorporated, e.g. high-performance ventilation or pathway intervention measures, and an associated sustainable system of management of maintenance of the gas control system, e.g. in institutional and/or fully serviced contractual situations.			
b)	The gas hazard is too high for this empirical method to be used to define the gas protection measures			
NOTE 3 The NHBC has published guidance for use on residential developments, which utilise an alternative classification (“traffic light”) system. This guidance typically applies to Type A buildings utilising beam and block floor constructions with clear void ventilation. The design choice variables are limited to decisions relating to the membrane specification and verification recommendations (see Table 7). Designers utilising this system would therefore need to refer to NHBC to assess compliance for specific recommendations [see 8485:2015 for further on this note]				
NOTE4 The method of selecting the combination of these types of protection is given in section 7.2 of BS8485:2015. Once type of measures has been decided, the detailed design and specification of the measures should be undertaken (section 7.3)				

Section 7.2 defines the order of selecting protective measures. The first choice is provided by structural barriers as defined in Table 5.

BS8485:2015 Table 5 Gas protection scores for structural barriers		
PROTECTION ELEMENT/SYSTEM	SCORE	COMMENTS
Floor and substructure design		
Floor slabs		
Block and beam floor slab	0	<i>General – score conditional that breaches of slab are sealed</i>
Cast in situ ground-bearing floor slab (with only nominal mesh reinforcement)	0.5	
Cast in situ monolithic reinforced ground-bearing raft or reinforced cast in situ suspended floor slab with minimal penetrations(with only nominal mesh reinforcement)	1 or 1.5	<i>To achieve 1.5, raft or suspended slab to be well reinforced to prevent cracking and minimal penetrations</i>
Basement floor and walls to BS 8102:2009, Grade 2 waterproofing	2	<i>Conditional that waterproofing is not based on geosynthetic clay liner</i>
Basement floor and walls to BS 8102:2009, Grade 3 waterproofing	2.5	

Ventilation methods are detailed in Table 6, and points can only be gained from using one of the five types

BS8485:2015 Table 6 Gas Protection Scores for Ventilation Protection Measures		
PROTECTION ELEMENT/SYSTEM	SCORE	COMMENTS
a) Pressure relief pathway (usually formed by low fines gravel or with a thin geocomposite blanket with strips terminating in a gravel trench external to the building)	0.5	<i>Whenever possible, a pressure pathway relief pathway (as a minimum) should be installed in all gas protection measures systems. If a layer has a low permeability and/or is not terminating in a venting trench (or similar), then the score is zero.</i>
b) Passive sub floor dispersal layer		
Very good performance	2.5	<i>Performance criteria shown in Fig B.6 and B.7 of BS 8484:2015.[See Annex B]</i>
Good performance	1.5	
Media used to provide the dispersal layer are:		
• Clear void		
• Polystyrene void forming blanket		
• Geocomposite void former blanket		
• No-fines gravel layer with gas drains		
• No-fines gravel layer		
c) Active dispersal layer, usually comprising fans with active abstraction (suction) from a subfloor dilution layer, with roof level vents. The dilution layer may comprise a clear void or be formed of geocomposite or polystyrene void formers	1.5 to 2.5	<i>This system relies on continued serviceability of the pumps, therefore alarm and response systems should be in place. [See Annex B].</i>
d) Active positive pressurisation by the creation of a blanket of external fresh air beneath the building floor slab by pumps supplying air to points across the central footprint of the building into a permeable layer, usually formed of a thin geocomposite blanket	1.5 to 2.5	<i>This system relies on continued operation of the pumps, therefore alarm and response systems should be in place. [See Annex B].</i>
e) Ventilated car park (floor slab of occupied part of the building under consideration is underlain by a basement or undercroft)	4	<i>Assumes car park is vented , designed to Building Regulations 2000, Approved Document F.</i>

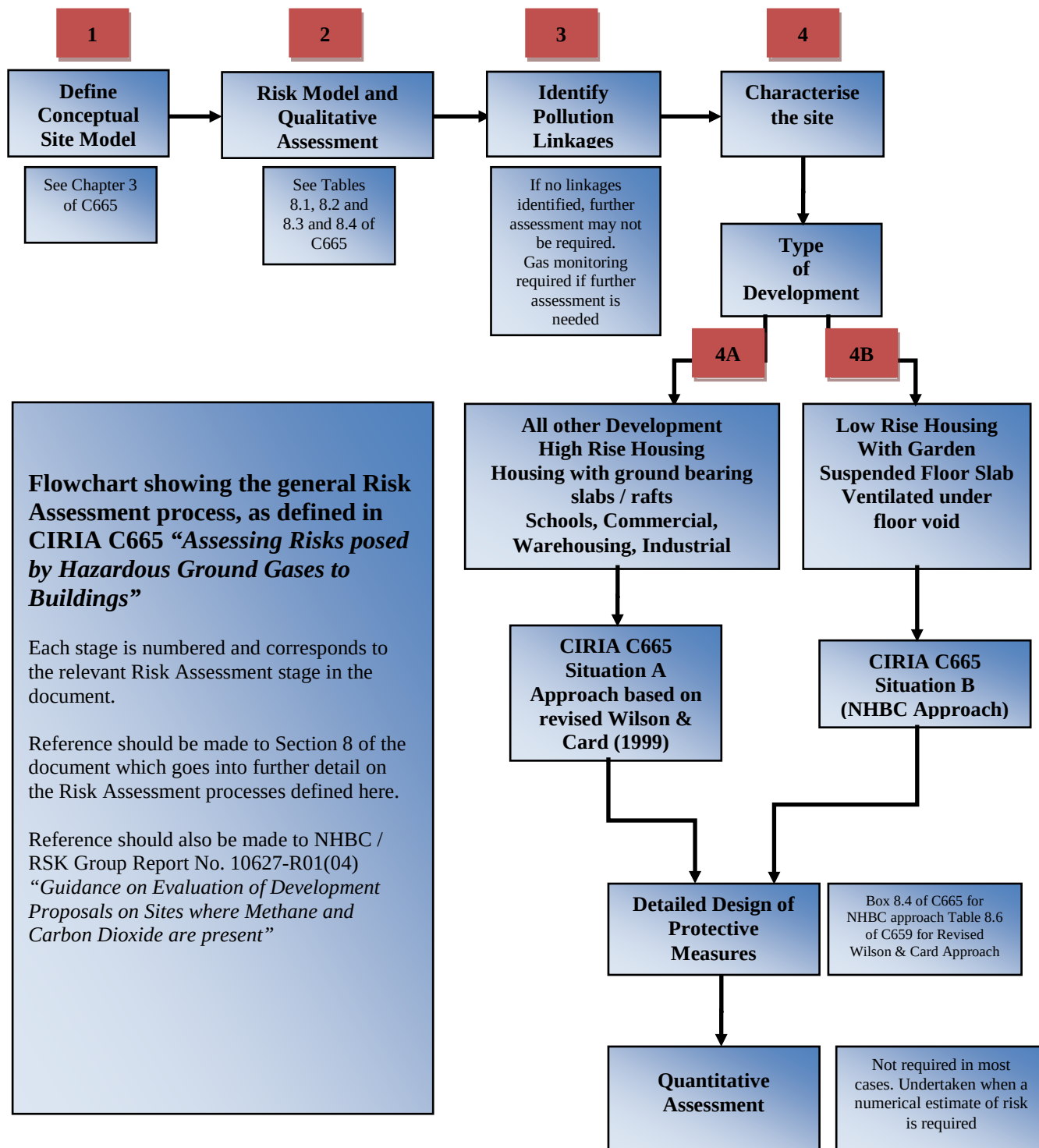
Membrane methods are detailed in Table 7.

BS8485:2015 Table 7 Gas protection score for gas resistant membrane		
PROTECTION ELEMENT/SYSTEM	SCORE	COMMENTS
Gas resistant membrane meeting all of the following criteria: • Sufficiently impervious to gases with a methane gas transmission rate $<40.0 \text{ ml/day/m}^2/\text{atm}$ (average) for sheet and joints (tested in accordance with BS ISO 15105-1 manometric method) • Sufficiently durable to remain serviceable for the anticipated life of the building and duration of gas emissions; • Sufficiently strong to withstand in-service stresses (eg settlement if placed below a floor slab); • Sufficiently strong to withstand the installation process and following trades until covered (eg penetration from steel fibres in fibre reinforced concrete, dropping tools etc); • capable, after installation, of providing a complete barrier to the entry of the relevant gas; and • verified in accordance with CIRIA C735	2	<i>The performance of membranes is heavily dependent on the quality and design of the installation, resistance to damage after installation, and the integrity of joints.</i> <i>If a membrane is installed that does not meet the criteria, then the score is zero.</i>

For a site which is impacted by migratory gases from an off-source, the development may be protected by imposing pathway intervention methods, which if successfully validated, could also remove the need for further analysis. It is essential that the gas regime in these circumstances has been fully characterised and that the only source impacting the site is located off site and that the pathway is clearly defined and its interception equally proven before construction commences. Pathway intervention methods may include vertical membrane installations, venting trenches, rows of stone columns, activated trenches and various proprietary systems. These systems are particularly relevant to domestic housing where there is limited scope for foundation type solutions.

Following the choice of protection measures, detailed design should be entered into [section 8 of BS 8485:2015].

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