# Introduction to coal mine gas risk assessment and protection design

SoBRA Early Careers webinar 18th February 2025

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# Contents

- Why mine gas? And how is it different from other ground gas sources.
- Key sources of information for the risk assessment
- Site investigation design for lines of evidence
- Limitations of gas monitoring and how to design response zones and effective monitoring strategies
- When you need to do DQRA, and when generic screening approach in BS8485 is not applicable
- Design of protection measures – more than adding up points!
- Q & A

# Intro to mine gas and CL:AIRE guidance

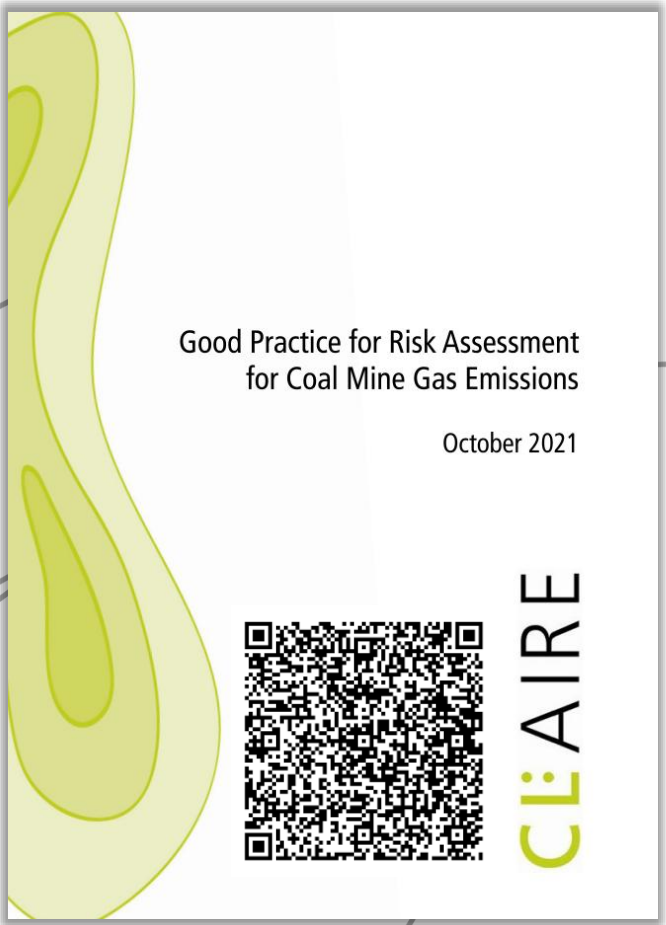
# Coal mine gas – high risk scenarios

Why is coal mine gas potentially high risk?

- Gas can accumulate in **large volumes in voids** in the ground.
- There is the possibility of open **preferential pathways** in the ground - shafts and adits
- The system of workings in the ground is heterogeneous and there is therefore likely to be **uncertainty in the ground model**. There is also the possibility of unrecorded shallow workings.
- Sites with coal mining legacy are often **well positioned** to be potentially developed.

# CL:AIRE (2021) *Good practice for risk assessment for coal mine gas emissions*

- **Competence** of those doing the assessment – chartered geologists or chartered engineers to sign off assessments and designs
- Importance of creating **visual CSM diagrams**
- GSVs and points score system in **BS8485 may not be relevant**
- Understanding the **uncertainty**
- **Revisit** the risk assessment once design details fixed
- Boreholes need to be **decommissioned**
- Coal mine gas is **different** from other sources
- **Transparency** and greater **effort** in reporting

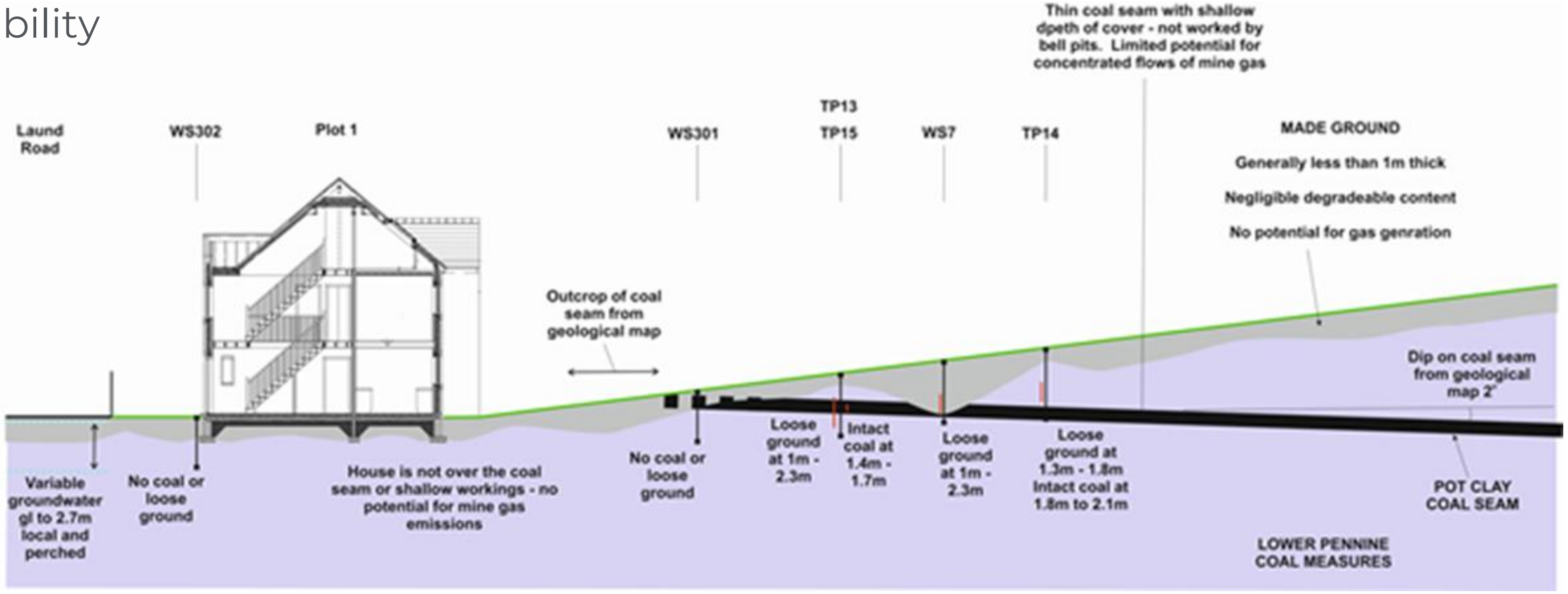

Good Practice for Risk Assessment
for Coal Mine Gas Emissions

October 2021

CL:AIRE

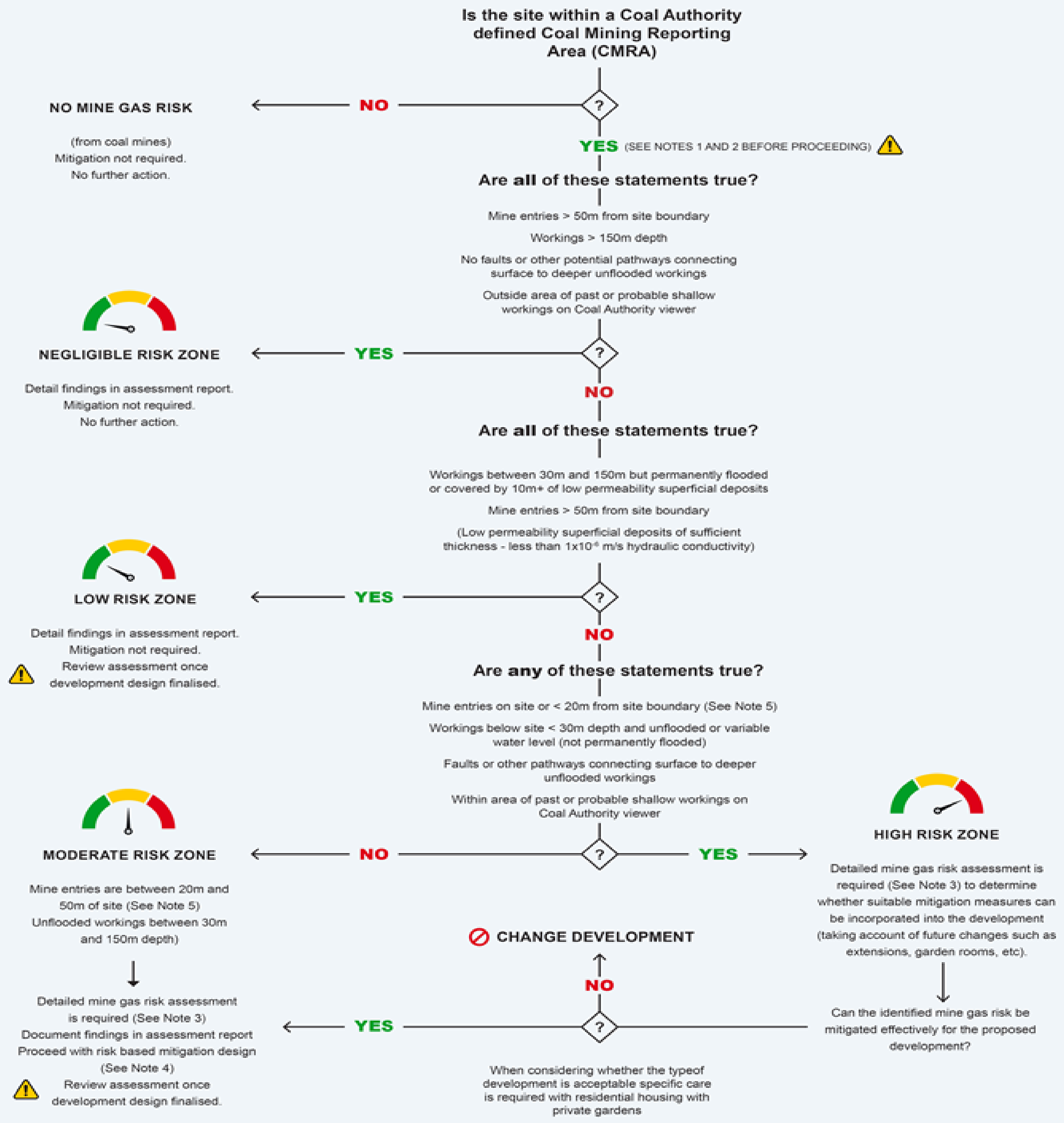
# Conceptual site model for mine gas – not optional

- Accurate topography – minimal vertical exaggeration
- Accurate dips of coal seams and faults - from 1:10,000 BGS maps now available online
- Presence and range of depth of cohesive Glacial Till or permeable drift deposits
- Groundwater depth and variability
- Shafts and adits
- Earthworks and building foundations



# Flow chart

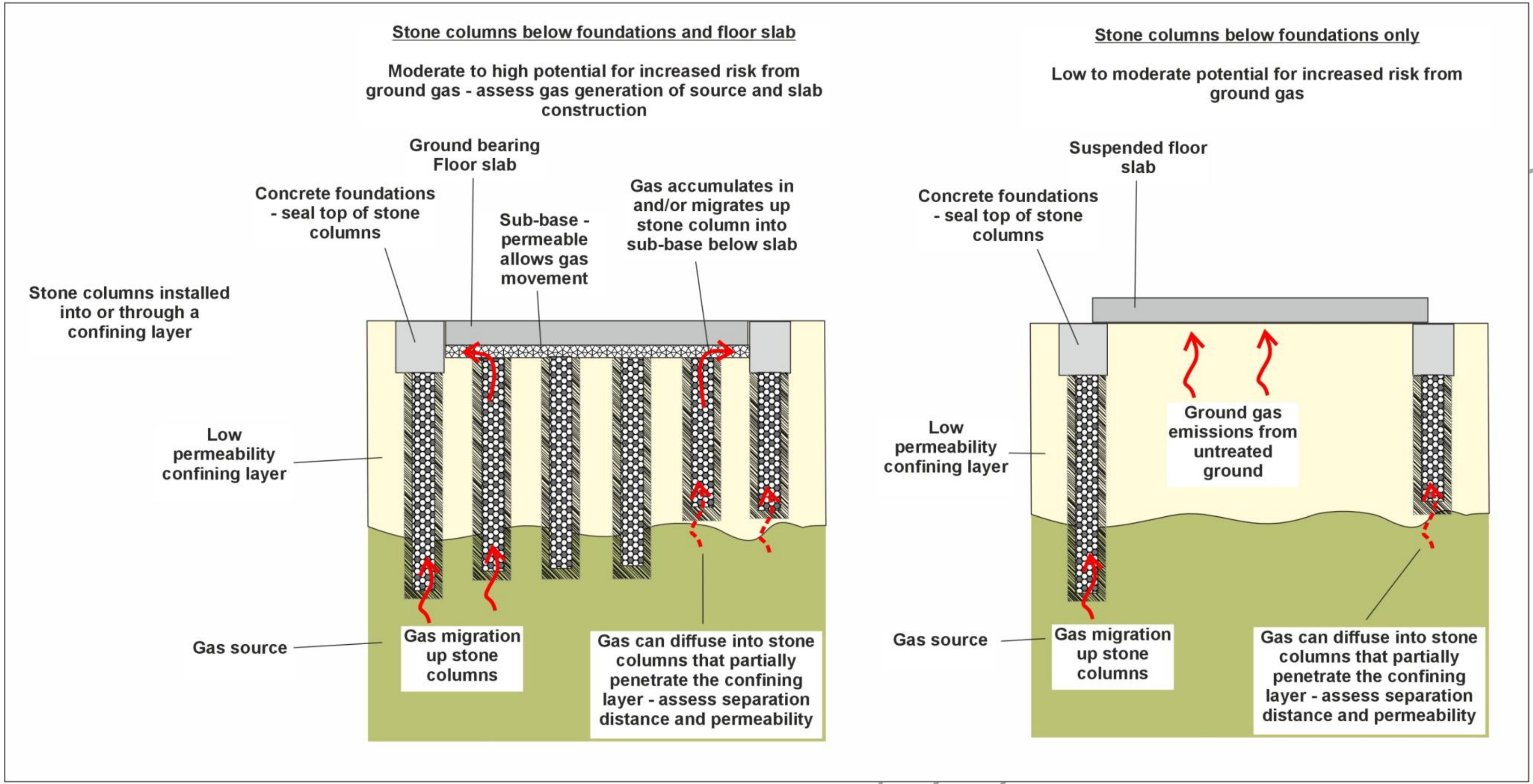
- Preliminary screening tool
- Read all the notes!
- After detailed investigation it is possible to move backwards and conclude a low risk even if some high risk factors are present



# Consider changes post-development

- Earthworks
- Grouting – treatment of drill and grout holes and verification tests
- Deep drainage – Note the 10m thickness of Glacial Till in flow chart allows for drainage to go to maximum of around 5m bgl, but if deeper than this, consideration required
- Stone columns or deep ground improvement (vertical wick drains)

# Stone columns



# Sources of information for the risk assessment and SI design

# Desk study information sources

- BGS
  - Onshore Geoindex
  - 1:10,000 maps
  - Old boreholes
- Mining Remediation Authority data
  - Online viewer
  - Consultants Report (NOT Con29M)
  - Abandonment plans
- Historical Ordnance Survey maps
- LiDAR data for topography
- Local history records and online searches
- Groundwater conditions
  - BGS hydrogeological data
  - Interpolation from main rivers (not tributaries perched on Till)
  - Groundwater level monitoring from previous investigations
  - NOTE: water strikes often obscured by water flush during drilling

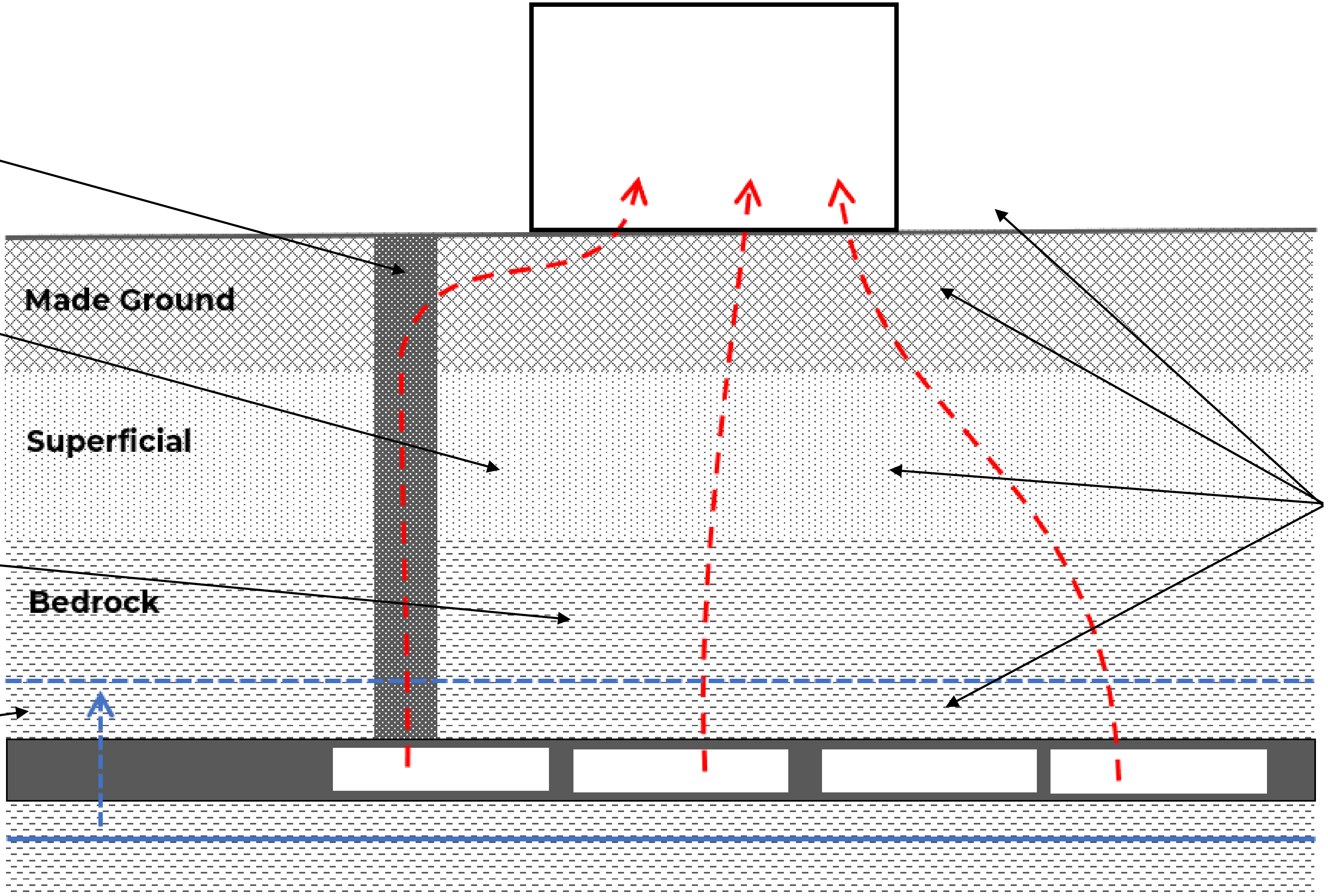
# Site investigation design targeted to CSM

Detailed investigation of former shafts and quality of backfill

Permeability testing to constrain gas flux calculations

Core recovery to assess fracture spacing and quality of rock

Groundwater monitoring at depth to assess if workings are flooded




Consider continuous monitoring

Gas monitoring at different depths and/or flux chamber tests

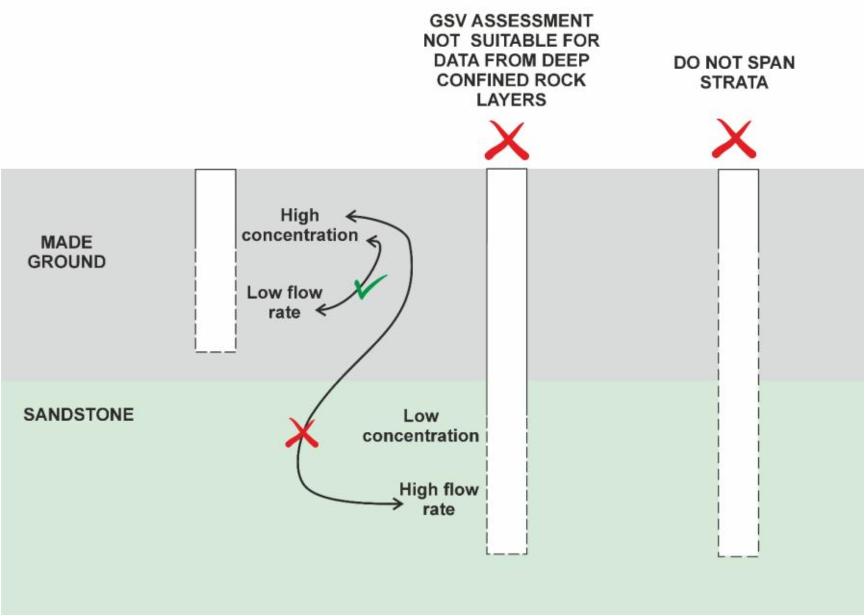
# Gas monitoring design

Response zones must ALWAYS be in the source materials/zone or intercepting a gas migration pathway

Gas monitoring in Glacial Till can have up to 21% carbon dioxide naturally due to biological respiration

Deep or confined response zones can have high flow rates as the well acts as a chimney

Gas in workings is variable over space and time, so if there are possible high-risk S-P-R linkages you might not pick these up, particularly if seasonal or sporadically occurring



# Limitations of site investigation

- Pillars of coal left in place.
- On widely spaced grid – easy to miss the worked areas.
- Drilling to prove absence of workings needs to be on tight grid.

# Limitations of gas monitoring data and GSV for high risk sites

# BS8485

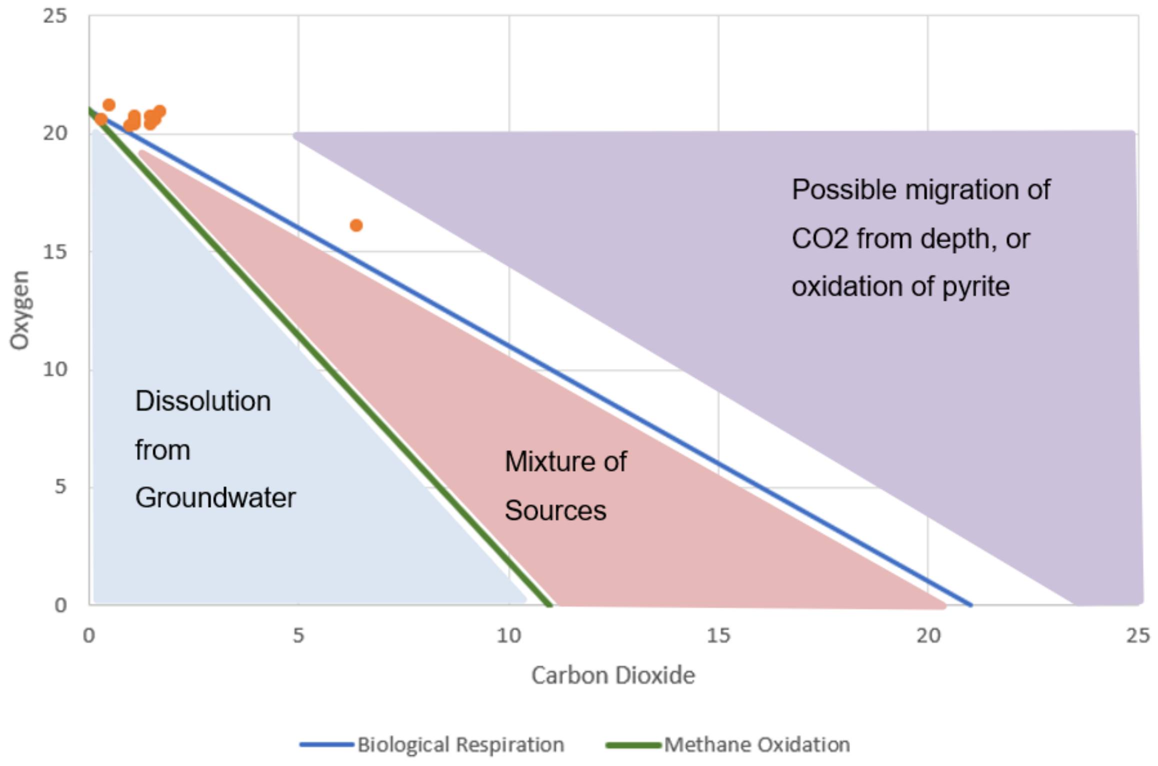
- GSV approach is generic screening approach for ground gas risk classification, based on concentrations and flow rates measures in boreholes.
- Assumes flow through soil – not via voids / preferential pathways
- Assumes shallow boreholes and response zones
- Not suitable for coal mine gas where there are high-risk scenarios with large volume reservoirs and preferential pathways

# Case study sites

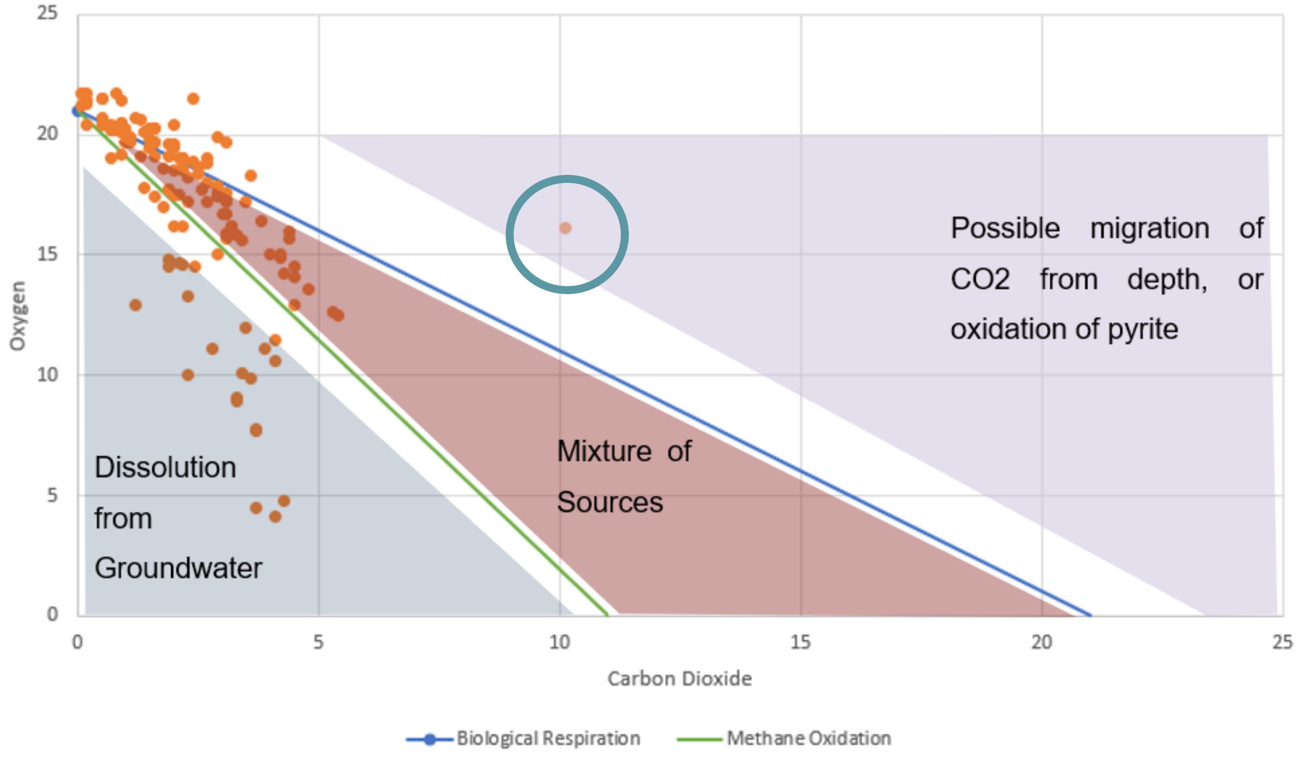
Which site is higher risk?

| | Site A | Site B |
|---|---|---|
| Flow rate | < 0.1 l/hr | < 0.1 l/hr |
| Methane | < 0.1 to 0.6 % | < 0.1 to 0.2 % |
| Carbon dioxide | Up to 6.4 % | Up to 10.1 % |

# Site A


25
20
15
10
5
0
Oxygen
0
5
10
15
20
25
Carbon Dioxide
Possible migration of CO2 from depth, or oxidation of pyrite
Dissolution from Groundwater
Mixture of Sources
Biological Respiration
Methane Oxidation

# Site B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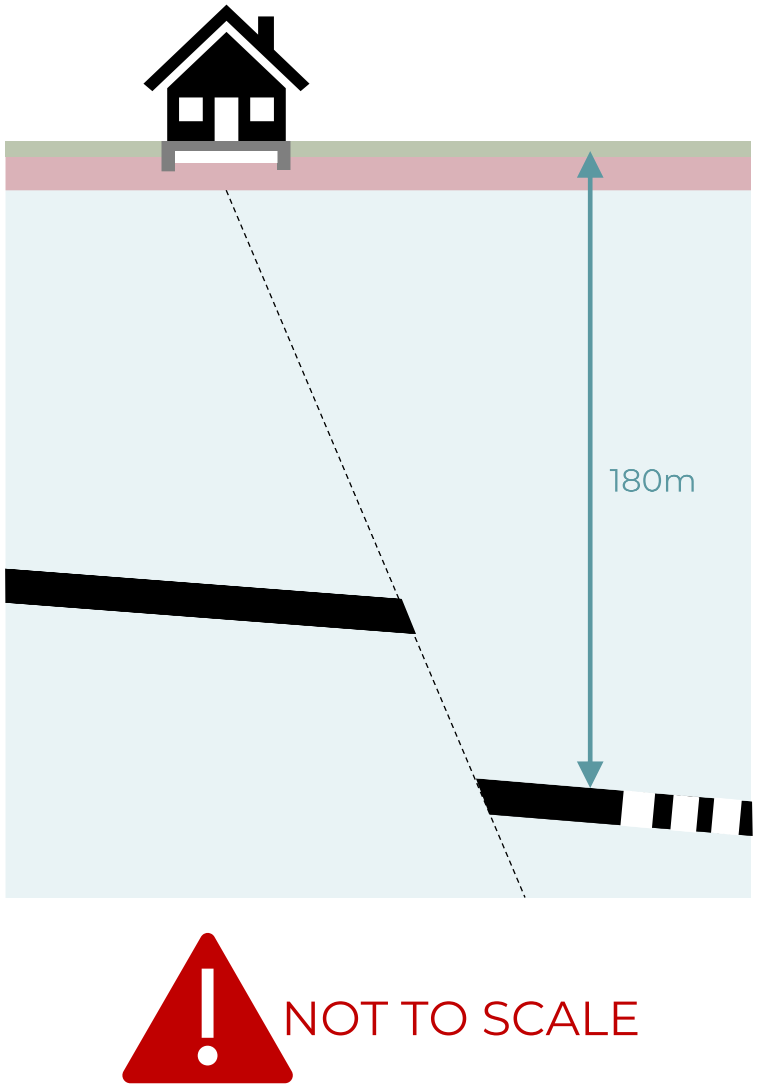
15
20
25
Carbon Dioxide
Possible migration of CO2 from depth, or oxidation of pyrite
Dissolution from Groundwater
Mixture of Sources
Biological Respiration
Methane Oxidation

# Site A

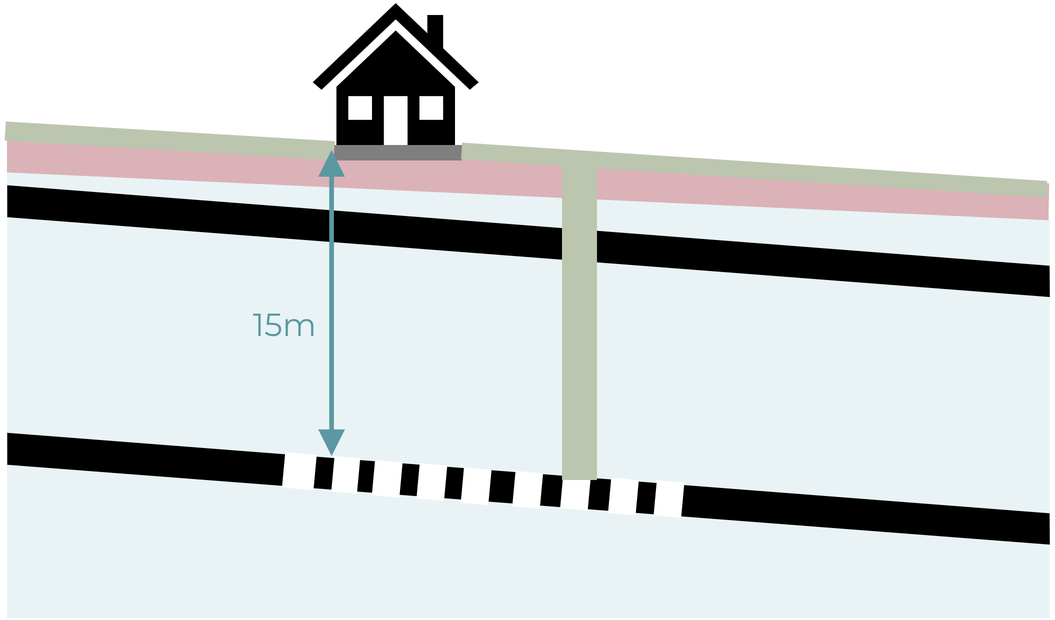
Located on the hill
Shaft 70m from site
Workings circa 180m depth
Fault located on site
Uncertainty in groundwater levels
Glacial Till (cohesive) to 1.8 to 2.5 mbgl
Beam and block floor with 150mm vented void

Low risk
No gas protection



# Site B

Located in the valley
Shaft on site
Workings 15m depth
Uncertainty in groundwater levels
Alluvium (granular and cohesive) up to 3.0 mbgl
Raft foundation




High risk - DQRA
Gas protection required

# DQRA / gas flux calculations
# When to use and how?

# When NOT TO use gas flux calculations for mine gas

- Preliminary assessment shows that the site is negligible or low risk (by flow chart)
- Preliminary assessment result is moderate or high risk, however,

  site investigation shows the site is conceptually low risk e.g.

  - Groundwater levels show mine workings fully saturated
  - Consistent covering of cohesive Glacial Till 5-10m and no deep drainage or foundations compromising it
  - Mine shaft fully grouted, or vented and maintained
  - Strong evidence that fault is not a pathway

- Preliminary assessment is moderate, but robust

  gas monitoring data shows the gas regime is CS1

# When TO use gas flux calculations for mine gas

- Preliminary assessment is moderate or high risk and following site investigation high risk factors remain, or gas monitoring data shows evidence of coal mine gas and/or elevated gas flow rates
- High risk factors:
  - Shallow <30m bgl unflooded mine workings – recorded or probable shallow workings area
  - Mine shaft or adit on site or within 20m linking to unflooded worked seam
  - Open or fractured fault zone linking to unflooded worked seam

# Principles of DQRA

**“All models are wrong but some are useful”**

- Make some conservative assumptions
- But not too many added together make sure it stays moderately realistic / possible!
- Sensitivity analysis on key input parameters if required - not always necessary when worst-case assumptions have been made

## Flick’s Law

- Diffusion - Gas flow along concentration gradient
- Determine effective diffusion coefficient from porosity and gas specific parameters
- Calculate flux from concentration difference, distance, and area.

## Darcy’s Law

- Advection – Gas flow due to pressure differential
- Key parameters: pressure differential, intrinsic permeability
- Calculate flux from concentration at source, distance, and area.

# DQRA example – Site B

1. Gas flux by diffusion from 1m bgl based on worst-case concentrations measured in boreholes, assumes bare earth floor.
2. Gas flux by advection due to stack effect from directly under the building through a crack in the raft around a water pipe.
3. Gas flux by advection due to atmospheric pressure drop from workings at depth up the mine shaft, assume 30% $CO_2$ in the workings.

**Scenario 1 - Gas flow by diffusion**

| | |
|---|---|
| Target gas | carbon dioxide |
| Gas concentration at source | 10% |
| Soil type | sandy loam |
| Migration distance | 0.6m |
| Development type | residential |
| **Indoor air concentration** | **0.068%** |

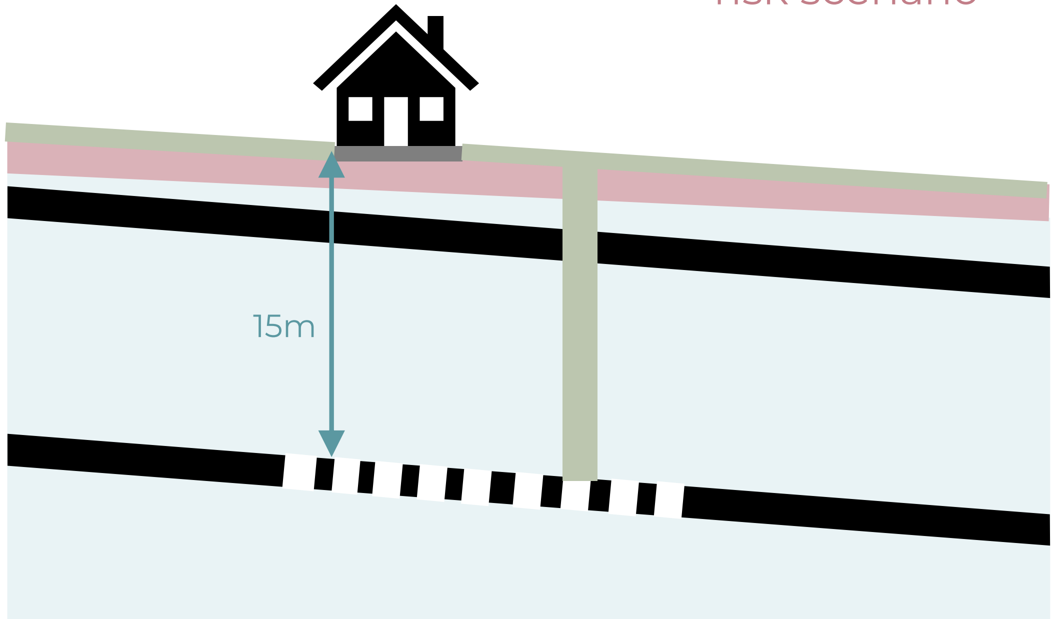
**Scenario 2 - Advection across slab via stack effect**

| | |
|---|---|
| Target gas | carbon dioxide |
| Gas concentration at source | 10% |
| Pressure drop | 3.1Pa |
| Crack ratio | 0.0001 |
| Slab thickness | 300mm |
| Development type | residential |
| **Indoor air concentration** | **0.039%** |

**Scenario 3 - Migration from depth with 4mb pressure drop**

| | |
|---|---|
| Target gas | carbon dioxide |
| Gas concentration at source | 30% |
| Pressure drop | 400Pa |
| Intrinsic permeabily of pathway | $1x10^{-7}cm^2$ |
| Pathway length | 15m |
| Development type | residential |
| **Indoor air concentration** | **1.32%** |

Gas protection required, due to potential high risk scenario



# Gas protection design

# Responsibility and competence

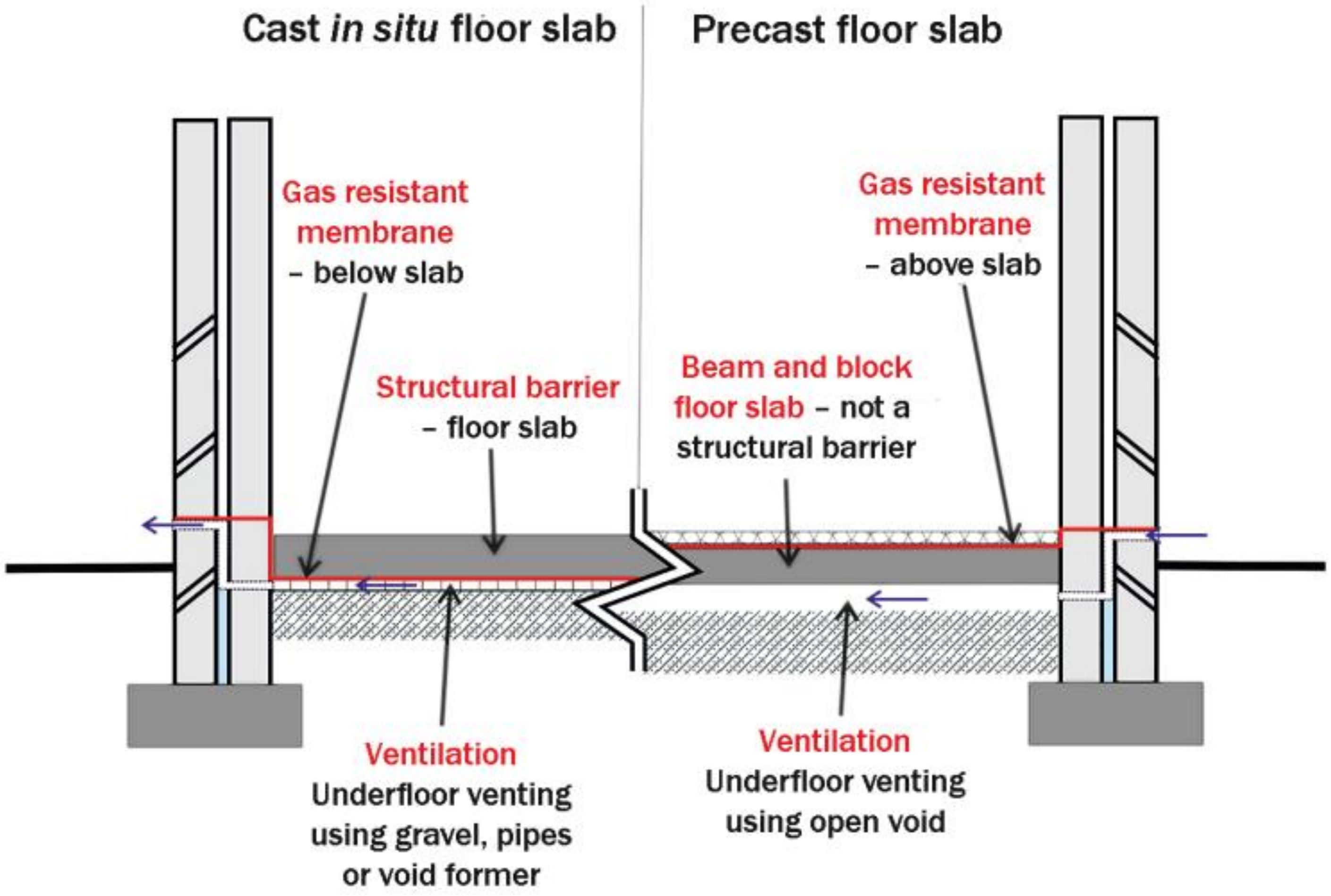
- Appointed under contract
- Appropriate PI insurance to cover for design
- If free advice is provided by manufacturers or suppliers and included in the design, then the designer will be responsible
- Need to have knowledge of the gas regime to provide competent design

## What do you need to provide as the designer?

- Design report
- Site specific drawings and sections
- Product specification
- Ventilation calculations
- Verification Plan

# Principles of design of gas protection

- Structural barrier
- Membrane
- Ventilation



# Different floor slab types – low rise residential

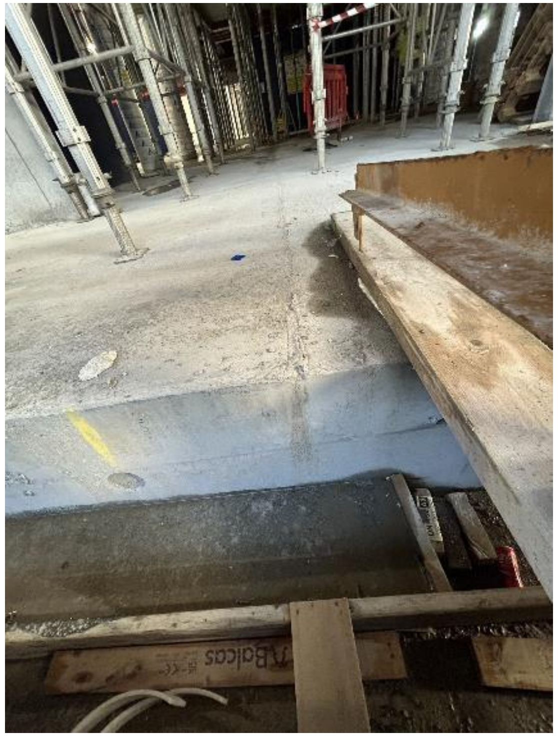
Raft

Precast suspended floor (beam and block)

Ground bearing

# Different floor slab types – larger buildings

Cast insitu suspended floor



Ground bearing

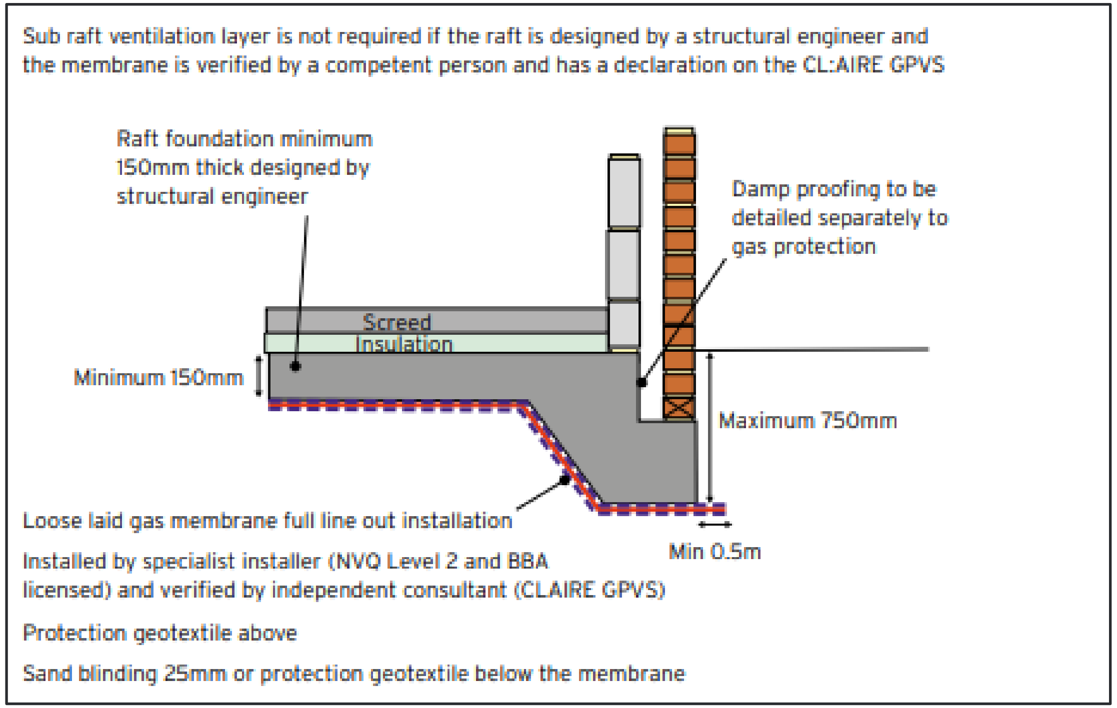
# Gas protection design for coal mine gas sites

- For high-risk sites (after detailed risk assessment). Gas protection via building measures only may not be sufficient, and **grouting specified for gas protection** may be needed.
- More robust assessment required to choose appropriate measures
- Two most common solutions that are likely to be acceptable on most sites:
  - Ventilated void and membrane above suspended floor, or
  - Raft foundation and membrane (sub-slab venting not required with raft foundations)

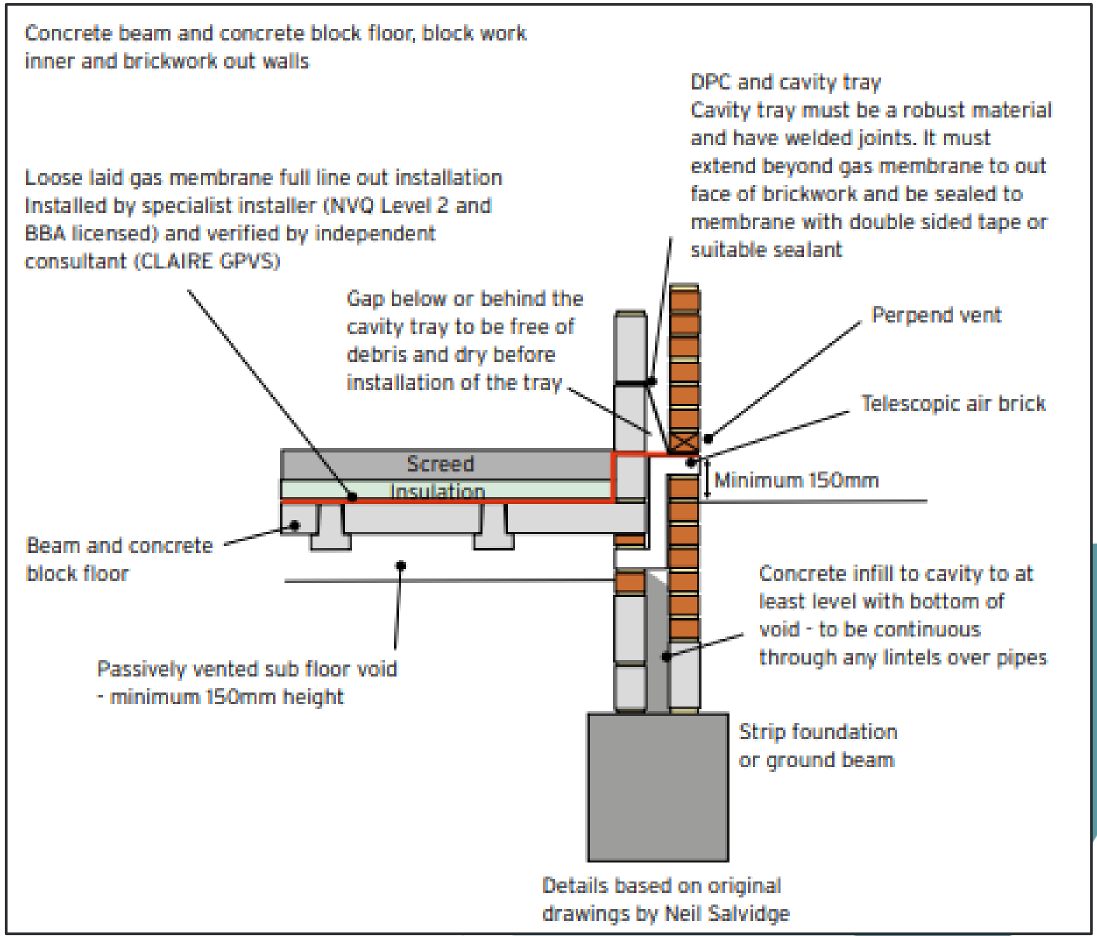
- Membrane above raft or suspended floor – typical membranes on market acceptable
- Membrane below raft – do not use aluminium foil membranes!
- **Seal the utilities ducts**

# Typical details – NHBC NF94

## Raft




## Pre-cast suspended / beam and block



# Additional considerations for mine gas sites

- Avoid ground bearing slabs with perimeter joint
- Avoid stone columns (they can be used but often increase risk so more protection measures will be required)
- Avoid drainage runs below buildings
- Consider the risk of deep stormwater attenuation tanks and soakaways
- Use shallow sustainable drainage systems (SuDS) such as permeable pavements wherever possible

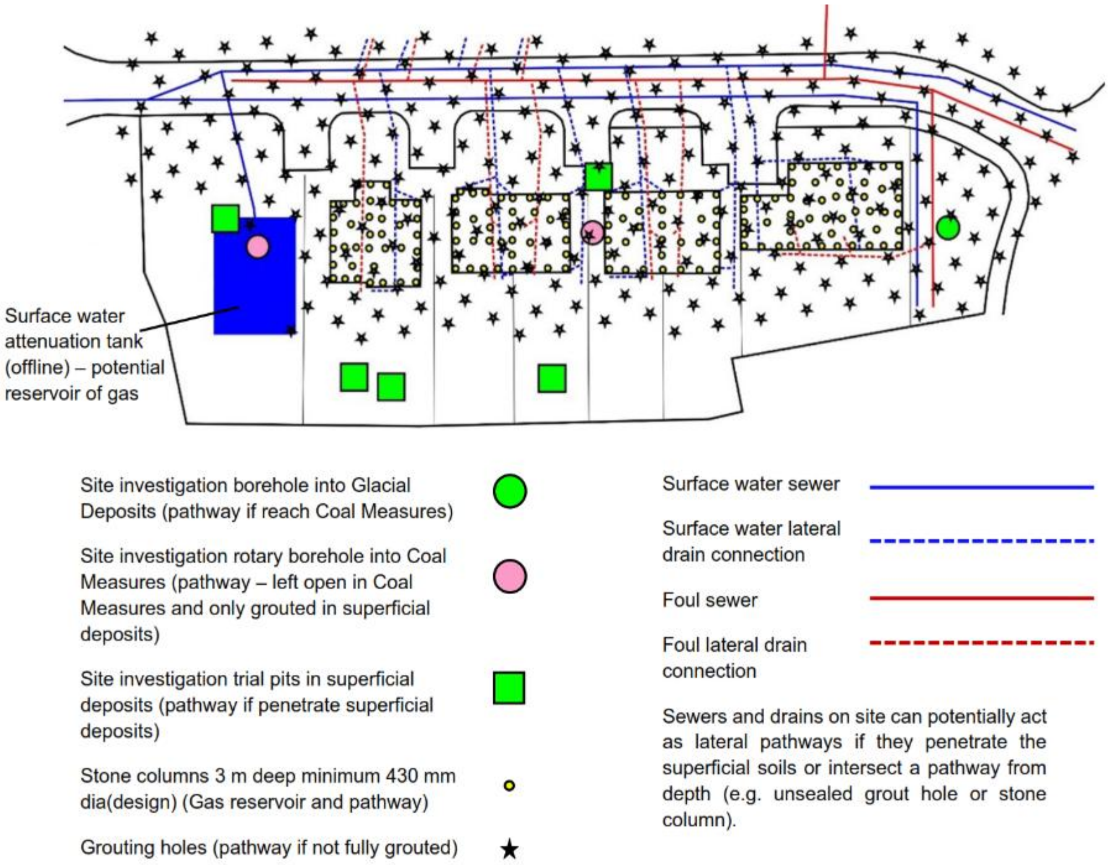
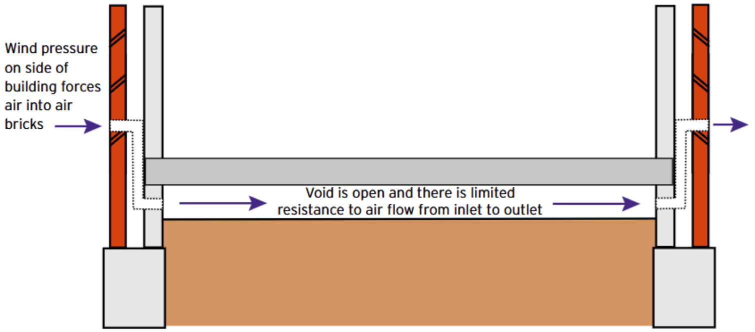


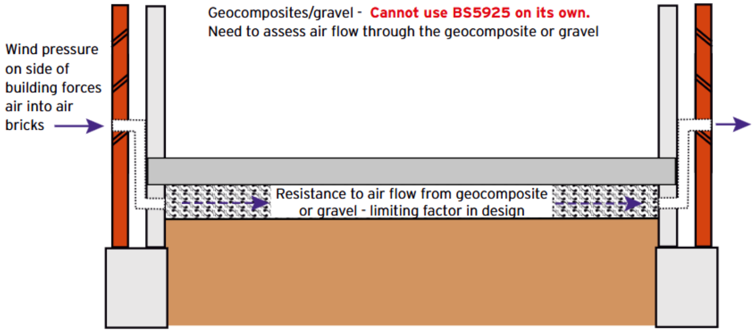

**Figure 10.2: Complexity of pathways and gas reservoirs introduced by the development construction.** For a larger version, see page 70.

# Difference between vent layer calculations – open void or geocomposite or gravel layer




Equation in BS5925 is to estimate air flow through a sharp edged orifice (hole) with free air movement on the inside

It calculates the vent area required to give the air flow through the air bricks (or other vent) for a given wind speed (pressure calculation is within the one equation)




Calculation in three parts

1. Calculate wind pressure on side of building
2. Estimate air flow in geocomposite to make sure air flow is sufficient for a given pressure (calculate from wind speed)
   - Darcy equation - need to know the intrinsic permeability of the geocomposite
3. Check vent area is sufficient to provide flow through geocomposite and is not the limiting factor

$$Q_w = C_d A_w U_r (\Delta C_p)^{1/2}$$

$A_w$ Equivalent area of an opening

$C_d$ Discharge coefficient for an opening

$C_p$ Surface pressure coefficient

$U_r$ Reference wind speed

Typical result for a house for flow through one air brick at either side of void - $Q_w$ = 1.1l/s

**Darcy's Law**

The equation for Darcy's Law is given below:

Flow of gas being considered in ground,

$$Q_v = \left[\frac{K_i \gamma A i}{\mu}\right] \text{ x gas or vapour concentration}$$

Where:

$Q_v$ = flow of gas being considered, in m³/s through area $A$

$K_i$ = intrinsic permeability of material through which gas or vapour is flowing in m²

$\gamma$ = unit weight of gas in N/m³

$\mu$ = viscosity of gas being considered in Ns/m²

$A$ = area of migration perpendicular to migration direction in m²

$i$ = pressure gradient along migration route (as a fluid gradient for the gas considered) = (gas pressure/unit weight)/length. The units for gas pressure in this equation are Pa.

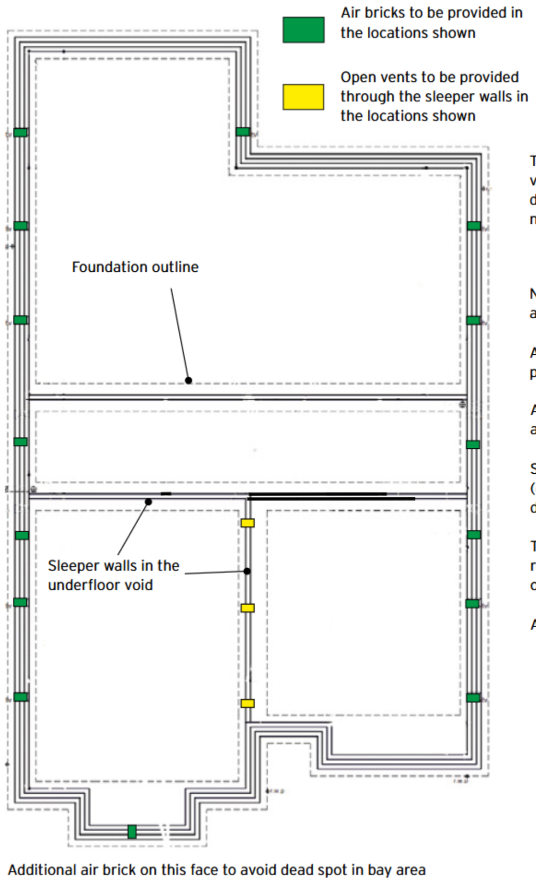
Typical result for a house for flow through geocomposite connected to one air brick at either end - $Q_w$ = 0.3l/s

**Figure 4.5** Calculation approach for open void and void formers

Open void is preferred and most effective

# Air brick placement – drawings required

**Typical sub floor design drawings (below beam and block floor) showing location of airbricks and cross wall ventilation**




The gas protection design to be submitted to the NHBC should include a plan of the sub-floor void showing the air brick locations (or other vent outlets) and cross wall ventilation. This drawing should be followed on site and the operatives should be aware of the required number and location of air bricks (or other vent points).

Note air brick positions to be cross checked with doors, french window, downpipes, etc to avoid clashes.

Adjustments must not be made on site without reference back to the designer of the gas protection system.

Air bricks nominally at 2m centres - but install at positions shown. Provide same number of air bricks on two opposite walls.

State ventilation area required for the air bricks (normally > 6,000mm²/m) and cross vents (6,000mm²/m the simplest approach is to use short sections of 100mm diameter PVC drainage pipe through the sleeper wall or construct it with gaps in the blockwork).

This gives 3,000mm² vent area/m of wall in this example. This is above the minimum requirement of 1500mm²/m but is required to provide even coverage and prevent dead spots on this building.

Air bricks properly ducted in accordance with Chapter 6.1 'External masonry walls'.

**Figure C2** Example drawing showing air brick locations

# Membrane specification – NHBC NF94

Membrane location, determines the properties required.

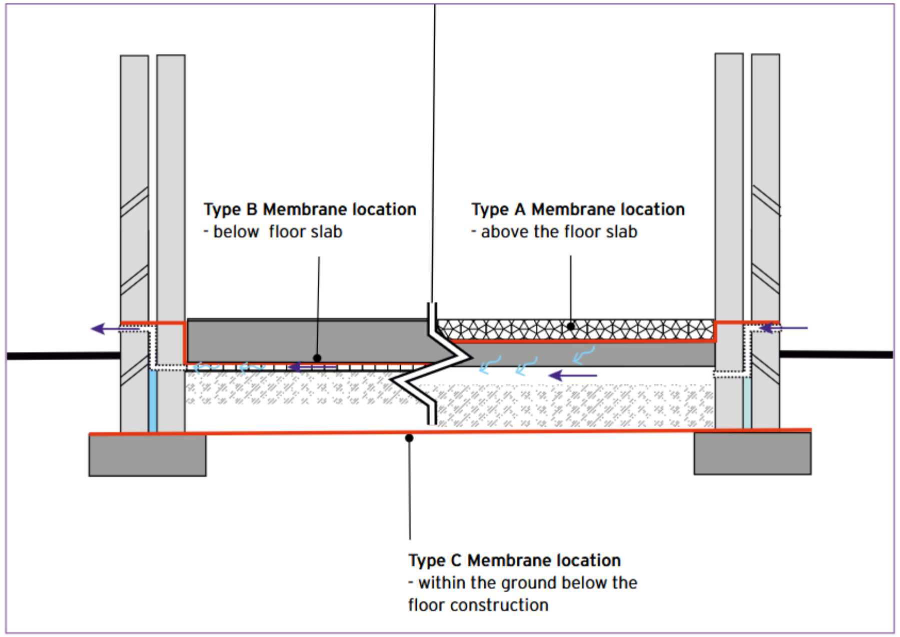



Figure 5.3 Membrane types and locations in a typical construction sequence

| Parameter | Test method | TYPE A - Above Slab | TYPE B - below Slab | TYPE C - In ground | Unit |
|---|---|---|---|---|---|
| Weight | EN 1849 | ✓ | ✓ | ✓ | $g/m^2$ |
| Thickness | EN 1849 | ✓ ≥0.4 | ✓ ≥0.5 | ✓ ≥0.6 | mm |
| Water vapour resistance (if also acting as DPM) | EN 1931 | ✓ | ✓ | ✓ | $m^2/s/(pa/kg)$ |
| Tensile strength | EN12311-1 or -2 | x | ✓ | ✓ | N/50mm |
| Tensile elongation | EN12311-1 or -2 | x | ✓ | ✓ | % |
| Shear strength of joints | EN12317-1 or -2 | x | ✓ | ✓ | N/50mm |
| Impact resistance | EN 12691: 2018 (A) | ✓ | ✓ | x | mm height |
| | EN12691: 2001 (B) | ✓ | ✓ | ✓ | mm dia. |
| Resistance to static load | EN 12730: 2015 (A) | ✓ | ✓ | ✓ | kg |
| Resistance to tearing (nail shank) | EN12310-1 | ✓ | ✓ | x | N |
| Seam jointing method | - | Taped or welded (welded only for VOC) | Welded | Welded | |

**Notes on taped joints:**
Taped joints must be two stage - double sided internal joint, and single sided cover joint (on exposed face of membrane). For membranes where elongation is >200% taped joints must achieve the same tensile strength as the membrane. This can be omitted for welded joints, as welded joints are as strong as the membrane.

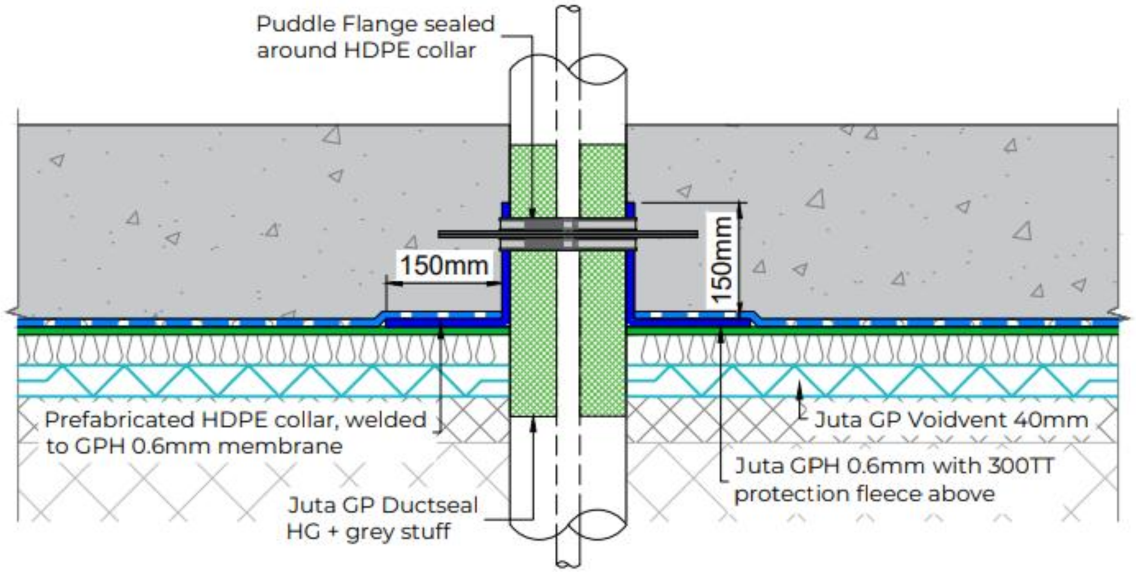
Table 5.2 Test data to be provided and assessed for gas membrane types

| | |
|---|---|
| **Type A** | Membrane is supported on a prepared and level concrete floor or slab - protection is a consideration if cover does not occur within 1 day before any follow-on works occur. |
| **Type B** | Membrane is laid below a floor slab or platform below a modular building. Laid on level sub-base surface, or insulation, free of movement. Protection above the membrane required. Protection below a consideration of subgrade condition. Aluminium foil membranes not suitable unless isolated from concrete (e.g. by insulation). |
| **Type C** | Membrane is laid within the ground on level surface free of movement. Protection above and below the membrane required. Membrane should terminate outside of the perimeter wall. Aluminium foil membranes are not suitable in this location. |

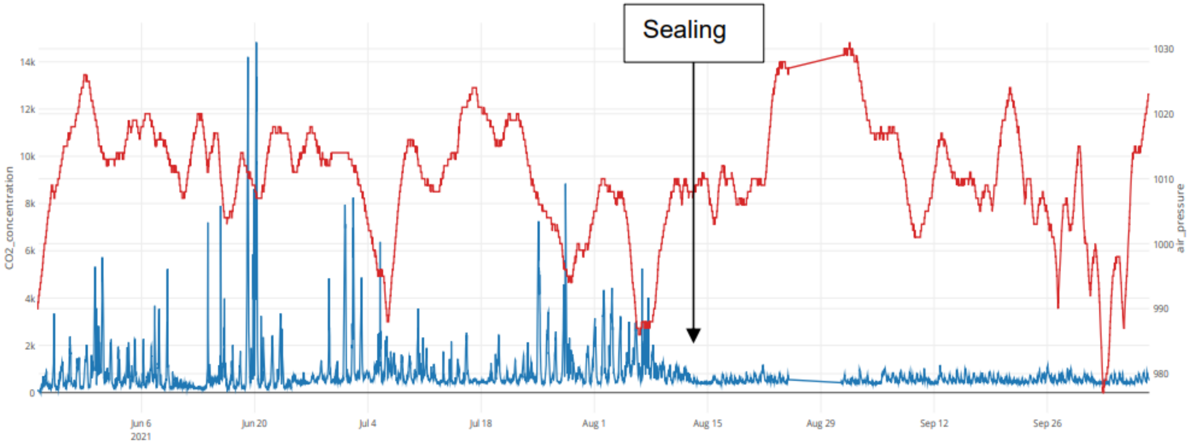
# Duct sealing

Design suitable sealing for ducts in new buildings with gas protection: to slab, to membrane, and the annulus.

We know this is important from sites with mine gas ingress issues into existing buildings!





# Drill and grout works - considerations

- Normally designed for stability not gas protection.
- Grouting will normally reduce the ground gas risk long-term as it reduces the volume of workings which mine gas can accumulate in

However, consider:

- If only under buildings, what is the remaining risk from external areas?
- Are the grout holes on a tight enough spacing to reduce the void space sufficiently?
- What verification drilling or testing will be done?
- Could the grouting “push” gas in workings from on site to impact off-site receptors?
- Sacrificial plastic casings could create vertical conduits and increase the permeability.

# Conclusion

# Approach to risk assessment and design based on risk profile

| Negligible risk | Low risk | Moderate risk | High risk |
| --- | --- | --- | --- |
| No plausible S-P-R | S-P-R shown to be low risk conceptually | S-P-R which is not low risk or there is significant uncertainty | S-P-R with high risk factor |
| No gas monitoring needed | Generic assessment appropriate | Detailed quantitative assessment shows that the risk can be mitigated | Detailed quantitative assessment including assessment of future changes |
| No gas protection needed | No gas protection needed | Gas protection appropriately designed | Might show the development needs to be changed |

BS8485 GSVs only to be used for low risk sites to prove low risk (CS1)

If gas protection is required you need to do **gas flux calculations** to inform the design

# More training is available on this topic!

- CL:AIRE Coal Mine Gas Risk Assessment virtual training run over two half days

  2025 courses on **23rd 24th April** or **14th 15th October**

  https://claire.co.uk/commerce/112387-good-practice-for-risk-assessment-for-coal-mine-gas-emissions

- CIRIA Ground Gas Protection Design

  None currently scheduled - contact Joanne Kwan joanne.kwan@CIRIA.ORG if interested

  https://www.ciria.org/Training/Training_courses/Design_of_ground_gas_protection_in_new_buildings.aspx

part of STRI group
epg environmental protection group

Thank you for listening

Live Q & A

or contact me on amyjuden@epg-ltd.co.uk