RSK Stirling

Research project to investigate prevalence of CO_2 from disused mineral mines and the implications for residential buildings

February 2019

Scottish Government
Riaghaltas na h-Alba
gov.scot

Report prepared by:
Andrew Gunning (Project Manager)
Tom Henman (RSK Geosciences)
Thomas Kelly
Brian Anderson
Casey McGuire

RSK Stirling
Unit 11 Beta Centre,
Stirling University Innovation Park
Stirling, FK9 4NF

The opinions expressed in this report are those of the authors.

Report commissioned by:
Building Standards Division
Local Government and Communities Directorate
Denholm House
Almondvale Business Park
Livingston
EH54 6GA

Tel: 0300 244 4000
e-mail: buildingstandards@gov.scot
web: www.gov.scot/Topics/Built-Environment/Building/Building-standards

Contents

1 Executive Summary

During April 2014, a number of cases of ill health were reported to be affecting some residents in the former mining area of Gorebridge, Midlothian. An Incident Management Team (IMT) was set up by NHS Lothian and a report compiled which produced wide ranging recommendations, some of which related to the Building Standards Division within Scottish Government.

RSKW were commissioned, in September 2018, to undertake fact finding research to investigate the prevalence of CO_2 from disused mineral mines and implications for residential buildings.

The aims of the research project were the following:

- Identify organisations who have produced guidance on mine gas mitigation;
- Build-up an inventory of similar events in Scotland; and
- Explore the building standards related issues in the Gorebridge IMT report.

The issues explored, as part of a process of stakeholder engagement and consultation with experts, included eight building standards related recommendations in the Gorebridge IMT report:

- The risk assessment process
- Mitigation measures
- Construction techniques
- Energy efficiency measures/airtightness
- Consideration of mandatory mine gas mitigation in selected areas
- Retrofitting of mitigation measures to existing properties

The project requirements were set out by the Building Standards Division and in responding to the project aims above, we have provided several options for consideration to reduce risks from CO_2 mine gas. Following our investigation, consultation and analysis, the proposed options for further consideration are as follows:

1. Use and enforcement of model planning conditions and/or changes to Scottish Planning and Building Standards and guidance to ensure adequate risk assessment of mine gas and design, construction and verification of gas protection measures.
2. Further research and preparation of supplementary technical guidance relating to the assessment of risks to new and existing developments from mine gas.
3. Consideration of mine gas issues and constraints at local development planning stage, especially related to large-scale developments and cumulative effects.
4. Improved co-ordination and communication between Planning, Building Standards and the Environmental Health/Contaminated Land staff in some local authorities.
5. Further research to assess the long-term effectiveness of granular fill and perforated pipe ventilation below slab construction.

6. Further consideration of the implementation of mandatory mitigation measures in former coal/oil shale mining areas.
7. Additional liaison between Scottish Government, Scottish Local Authorities and Northumberland County Council may be mutually beneficial.
8. Validation of risk assessment and mitigation design experience of consultants within the developers' procurement process.

2 Glossary

Abbreviations	
BGS	British Geological Survey
BSi	British Standards Institution
CA	The Coal Authority
CH_4	Methane
CIRIA	Construction Industry Research and Information Association
CL:AIRE	Contaminated Land: Applications in Real Environments
CO	Carbon monoxide
CO_2	Carbon dioxide
CSM	Conceptual site model, which represents the characteristics of a site in diagrammatic or written form that shows the possible relationships between contaminant sources, pathways and receptors.
DETR	Department of Environment, Transport and the Regions (now Defra)
EA	Environment Agency (environmental regulator covering England)
GIS	Geographical Information System – Digital mapping software to manage complex spatial data
H_2S	Hydrogen sulphide
HSE	Health and Safety Executive
IMT report	Gorebridge Report written by the Incident Management Team, NHS Lothian
LA	Local Authority
LDP	Local Development Plan
N_2	Nitrogen gas
NHBC	National House Building Council
NQMS	National Quality Mark Scheme for land contamination
NHS	National Health Service
O_2	Oxygen
Ppm	Parts per million
RA	Risk assessment
Rn	Radon
SEPA	Scottish Environment Protection Agency
SG	Scottish Government
SO_2	Sulphur dioxide
SPR	Source-Pathway-Receptor methodology used to assess land contamination risks as part of development of a conceptual site model
VOCs	Volatile organic compounds

Technical terms	
Adit	Horizontal access or drainage passage into a mine
Atmospheric pressure	The pressure excreted by the weight of air in the atmosphere
Characteristic gas situation (CS)	Ground gas regime assumed for design of gas protective measures from the refined conceptual site model after an adequate site investigation (BSi, 2015)
Dewatering	Removal or draining groundwater or surface water from a riverbed, construction site or mine shaft by pumping or evaporation
Drift	Sub-horizontal passageway in a mine that may or may not intersect the surface
Gas resistant membrane	A membrane placed above, below or within the floor slab construction (and walls of a basement) to restrict methane and carbon dioxide migration from the ground into a building (BSi, 2015)
Ground gas	All gases occurring and generated within the ground whether in made ground or natural deposits (BSi, 2015)
Ground investigation	A geotechnical or geological field assessment that is an essential part of a site investigation
Shaft	A long, narrow hole or tunnel that provides access to a mine or provides ventilation
Site investigation	The process of collating information, assessing data, and reporting on risks beneath a site
Solum	The ground on which a building stands
Sump	A device that creates a low-pressure void to draw gas into it and safely vent it away through an exhaust pipe
Verification	The process of demonstrating that the risk has been reduced to meet remediation criteria and objectives (as opposed to the term used by Building Standards)
Vibro-stone column	Crushed stone pillars below a structure that increase the soil’s load-bearing capacity

3 Introduction

3.1 General Introduction

During April 2014, a number of cases of ill health were recorded affecting some residents in the former mining area of Gorebridge, Midlothian. An Incident Management Team (IMT) was set up by NHS Lothian to investigate the cases. It was discovered that the residents had been suffering from health issues related to carbon dioxide (CO_2) exposure. Radiocarbon analysis indicated that the CO_2 was derived from a geological origin indicating that old coal mines were the root cause.

A report was compiled by the IMT (Carbon Dioxide Incident in Gorebridge, Midlothian, April 2014 – final report of the Incident Management Team November 2017) which produced numerous recommendations, some of which were made to Scottish Government and relate to building regulations. Based on these recommendations in the Gorebridge IMT report, the Building Standards Division within Scottish Government commissioned RSKW to address the issues. The project definition was:

"a research project to investigate the prevalence of CO_2 from disused mineral mines and implications for residential buildings."

The aims of the research project are the following:

- Identify organisations who have produced guidance on mine gas mitigation and establish if a review is required;
- Build-up an inventory of similar events in Scotland; and
- Explore the eight issues (detailed in the following section) surrounding the Building Standards system and building regulations.

The project was commissioned in September 2018 and this report presents the outcome of the fact finding carried out via a literature review, stakeholder engagement, a consultation with industry experts, plus an analysis of the main findings and compilation of a number of options to consider for further work in this area.

3.2 Project Requirements

The research project requirements were set out in the contract award sent to RSKW on 3rd October 2018. The project comprises four main stages:

- Project Start Up
- Stage 1 - Engagement
- Stage 2 – Consultation with experts
- Stage 3 – Analysis & Research Output.

Throughout the process, regular updates were submitted to the Scottish Government (SG). The final project output was to document our findings and further options for consideration/research, as detailed in this report.

The following section sets out the main requirements of each project stage.

Project Start Up

- Project inception meeting – review aims, objectives and identify key stakeholders;

- Project setup and literature review. Provided the project team with the opportunity to review the latest related reports, research, guidance and regulatory requirements.

Stage 1 – Engagement (Section 7)

- Collect views from the Local Authorities (LAs) and regional NHS Boards where CO_2 mine gas (shale and coal mining) events have occurred in the last 54 years (the time that has elapsed since national building regulations came into force), extracting as much information about each event as possible;

- Engage with the 32 LAs where applicable to find out how they each scrutinise the possibility of CO_2 mine gas migration for new development. Carry out a review of the guidance available on mining gas mitigation in new development; and

- Hold a stakeholder event to collect views and discuss issues.

For this task a GIS map was generated to overlay the areas of former coal workings and the LAs under which they exist. This exercise was repeated with NHS boards to ascertain who to contact for the stakeholder engagement. A generic email invite was sent out along with a series of initial questions and a request for any additional data on similar events in Scotland related to mine gas (particularly related to CO_2).

Stage 2 – Consultation with Experts (Section 8)

- Work with industry experts to consider the questions raised to collect unbiased views.

The consultation involved a series of conference calls or face-to-face meetings using a structured list of questions to tease out the information and to ensure conversations remained on topic. Each expert was given time to express their viewpoint in detail with thorough justification to ensure maximum information was collected.

Stage 3 – Analysis (Section 9)

- Bring together the findings from the research to provide a finalised report (No direct recommendations are required as a result of the research, but options to consider have been requested).

A systematic approach to the analysis phase was taken. All the issues that arose during the stakeholder engagement and expert consultation were collated into an issues log. The issues were then grouped to understand where in the process, assessment or mitigation measures, the issues occurred. The issues were paired to solutions and additional detailed comments obtained from the expert consultation to direct the 'options for consideration' detailed in Section 11.2 of this report.

3.3 Project Context

3.3.1 Definitions

It is important to understand that the purpose of this document is fact finding in relation to the risks that carbon dioxide (CO_2) poses to residential properties from former mine workings. However, this is not to be confused with the more blanket term 'mine gas', that tends to include all 'natural/harmful' gases produced by coal workings. **Table 3-1 A summary of mine gas terminology** delineates the variety of terms used to describe mine gas and to what principal gases or gas mixture they refer. The Gorebridge IMT report uses the term 'mine gas' within their report when discussing just carbon dioxide. Within this project, the focus has been on CO_2 from mine workings, but we have also considered the related issues from mine gas generally. The key terms that relate to the conditions at Gorebridge (a rise in CO_2 and decline in oxygen (O_2)) are blackdamp, stythe and choke damp.

Table 3-1 A summary of mine gas terminology

Word/phrase	Definition	Principal gas(es)
Mine gas(es)	Any of various harmful vapours produced during mining operations.	CH_4, CO, CO_2, H_2S, VOC's (volatile Organic carbons), Rn
Damps	Damps is the collective name given to all gases or combination of gases (other than breathable air) found in coal mines. The word corresponds to German 'Dampf', the name for vapour.	Various
Blackdamp Other names: stythe, choke damp	Reduction in oxygen and increase in carbon dioxide beyond which is capable of sustaining human life. Principally carbon dioxide, with minor denominations of nitrogen and water vapour. (Most dangerous compared to other damps as it provides no warning)	CO_2, N_2, H_2O
Firedamp	Mine gas which is primarily methane.	CH_4
Whitedamp	Noxious mixture of gases formed by the combustion of coal	CO, H_2S

	(normally enclosed environment). Mainly carbon monoxide and hydrogen sulphide.	
Afterdamp	After an explosion of firedamp. Consists of carbon dioxide, carbon monoxide and nitrogen. Hydrogen sulphide and carbon monoxide also present.	CO_2, CO, N_2, H_2S
Stinkdamp	Mine gas which is predominantly hydrogen sulphide.	H_2S

Throughout this document the issue will be referred to as carbon dioxide or blackdamp. Although the research project is related to the risk of exposure to carbon dioxide, this normally coincides with a drop in oxygen (or an oxygen deficient atmosphere). This occurs because there is an inverse relationship; CO_2 concentrations increase as O_2 concentrations decrease when coal is oxidised on exposure to air (Xu-yao et al., 2009). Therefore, an O_2 depleted atmosphere is also included within the scope of a CO_2 related incident or similar. Our terms of reference are limited to residential properties in former coal mining areas; commercial properties and public buildings are outwith the scope of this study.

3.3.2 Scale of the problem

The true scale of the issue is unknown because of the distinct nature and effect of CO_2 (blackdamp) related events. Section 5 highlights the known incidents related to a rise in carbon dioxide and/or depleted oxygen atmosphere related to former coal workings.

In former mining areas there has always been an awareness of mine gas issues in confined spaces. The surface impacts from underground coal workings either through mine gas releases or subsidence are not new. With the closure of the mines, local regeneration and new housing developments, there are likely to be areas where a combination of a CO_2 source in proximity to properties could create issues. With older properties, it is suspected that due to underfloor ventilation and poor air tightness, there is a reduced risk of CO_2 build-up over time because CO_2 can escape from the building. It has been noted that new build properties in Scotland will be more airtight and may have an unventilated concrete slab floor; therefore, without a form of mitigation in place, they may be at higher risk.

Major fire (methane) mine gas events expose themselves quite readily because the events generally result in an explosion or fire. One notable event, that made national press, was the explosion in Loscoe, Derbyshire. Although this event was related to an adjacent landfill site, the methane emission followed a low-pressure weather event. This mirrors the pattern of methane (and carbon dioxide) releases from former coal mine workings.

Similarly, those events related to hydrogen sulphide (H_2S) are detected quickly due to the ‘rotten eggs’ smell produced by the gas at low concentrations (incident data, The Coal Authority).

CO_2 is odourless and in combination with depleted O_2, causes symptoms that are relatively generic (headache, dizziness etc.) and similar to those of a minor illness. For this reason, an event involving exposure to levels of CO_2 that can cause ill-health may be unreported. Unless the symptoms are sudden and/or widespread, such as the case at Gorebridge, or a person is discovered either in a collapsed condition or found dead from exposure as occurred in Northumberland in 1995 (Coal Authority, 2018).

In addition to the potential for under-reporting of chronic events it has been suggested in the IMT report that events like Gorebridge may become more frequent in the future due to changing environmental conditions.

3.3.3 Factors affecting gas generation and migration from mine workings

The factors affecting gas generation and migration from mine workings include:

- Meteorological pressure and temperature changes
- Rising groundwater levels e.g. changes in water levels within former mine workings
- Creation of preferential pathways by anthropogenic activity

The correlation between low pressure meteorological events and an increase in CO_2 emissions from abandoned mine workings and landfill sites is well documented (Teasdale et al., 2018; Hendrick & Sizer, 1992). Low pressure weather systems can also cause heavy rainfall; therefore, rainfall can act as a proxy for low pressure events.

There are, however, instances of mine gas emissions which are unrelated to meteorological events (Lagny et al., 2013; Wrona et al., 2016). This is likely to reflect the nature of the mine workings beneath a particular site. Shallow mine workings, such as those found in parts of the Scottish Coalfield and Northumberland, are more likely to be impacted by low pressure events than deeper mine workings (Robinson, 2000).

Global climate change may result in more extreme low pressure events in the future creating the sudden drops in air pressure favourable for CO_2 migration (CL:AIRE, 2018) as well as heavy rainfall events.

Rising groundwater levels

Within working mines, pumping of water was used to keep the hydraulic head artificially low to prevent flooding of the workings. Rising water levels within abandoned mine workings have been described in detail (Adams and Younger, 2001; Robinson, 2000) particularly in relation to the impacts on the water environment. Another impact of rising groundwater levels is the potential for an increase in gas pressure as a rising hydrostatic head displaces gas within abandoned mines and reduces gas storage capacity. In the longer term, water levels in mine workings will reach equilibrium with the storage capacity stabilised at a lower level. However, there may be competing factors affecting gas generation, including dissolution of gases from mine waters and the generation of additional CO_2 through the interaction of rising acidic mine water within limestones.

Research has been carried out to better understand the potential impact of greenhouse gas emissions from abandoned mine workings on climate change (DECC, 2011). However, there seems to be little recent published research in relation to the impact rising groundwater levels may have on the source of gas within mine systems, particularly around the volumes of methane and carbon dioxide held in solution within rising mine waters and the interaction of rising water within shallower rock formations.

Another factor to consider is that the effects that climate change may have on groundwater levels across the UK are uncertain. According to UK Climate Projections (UKCP09), the UK climate will become warmer due to climate change, winter rainfall will increase by 10 to 30% and summers will be drier. Aquifers will likely be recharged during wetter winters (Jackson et al., 2011), but overall groundwater levels depend upon the balance between winter recharge and summer evaporation, transpiration, and the increased stress on groundwater resources during drier times (BGS, 2019).

Yawson et al. (2019) found that groundwater recharge will likely increase in Scotland, Northern Ireland and Wales whereas groundwater reductions will likely occur in England, which is supported by Herrera-Pantoja and Hiscock (2007). However, the effects of climate change on groundwater are site specific and are dependent on a variety of factors including land use and vegetation types (Jackson et al., 2011). Additionally, location plays a factor as climate change is expected to increase the landward intrusion of seawater into coastal aquifers, which will affect aquifers near the coast (Safi et al., 2018; Abd-Elhamid and Javadi, 2008; Sherif and Singh, 1999).

Therefore, predicting the future changes to groundwater levels in abandoned mines and the resulting effects on gas generation are complex. Further research is recommended to assess the effects of climate change on the interaction of groundwater resources and abandoned mine workings.

Anthropogenic activity

New preferential pathways between mine workings and the surface can be created by a number of anthropogenic activities associated with site development including:

- ground investigations
- abstraction boreholes for water resources
- ground source heating systems
- on shore oil and gas drilling
- geothermal exploration in Scottish coal deposits and abandoned mine workings
- mine stabilisation works
- creation of foundations related to infrastructure or development.

The assessment of many of these issues is referred to in existing standards and guidance, such as BS 8485:2015+A1:2019. Works involving drilling or piling into mine workings and treatment of abandoned coal mine workings for ground stability purposes are subject to Coal Authority permitting (Banton et al., 2015).

Ground sealing as a result of development may also affect ground gas migration from mine workings to its effect on existing passive venting of gases to the surface.

Cumulative development over a short time period could be particularly significant. This issue was identified as a concern in the Gorebridge IMT Report and in stakeholder engagement as part of this project and particularly in areas where rapid development is being undertaken in some areas of the former Scottish coalfields.

3.3.4 Planning and Building Standards Process

The Planning and Building Standards systems in Scotland were referred to both by Local Authority (LA) and other stakeholders in the consultation phase of the project. Therefore, in order to provide context, we set out the key elements of the system at national and regional levels as it operates in the development of sites and individual properties.

Building Standards

Responsibility for Building Standards system in Scotland sits with the Building Standards Division under the Scottish Government's Directorate for Local Government and Communities.

Under The Building (Scotland) Act 2003, Scottish Ministers may make building regulations for purposes including "securing the health, safety, welfare and convenience of persons in or about buildings". These regulations are published as The Building (Scotland) Regulations 2004.

The Scottish Government publishes several documents covering procedural and technical guidance which are reviewed on a regular basis. They also conduct any necessary research and consult on changes to the building regulations and associated Technical Handbook guidance on behalf of the Scottish Ministers.

Information on the Building Standards system is available via the Building Standards website. Although updated in 2017, it is noted that the current 'Technical Handbook – Domestic' document does not provide any information on ground gases, including mine gas. The equivalent document in England titled 'Approved Document C - Site preparation and resistance to contaminants and moisture' was reviewed in 2013 and references ground gas risk throughout the document with a small section covering methane and other ground gases.

Although the Building Standards system is overseen by the Building Standards Division, the regulations are enforced at a local authority level. Local authorities are also appointed as building standards verifiers tasked with granting building warrants when they are satisfied proposed work meets building regulations and accepting completion certificates where completed works also comply.

The Building (Scotland) Regulations 2004 implement building standards that are required to be met in the completed building so that there will be no threat to the building or the health of the people in and around it due to the presence of harmful or dangerous substances.

Planning

The planning system in Scotland is overseen by the Scottish Government who is responsible for the development and implementation of legislation and national planning policy (The Scottish Government, 2019).

The primary responsibility for the delivery of the planning services in Scotland lies with the 32 local authorities and the two national park authorities: the Cairngorms and Loch Lomond and the Trossachs.

Planning authorities are responsible for administering the three main parts of the planning system:

- Development planning – setting out how places should change in the future using plans
- Development management – making decisions on planning applications guided by policies in the development plan
- Enforcement – ensuring development is carried out correctly and acting when necessary.

There are also currently four Strategic Development Planning Authorities (SDPAs):

- Aberdeen City and Shire SDPA
- Glasgow and the Clyde Valley SDPA
- SDPA for Edinburgh and South East Scotland – SESplan
- SDPA for Dundee, Perth, Angus and North Fife – Tayplan.

In addition, Scottish agencies, such as Scottish Water, Scottish Environment Protection Agency (SEPA), Scottish Natural Heritage (SNH), Transport Scotland and Historic Environment Scotland, have a duty to engage in the development plan process at different stages.

The Town and Country Planning Act (Scotland) 1997, amended in 2006, forms the basis of the planning system in Scotland. Development plans and planning decisions are guided as appropriate by Scottish Government documents, such as the National Planning Framework (NPF), the Scottish Planning Policy (SPP), Circulars and Planning Advice Notes (PAN).

In this context PAN 33 is particularly relevant as it covers land contamination and related issues including ‘flammable and toxic gases. The PAN also states that one of the key principles adopted by Scottish Government is the ‘suitable for use’ approach. It is the responsibility of the developer to undertake an adequate risk assessment of a site, and to propose measures to ensure that these risks are appropriately addressed. The planning authority and building standards have the role of ensuring that developments are ‘suitable for use’.

In terms of land contamination, to ensure that land is made suitable for the proposed new use, planning authorities should require that applications include suitable provision for site assessment and where applicable, remediation measures.

PAN 33 recommends that “even before an application is made, informal discussions between the developer, planning authority and any other interested party should be beneficial in identifying the likely state of contamination and the most appropriate means of remediation.”

When considering a planning application, a planning officer will need to consider, with specialist advice (from within the authority or externally) whether or not the developer has adequately identified the sources of contamination and put forward a suitable restoration scheme for the proposed use. Planning permission may be granted on the condition that development will not be permitted to start until a site investigation and assessment has been carried out and that the development itself will incorporate measures shown in the assessment to be necessary. Planning conditions are normally included to this effect. If an issue cannot be resolved by imposing a planning condition, it may be possible to do so by concluding an agreement under section 75 of the Town & Country Planning Act 1997.

According to PAN 33, planning authorities, through Development Plans, are expected to promote the reuse of brownfield land, including sites affected by land contamination. Development plans allow authorities to set out their priorities for the reclamation/reuse of contaminated land and to inform developers of the availability of sites and any potential constraints associated with them. Local development plans should set out specific proposals for land use in their area so that opportunities for development are easily identifiable by landowners, potential developers and the community. Planning authorities should not be deterred from allocating potentially contaminated land for development on the grounds that remediation is required, but this should be a material consideration in granting planning approval for a specified development.

The applicant therefore needs to satisfy the planning authority that any unacceptable risks from existing contamination will be successfully addressed through remedial actions with as little impact to the environment as possible during and following the development. Any measures agreed upon concerning the post-development monitoring or maintenance must be presented to any future owner so that they are fully aware of the responsibilities that are tied to the land.

Supplementary planning guidance has been published by a number of local authorities in the Central Belt of Scotland in relation to land contamination issues including mine gas issues (Joint Scottish Contaminated Land Regulatory Officers 2010). A revised version of the joint document is currently being reviewed by Environmental Protection Scotland.

Some individual local authorities, e.g. Falkirk and West Lothian Councils, have also produced their own supplementary planning guidance related to contaminated land.

A major update of planning legislation in Scotland is pending. The Planning (Scotland) Bill was introduced to Parliament on 4 December 2017 and continues to be considered by the Scottish Parliament.

The Bill is intended to strengthen the planning system's contribution to inclusive growth and empowering communities. The Bill sets out the Scottish Government’s proposed

high-level changes to the overall framework under which planning operates, in particular the Bill proposes a major update of the way local development plans are taken with a 10 year cycle as opposed to the current five years. This is referred to further in the analysis section of this report.

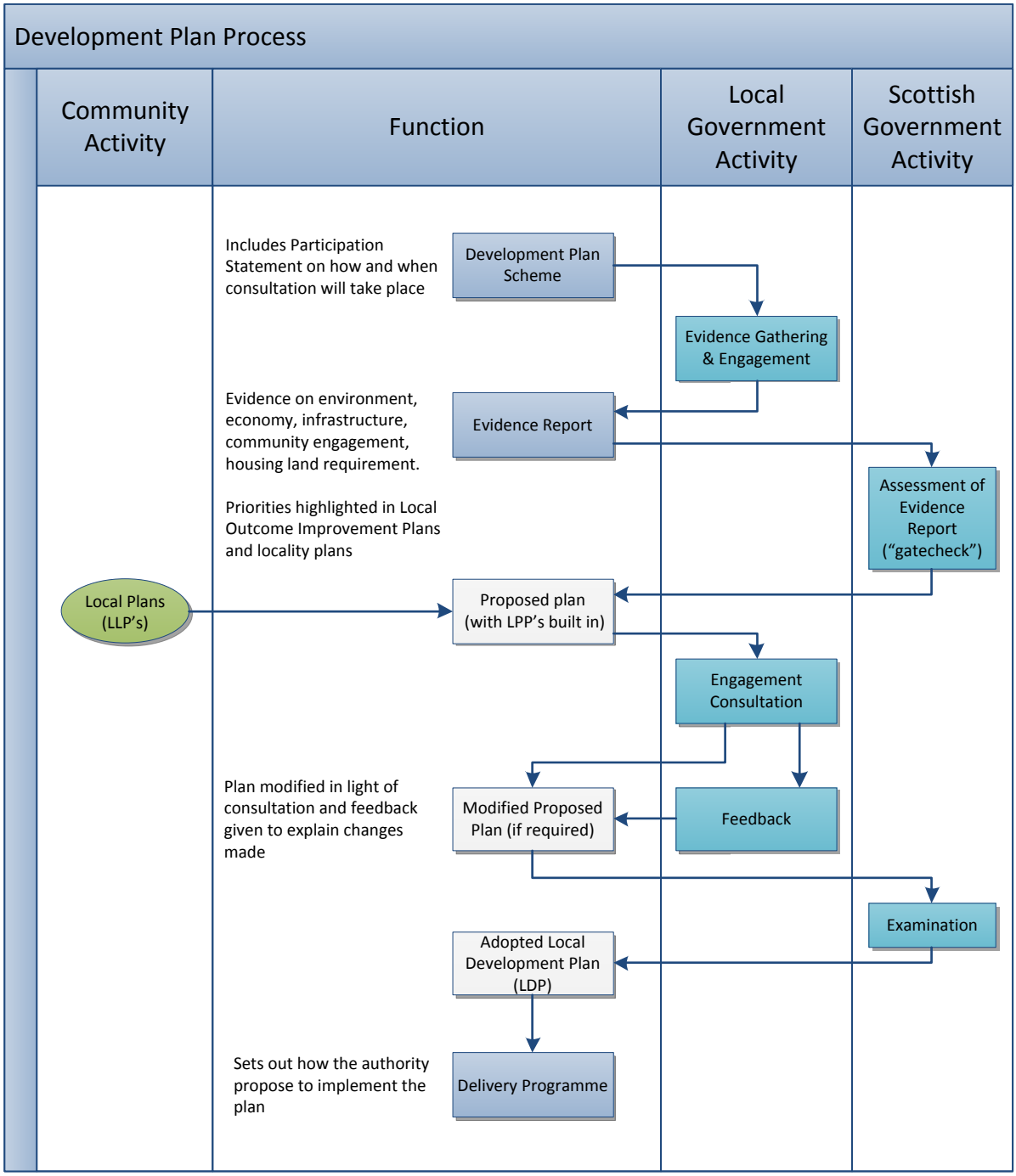


Figure 3-1 Scottish Development Planning Process

3.3.5 The Part IIA Regime

Part IIA of the Environmental Protection Act 1990 is the primary legislation in the UK that relates to the assessment and remediation of land contamination under its current

use. This was implemented in Scotland through the Environment Act 1995 and the Contaminated Land (Scotland) Regulations 2000. The Statutory Guidance provides details to all parties on how the regime should be implemented (see Scottish Executive, Environmental Protection Act 1990: Part IIA Contaminated Land Statutory Guidance: Edition 2, May 2006, Paper SE/2006/44).

Local authorities are the lead regulators under Part IIA with SEPA responsible for regulating certain 'Special Sites' and advising on water pollution cases.

The Contaminated Land (Scotland) Regulations 2005 were implemented by the Scottish Government in April 2006.

The definition of "contaminated land" under these regulations is as follows:

"any land which appears to the local authority in whose area it is situated to be in such a condition, by reason of substances in, on or under the land, that –

(a) significant harm is being caused or there is a significant possibility of such harm being caused; or

(b) significant pollution of the water environment is being caused or there is a significant possibility of such pollution being caused."

In this context, relevant categories for 'significant harm' stated in the Statutory Guidance comprise:

- Human health effects: **death**, disease, **serious injury**, genetic mutation, birth defects or the impairment of reproductive functions
- Property in the form of buildings: **structural failure, substantial damage or substantial interference with any right of occupation**.

The Part IIA regime relates to the current use of land, in contrast to the planning regime which considers proposed future use. Part IIA is therefore the legislation applicable for considering whether existing properties are impacted by CO_2 from mine gas.

4 Report Objectives

4.1 Summary of IMT Building Standard Related Questions

The following list is a summary of the key building standard related questions highlighted by the Gorebridge IMT report (for the full questions, see **Table 7-2 IMT Questions to Building Standards Stakeholders**):

- Is the current mine gas risk assessment process adequate?
- Is the current risk assessment process fit for purpose particularly in terms of taking account for future potential changes?
- Is there sufficient emphasis in the current mine gas risk assessment process on the potential for other interventions?
- Are current mitigation processes sufficiently precautionary?
- In determining the need for mitigation measures, is the current scope for interpretation of the guidance open to developers at present appropriate?
- Are ventilated solums more appropriate?
- Is the drive to improve the energy efficiency/air tightness of modern properties a potential factor contributing to the retention of mine gas emissions in a property?
- Would the simplest and most appropriately precautionary solution be to require mandatory gas risk mitigation measures in all new residential and similar developments in former coalfields?

4.2 Objectives

The main aims and objectives were detailed within the Scottish Government tender documents. In summary the aims for this project are to:

- Understand details of any similar past incidents in Scotland;
- Identify other organisations which provide guidance on mine gas mitigation, understand what that guidance is and if they intend to review that advice;
- Determine if different, modern construction techniques no longer offer the same levels of protection on residential properties for mine gas mitigation issues;
- Consider and investigate if there are any other applicable and suitable mitigation measures that could be utilised on existing properties; and
- Consider the eight building standards related recommendations in the Gorebridge IMT report.

These aims and objectives have been addressed by fact finding carried out by a literature review, stakeholder engagement and consultation with experts followed by an

analysis of the findings. In that analysis, which is presented in Section 9, we have considered the following points:

- What retrofitting works (e.g. gas membranes and/or ventilation/pressurisation) can be carried out to existing properties that would give certainty to successfully 'managing' the presence of CO_2?
- Given that it is assumed that CO_2 would take the path of least resistance, is it possible to create paths in affected buildings that would result in escape routes for the gas?
- High levels of CO_2 may eventually become exhausted, are there any ways of determining how and when that might happen? Would there be any way of accelerating such a process?
- What are the implications for existing properties surrounding a new-build development if gas membranes are deployed (e.g. is there a need for venting trenches surrounding the site or buildings to prevent gas migration)?
- What are the maintenance requirements for any potential mitigation arrangements?

5 Previous Incidents

5.1 Incident Record

One of the key objectives of the research project is to collate a record of all the past incidents of CO_2 'mine gas' in Scotland that have occurred in the last 54 years which is the time elapsed since national building regulations have come into force.

Annex 1 - Table of past incidents is a summary of all the incidents uncovered in the research project. They have been split into four main categories:

1. Previous incidents of CO_2/low O_2 in Scotland
2. Other incidents of CO_2/low O_2 in the rest of the UK
3. CO_2/low O_2 events elsewhere in the world
4. Other mine gas events in Scotland (where the major component was not identified or believed to be in CO_2 or an O_2 deficient atmosphere).

All the previous incidents are listed in chronological order starting with the oldest event. Where information is sketchy, or anecdotal, they have been added to the end of the section.

The sources of the case studies came from:

- The Gorebridge IMT report (main section and Appendix 4)
- The Coal Authority (Incidents database)
- Chartered Institute of Environmental Health, The local authority guide to ground gas, 2008
- Local Authorities
- Relevant experts consulted for this report.

Due to the nature of CO_2 related incidents, noted earlier in this report, it is mainly the acute incidents, e.g. sudden fatalities or collapse that are reported, and some earlier reports are more anecdotal. Where possible, detail has been given on the incident or mitigation measures since put in place. See Annex 1 - Table of past incidents.

5.2 Observations and Analysis of Previous Incidents

During the collation of previous incidents, similar to that of the Gorebridge event, a number of observations were made from an analysis of the data. Although the data is fairly sparse with no obvious trends, there are some general themes and characteristics which are detailed in the subsections below.

Pathways

On examination of the data, it appears that many of the CO_2 ingress events were related to the proximity to old or undiscovered shafts (and adits). This would indicate that old shafts, drifts, and adits are significant pathways for CO_2 (and mine gas in general). On occasion this includes unrecorded historic workings such as bell pits. Some of the incidents were related to known shafts which were poorly infilled, indicating that even if there is a known risk, there should not be an assumption that the shaft was sufficiently grouted and there is no gas risk. Several reasons, such as poor initial grouting, further collapse on the edge of the shaft/cavity or general degradation of the original grout may generate a new pathway in what might be regarded as safe, sealed former workings.

Construction

As discussed above it is the proximity of shafts/adits which was an important factor in previous incidents. Within the available datasets there is limited description of the age of the domestic property impacted nor information on construction within the immediate vicinity.

While it has been proposed that previous or ongoing construction activity may increase the risk by altering existing pathways or creating new ones, the data available from previous events is insufficient to assess this.

Data & Reporting

It should be noted that the CA records only date back to 1994 which is when the CA was formed, and a formal database of gas incidents was set-up. In addition to this the information generated by the CA for this report had several errors, such as an incident being listed as non-residential yet in the detail column mentions of effects to ‘residents’. Detail was also lacking on the ‘outcome’ that was recorded. Occasionally the outcome was a very detailed account, but it was mainly limited to basic effects.

Similarly, some incidents are anecdotal and lacking data such as date, location or the nature of the event and therefore also require further verification. In addition to this, based on the nature of CO_2 events, it is possible that many chronic events have gone unrecorded, as addressed in the introduction.

Nature of Events

As mentioned previously, CO_2 and O_2 deficient atmosphere events can be split into two categories, acute and chronic:

- Acute events are typically a fatality or sudden collapse from asphyxiation. Many of these occur when persons enter a subfloor level room or enclosed spaces below ground where significant accumulation of CO_2 has occurred.

- Chronic events are indicated by people falling asleep/unconscious, feeling dizzy, or a failure to light a fire or boiler. Flames extinguished in a household therefore indicate a low O_2 environment.

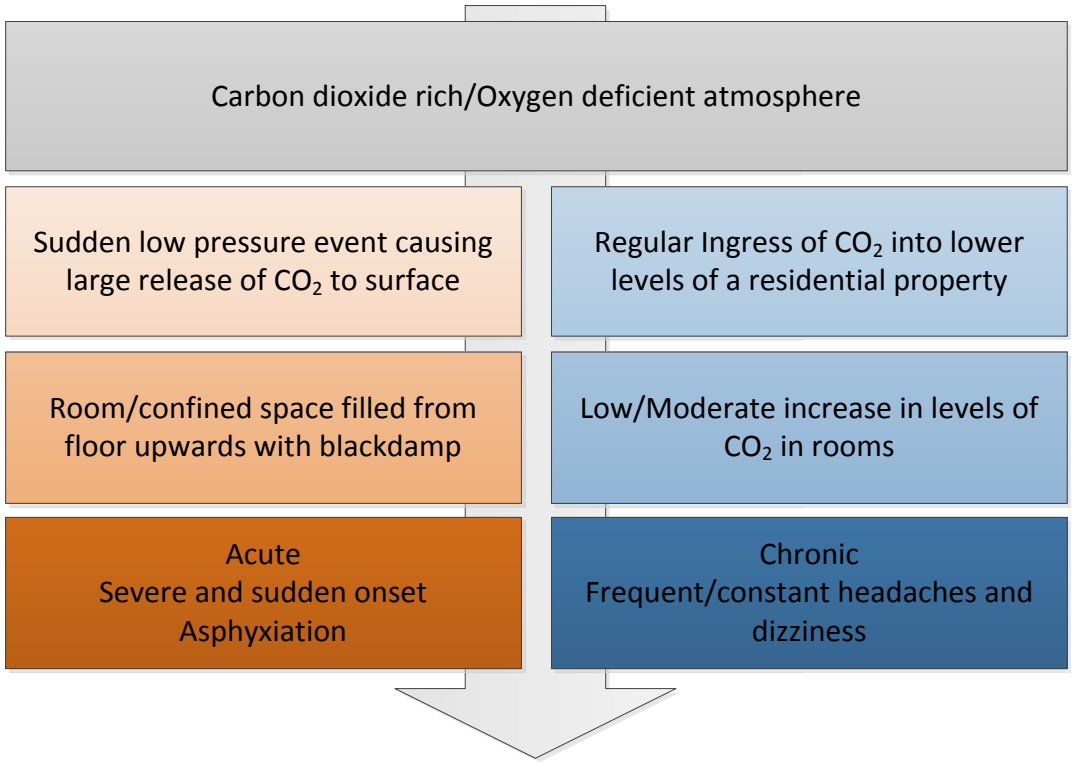


Figure 5-1 CO_2/O_2 deficient health effects: chronic & acute

Most previous incident reports provided no CO_2 or O_2 data. In the small subset of domestic properties where this was provided, the information often indicates that an acute event is being investigated e.g. O_2 as low as 12% within a domestic property, with one basement area recording 10%.

To give these values some perspective, health effects for depleted O_2 levels (Air Products, 2014) occur as follows:

- 19%: Some adverse physiological effects occur, but they may not be noticeable
- 15%–19%: Impaired thinking and attention, increased pulse and breathing rate, reduced coordination, decreased ability to work strenuously, and reduced physical and intellectual performance without awareness
- 12%–15%: Poor judgment, faulty coordination, abnormal fatigue upon exertion, and emotional upset
- 10%–12%: Very poor judgment and coordination, impaired respiration that may cause permanent heart damage, possibility of fainting within a few minutes without warning, and nausea and vomiting
- <10%: Inability to move, fainting almost immediate, loss of consciousness, convulsions, and death.

Of those domestic properties where CO_2 levels were available the highest found within a domestic property was 7% or 70,000 ppm. The lowest value noted in the previous incident reports was 0.8% or 8000 ppm CO_2.

Again, to provide some perspective health effects for CO_2 levels occur as follows:

- 250-400 ppm: Background (normal) outdoor air level
- 350-1,000 ppm: Typical level found in occupied spaces with good air exchange
- 1,000-2,000 ppm: Level associated with complaints of drowsiness and poor air quality
- 2,000-5,000 ppm: Level associated with headaches, sleepiness, and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate and slight nausea may also be present.
- >5,000 ppm: This indicates unusual air conditions where high levels of other gases could also be present. Toxicity or oxygen deprivation also likely to occur.

From the available data there has been no detailed investigation initiated in domestic properties where CO_2 levels were below 5000 ppm. Whilst adjoining properties were subsequently found to have similar issues the reports do not provide data on the gas levels found in these properties. There are few recorded acute events and there is insufficient data to estimate the incidence of lower level chronic effects of CO_2 or O_2 deficiency within domestic properties (Bonino, 2016).

The symptoms attributed to elevated CO_2 or O_2 deficiency within a confined space can also be found with many other health issues ranging, for example, from heart problems through to a simple cold. It is, therefore, possible that a low level chronic or transient low-level CO_2 event would not be identified as the root cause from a member of the public reporting these symptoms to their doctor.

All previous events recorded at domestic properties have been identified where symptoms are acute or in conjunction with reports of multiple people reporting illness or breathlessness in close proximity.

Mitigation Measures

Where there are mitigation measures recorded against previous occurrences it should be noted that these are a response to an acute event. In most cases the source and pathway were in close proximity to the receptor (i.e. properties) and the reports have been investigated by the Coal Authority with any follow-on mitigation carried out at their direction.

The mitigation measures utilised vary from demolition to passive venting and monitoring, depending on the seriousness of these occurrences. Works completed have included:

- Installation of active venting on nearby shafts
- Continual monitoring
- Existing shafts and adits sealed alongside installation of additional passive venting

- New shafts sunk to access mine workings to allow ventilation
- New boreholes sunk around properties to provide a pathway for ventilation
- Demolition of properties
- Active or passive underfloor ventilation fitted in conjunction with gas membrane
- Shallow workings accessed, and ventilation stacks installed
- Monitors supplied to homeowners.

Where active measures were installed, it is picked up within the Coal Authority's ongoing monitoring and maintenance regime. It was noted that, within the 1980 occurrence at Cramlington, efforts to mitigate issues at receptor properties using a gas membrane alongside underfloor ventilation were unsuccessful. From the previous occurrences the preference appears to be ventilation in most cases with demolition required where the pathways lead directly underneath the properties.

5.3 Context for Scotland

A key area of the research for this project was to indicate previous incidents in Scotland. A total of 12 incidents were found including the Gorebridge event. **Figure 5-2 Distribution of past CO_2 events** in Scotland shows a map of the distribution around Scotland. Although there are not many recorded incidents in Scotland, CO_2 related events have occurred throughout the rest of the UK's former coalfield areas (detailed in Annex 1 - Table of past incidents).

The CO_2 events occurred in South Lanarkshire, Dumfries and Galloway, Midlothian and Fife. From the data, there are three non-CO_2 related mine gas events in Scotland. A methane event in Chryston, North Lanarkshire and two incidents in Leven, Fife which were both related to methane accumulation and burning coal.

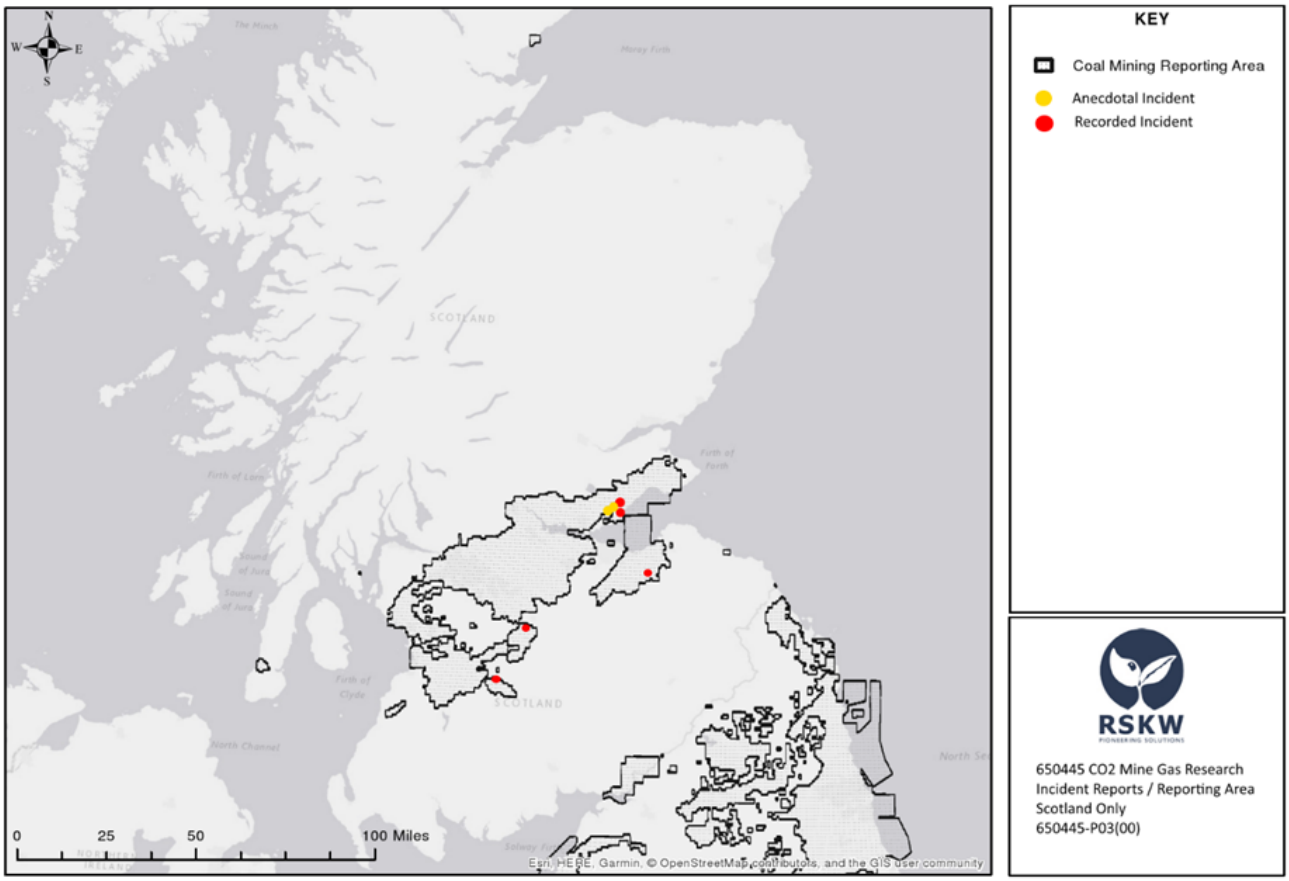


Figure 5-2 Distribution of past CO_2 events in Scotland

6 Standards and Guidance

6.1 Review of Current Standards and Guidance

There are a series of available standards and guidance relating to ground gas assessment and mitigation that have been developed since the late 1980s. The term 'ground gas' includes CO_2, one of a number of gases occurring and generated within the ground in both made ground or natural deposits, including former mine-workings (BSi, 2015).

A number of high profile incidents occurred in the 1980s, predominantly relating to landfill gas, which caused the displacement of people, severe damage to structures and loss of life. This raised awareness of hazards relating to ground gas and triggered research and the development of best practice approaches, which have fed into development of ground gas guidance over the last 30 years. Much of the early guidance (led by BRE and CIRIA) was driven by the need to understand risks from landfill gas, but this later expanded to include all sources including mine gas. Methane has often been seen as the primary risk driver in relation to mine gas, although CO_2 has frequently been considered.

There are now a considerable number of guidance documents available as detailed in Annex 2. These have more recently been consolidated into two British Standards:

- British Standard BS 8485: Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings, first published in 2007 and updated in 2015
- British Standard BS 8576 Guidance on investigations of ground gas, 2013.

BS 8485:2015 covers site investigation and risk assessment methods for ground gas as well as the design of appropriate protection measures. It states that 'it is anticipated that specialist advice is needed in the assessment of the ground gas data and in the risk assessment phase.' It also states that 'the framework is not prescriptive and professional judgement may be made as to the acceptability of risk and whether there might be benefit in undertaking more rigorous site assessment or adopting conservative measures in design'.

BS 8485:2015 states that it is recognised 'that there are a number of factors requiring consideration which affect the sensitivity of a development to the effects of ground gas and that there are a range of design solutions available for different situations. Emphasis is placed on the justification and recording of risk assessments and design decisions throughout the process. As a code of practice, this British Standard takes the form of guidance and recommendations and it should not be quoted as a specification'.

BS 8576:2013 provides guidance on the monitoring and sampling of ground gases and is intended to be used in conjunction with BS 10175:2011+A2:2017 'Investigation of potentially contaminated sites – Code of practice'. It covers volatile organic compounds (VOCs) and permanent gases, including carbon dioxide, methane and oxygen. The

focus of the document is on development sites and the risk posed by gassing sites to neighbouring land and developments, although it is also stated to be relevant to Part IIA.

Other key guidance documents that provide useful reference sources for many aspects of ground gas assessment and mitigation include:

- CIRIA, Assessing risks posed by hazardous ground gases to buildings, C665, 2007
- NHBC, Guidance on evaluation of development proposals on sites where methane and carbon dioxide are present, 2007
- Chartered Institute of Environmental Health, The local authority guide to ground gas, 2008.

Further detailed information is provided in Annex 2 - Table of Standards and Guidance.

6.2 Ground Gas Risk Assessment

All the documents referred to above are based on the framework provided in Model procedures for the management of land contamination, CLR11 (EA, 2004). This provides the technical framework for structured decision making about land contamination. The overall approach presented in CLR11 in dealing with past land contamination is one of risk management, including 'all the processes involved in identifying, assessing and judging risks, taking actions to mitigate or anticipate them, and monitoring and reviewing progress'. Risk assessment for land contamination, including ground gas, in CLR11 is based on the contaminant source-pathway receptor approach. A pollutant linkage is present and hence a risk is realised when all three elements are in place. The conceptual site model represents the characteristics of the site in diagrammatic or written form that shows the possible relationships between contaminants, pathways and receptors.

BS 8485:2015 states that 'before protective measures for buildings can be designed, an appropriate risk assessment should be carried out to decide whether there is a potentially hazardous situation and what the magnitudes of associated risks are.' Two approaches are presented:

- An empirical, semi-quantitative approach
- A detailed quantitative assessment approach.

The former, which is most commonly used, involves the use of monitoring data collected from gas monitoring standpipes installed in the ground. This approach leads to derivation of an appropriate gas screening value (GSV) and is also referred to as the Modified Wilson and Card approach. The GSV is defined as the 'flow rate of a specific hazardous gas representative of a site or zone, derived from assessment of borehole concentration and flow rate measurements and taking account of all other influencing factors, in accordance with a conceptual site model'. The GSV is then used to select an appropriate Characteristic Situation (CS) for selection and design of gas protective

measures. Characteristic situations range from CS1 to CS6, with the higher the CS level, the higher the hazard potential.

It is important to note that the GSV thresholds are guideline values and not absolute. The GSV thresholds may be exceeded in certain circumstances, if the site conceptual model indicates it is safe to do so. Similarly, consideration of additional factors such as very high gas concentrations, should lead to consideration of the need to adopt a higher risk classification than the GSV threshold indicates.

Protection measures within new buildings can be prescribed using a point scoring system. A key feature of the GSV approach is that it should include consideration of worst-case conditions, such as a rapid fall in atmospheric pressure.

BS 8485:2015 also states that 'a detailed quantitative assessment of gas emissions should be carried out in appropriate situations, such as where sites have moderate to high hazards, where buildings have complex foundations, and where the [CS] approach described suggests an over-conservative assessment of risk posed by the presence of gas in the ground'.

An alternative and commonly used method of ground gas risk assessment, referred to as the 'Traffic Light System', is contained within the NHBC guidance. This is designed to be applicable to low rise residential development utilising beam and block floor constructions with clear void ventilation.

BS 8576:2013 focuses on appropriate methods for data collection in the site investigation phase rather than risk assessment. It does however state that "in order to complete an assessment of the risks posed by the presence of permanent and other ground gases, it is necessary to understand the potential sources of gas in and around a site. It is important to collect information on the other aspects of the site, including for example the history of the site, the natural and man-made geology of the site and surrounding areas, the hydrogeological regime, and the uses of the site and surrounding land. This information is used to develop a conceptual model of the site and surrounding area. Development of the conceptual model requires an understanding of both the short-term (e.g. explosion or asphyxiation) and long-term hazards posed by the permanent gases and VOCs that might be present."

Other recent changes in ground gas assessment relate to the availability and increased use of 'continuous' ground gas monitoring equipment as an alternative or supplementary to 'spot' monitoring.

6.3 Ground Gas Mitigation and Verification

BS 8485:2015, and other guidance referred to above and in Annex 2, detail the approaches to design of gas protection measures. BS 8485:2015 states that it 'is intended to be used by designers of gas protection measures and by regulators involved in the assessment of design solutions'. It presents a points-based system for the selection of appropriate gas protection measures based on the CS and building type spanning the range of private residential to large commercial/industrial. This approach is intended to be used 'unless the protective measures are designed using quantitative modelling methods'.

When the minimum gas protection score has been determined for the building as a whole, or for each part of the building, then a combination of two or more of the following three types of protection measures should be used to achieve that score:

- The structural barrier of the floor slab, or of the basement slab and walls if a basement is present
- Ventilation measures
- Gas resistant membrane.

Once the types of protection measures have been decided, the detailed design and specification of the measures should be undertaken and recorded in a design report.

It should be noted that BS 8485:2015 concerns the construction of new buildings only; the retrospective design of protection measures for completed buildings and the design of retrospective protection measures after completion of building construction are not covered.

Following increasing recognition that verification of gas protection measures was an area requiring improvement due to poor construction industry practice, CIRIA produced supplementary guidance C735, 'Good practice on the testing and verification of protection systems for buildings against hazardous ground gases' in 2014.

BS 8485 was then updated in 2015 and comments that 'the installation and subsequent protection of the membrane are key factors in its performance'. A poorly installed membrane cannot perform, however well detailed and irrespective of the performance of the material. Historically, reference has been made to verification and integrity testing without having any referenced documents against which to judge. The verification process is now described in CIRIA C735 and as such, confidence in the installed solution can be measured. The process removes the uncertainty of unqualified or inexperienced installation operatives by requiring a verification plan to be drawn up prior to the installation, with frequency and type of verification being dependent upon the qualifications of the installation operatives, site risk and design criteria. Verification in accordance with C735 therefore now forms part of the points-based system in BS 8485:2015.

A Level 2 non-vocational qualification (NVQ) is available for installers of gas membranes. A proposed NVQ (Level 4) for verifiers of ground gas protection measures led by the British Verification Council is currently going through the approval process, with the Property Care Association (PCA) as the administrating body.

6.4 Research and Emerging Guidance

The outcome of consultation with organisations involved in the production or publication of relevant standards and guidance is detailed below **Table 6.1 Guidance Body Consultation findings**.

Table 6-1 Guidance Body Consultation findings

Organisation	Consultation findings
CIRIA	CIRA remain active in this area. About to commission project to develop guidance on retro-fitting of gas protection measures.
CL:AIRE	CL:AIRE is active in this area with recent publications and ones in preparation. Related publications planned for 2019 include continuous ground gas monitoring and the lines of evidence approach to risk assessment, and a case study publication on the Gorebridge case.
BSi	BSI committee EH4 reviewed whether BS8576:2013 required revision earlier this year and decided that it was not necessary at present. The next review will be considered in about 2023. BS 8485:2015+A1:2019 issued in January 2019.
BRE	BRE are not currently active in the area of ground gas. They have produced guidance on radon but have no major research currently underway in this area.
NHBC	NHBC has produced technical guidance previously and is currently planning to review and update their existing ground gas publication in 2019/2020.
CIEH/ EPG	The CIEH Local Authority Guide to Ground Gas is planned to be updated with interim issue of Ground Gas Information Sheets by EPG Ltd.

7 Stakeholder Engagement

7.1 Stakeholder Engagement Methodology

A project requirement was to engage with LAs, regional NHS boards and other stakeholders to:

- Collect information on where CO_2 mine gas (shale and coal mining) events have occurred since national building regulations came into force (54 years ago)
- Engage with Local Authorities to find out how they each scrutinise the possibility of CO_2 mine gas migration for new development
- Carry out a review of the guidance available on mine gas mitigation in new developments
- Hold a stakeholder event to collect views on the questions raised within the research brief and discuss issues arising.

We reviewed the Coal Authority Planning Policy constraints area that highlights the former coal mining areas within Scotland to narrow the selection down to cover only those areas affected. This identified 23 local authorities and 10 regional NHS Health Boards with the potential to be affected by CO_2 from disused coal or oil shale mine workings within Scotland.

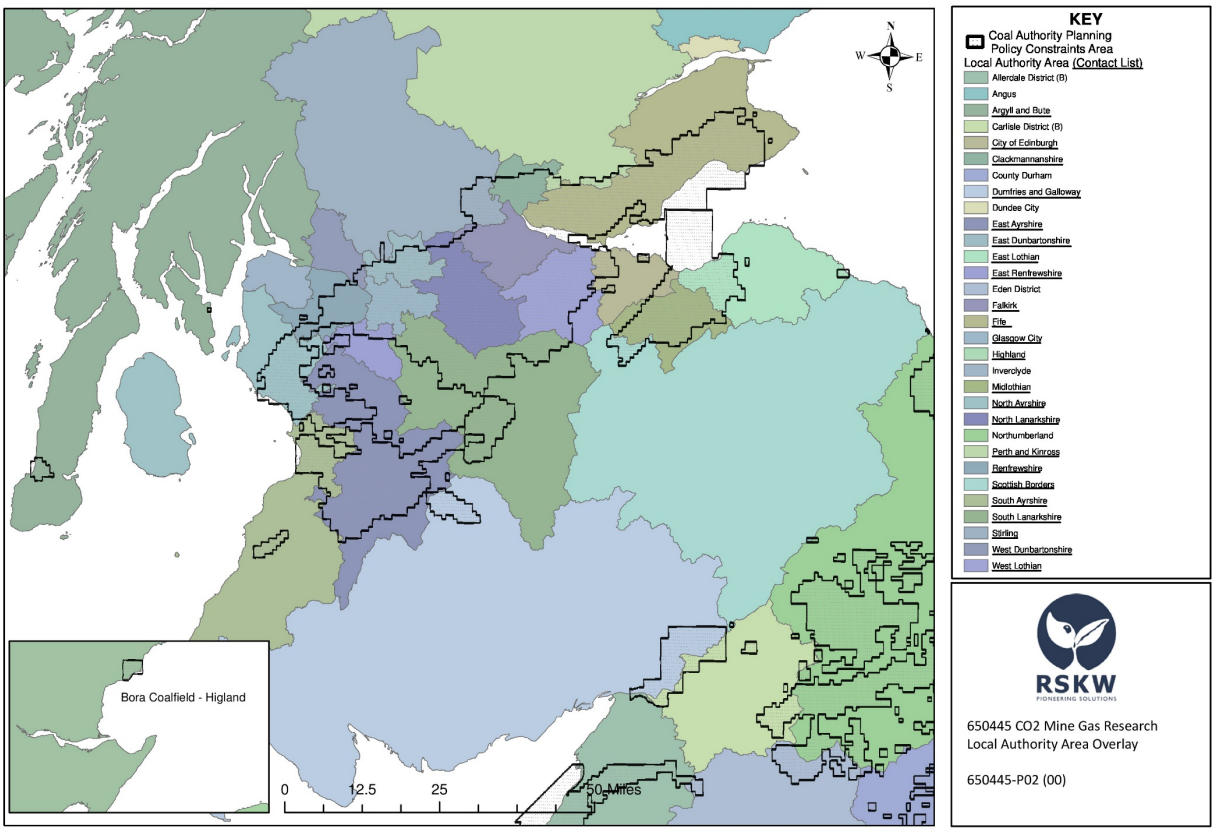


Figure 7-1 Local Authority overlay of CA reporting area

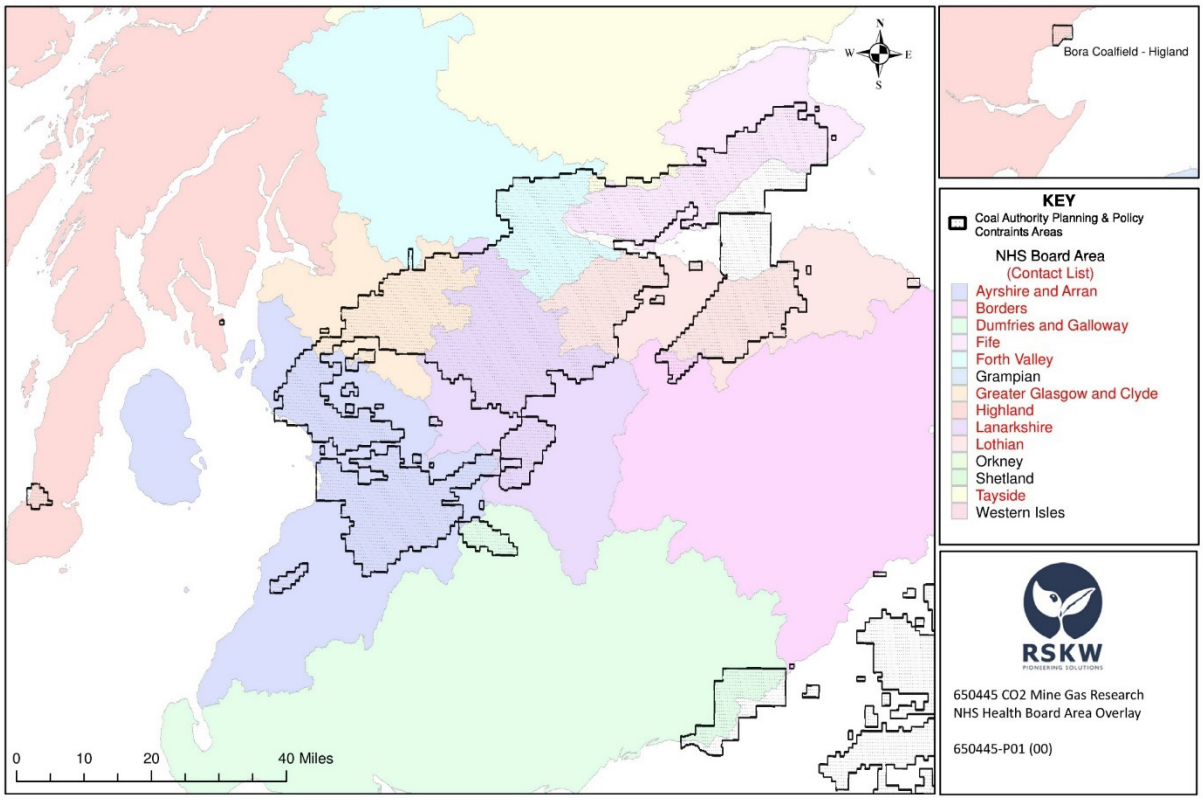


Figure 7-2 NHS board overlay of CA reporting areas

Having reduced the stakeholder list to twenty-three local authorities and ten NHS board areas, we developed a contact list comprising:

- LABSS Building Standards Managers List
- Consultants in Public Health with the 14 NHS Boards Health Protection Teams
- RSKW/ RSK contacts within LA environmental health departments or contaminated land officers (CLO's)
- Local authority planning departments
- Key additional stakeholders i.e. Coal Authority, BGS CIRIA, CL:AIRE, etc.

Using this list, we were able to contact approximately 130 individuals to whom we submitted:

- A project introduction outlining the project aims and objectives
- Their invitation to our CO_2 project workshop on 8th November 2018
- A request for information on previous CO_2 incidents
- A short questionnaire related to the Building Standards questions raised within the Gorebridge IMT report.

7.2 CO_2 Mine Gas Workshop

The Building Standards Division requested we organise a workshop to discuss the issues related to the prevalence of CO_2 from disused mine workings. The main objectives in addition to raising awareness in this area were:

- To consider the building standards related questions which were flagged up in the NHS Lothian, November 2017, Gorebridge IMT report
- To collate information on incidents (other than Gorebridge) where CO_2 events have occurred in the past
- To discuss the degree of scrutiny of the risk of CO_2 mine gas migration in new developments.

The agenda for the day, shown in **Table *7-1***, aimed to outline the issues and comprised a mix of speakers covering the existing guidance and an overview of the Gorebridge IMT report and its recommendations.

Table 7-1 Stakeholder Workshop Agenda 8th November 2018

Agenda	
9:00 - 10:00	Opening Remarks Keynote Speakers: • Andrew Gunning RSKW – Objectives for workshop • Dr Tom Henman RSK – The Evolution of Ground Gas Guidance • Dr Colin Ramsey NHS – The NHS Lothian Gorebridge IMT Report, April 2018.
10:00 - 10:30	Coffee and networking

10:30 - 12:00	Breakout session
	Three groups to consider one of the following issues:
	• Group A (Facilitator Andrew Gunning, Partner RSKW)
	  ○ How is the risk of CO_2 mine gas migration for new development scrutinised by Local Authorities (topic for all 3 breakout sessions);
	  ○ Key discussion topics: Lessons from the NHS Lothian Gorebridge IMT report and how they might influence a precautionary approach to public health.
	• Group B (Facilitator Stuart Borland, MD RSK Building Sciences)
	  ○ How is the risk of CO_2 mine gas migration for new development scrutinised by Local Authorities (topic for all 3 breakout sessions);
	  ○ Energy efficiency and construction factors – could these be contributing to the retention of mine gas in properties.
	• Group C (Facilitator Dr. Tom Henman, Director RSK)
	  ○ How is the risk of CO_2 mine gas migration for new development scrutinised by Local Authorities (topic for all 3 breakout sessions);
	  ○ Risk assessment – is the current risk assessment process robust?

12:00 - 12:30	Presentations from each of the 3 breakout sessions / follow up Discussion: • Information on incidents (other than Gorebridge) where CO_2 events have occurred in the past • How is the risk of CO_2 mine gas migration for new development scrutinised by Local Authorities • Summary of main actions arising: Andrew Gunning RSKW.
12:30 - 14:00	Lunch and networking

As shown in **Table 7-1 Stakeholder Workshop Agenda 8th November 2018** we organised three breakout groups each of which had two issues to address within the allocated time with RSKW providing a facilitator and secretary for each to ensure the discussion moved along and responses were recorded. The format for the workshops comprised:

1. A common question (30 mins)

2. How is the risk of CO_2 mine gas migration for new development scrutinised by Local Authorities (topic for all 3 breakout sessions)?

3. A specific topic to explore taken from Annex A of the contract scope, shown in **Table *7-2* IMT Questions to Building Standards Stakeholders**, plus opening question(s) to get the discussions going.

Table 7-2 IMT Questions to Building Standards Stakeholders

IMT Building Standards Questions	Group
1/ Is the current mine gas risk assessment process adequate to correctly determine the level of risk, especially in relation to the requirements for assessing mine gas levels at sub-surface depths likely to be representative of gas migration potential from underground mine sources?	Group C
2/ Is the current risk assessment process fit for purpose particularly in terms of taking account of future potential changes in mine gas dynamics and migration risk factors (e.g. due to ground stabilisation measures, additional developments, etc.) that could lead to an increased risk of gas migration into properties over the long term?	Group C
3/ Is there sufficient emphasis in the current mine gas risk assessment process on the potential for other interventions affecting the soils or substructures underpinning any building development, to alter the risk of mine gas migration and consequently to render any pre-development assessment redundant and inadequately precautionary to protect public health?	Group A & Group C
4/ Are the current criteria used for deciding what constitutes a sufficiently precautionary approach to mitigation appropriate; particularly where there is known to be a potential risk of mine gas migration? Does the process adequately emphasise the need to take account of construction methods that may add to that risk (e.g. the use of vibro-stone underpinnings or solid slab floors that are not separately vented to the outside atmosphere)?	Group A
5/ In determining the need for mitigation measures, is the current scope for interpretation of the guidance open to developers at present appropriate?	Group B

IMT Building Standards Questions	Group
6/ Are construction methods that do not involve creating a ventilated solum beneath the ground floor of a property inherently more liable to permit the transmission of mine gases to the inside of these properties compared to a traditional ventilated solum construction type?	Group B
7/ Is the drive to improve the energy efficiency of modern properties by increasing the levels of insulation and ensuring they are less prone to uncontrolled air movement (draughts) and are consequently more air tight, a potential factor contributing to the retention of mine gas emissions that manage to penetrate a property?	Group B
8/ Would the simplest and most appropriately precautionary solution to the problems highlighted by the Gorebridge incident be to require mandatory gas risk mitigation measures in all new residential and similar developments in areas of Scotland defined by the Coal Authority as former coalfields?	Group A

The workshop was attended by 42 individuals representing 25 of the key stakeholders as shown in **Table 7.3 Stakeholder Workshop Attendees**.

Table 7-3 Stakeholder Workshop attendees

Argyll and Bute Council Environmental Health
BGS
Building Standards Division
CIRIA
City of Edinburgh Council Environmental Health
Coal Authority
East Ayrshire Council Building Standards
East Dunbartonshire Council Environmental Health
Falkirk Council Environmental Health
Fife Council Environmental Health
Glasgow City Council Environmental Health
Homes for Scotland
Melville Housing
Midlothian Council Building Standards & Environmental Health
NHBC
NHS
North Ayrshire Council Building Standards & Environmental Health
North Lanarkshire Council Building Standards & Environmental Health
Renfrewshire Council Building Standards
Scottish Borders Council Environmental Health
South Ayrshire Council Building Standards
South Lanarkshire Council Building Standards & Environmental Health
Stirling Council Environmental Health
West Dunbartonshire Council Environmental Health
West Lothian Council Building Standards

A summary of feedback received from the attendees is shown in **Table 7.4 Discussion Items from Stakeholder Workshop** and in the findings log set out in Annex 3 – Stakeholder Engagement

4(a) Issues log from Stakeholder Engagement.

.

Table 7-4 Discussion Items from Stakeholder Workshop

Issues Raised: Stakeholder Workshop 8th November 2018
The themes discussed within the workshop are fully noted in Annex 4 and 4b, the full analysis of the feedback is outlined within Section 9.1. To provide an overview of the views from the attendees we have summarised the discussion points raised under the following key areas: • Gas Membranes – concerns over quality of fitting, verification, and their long-term protection • Gas Risk Assessments (Conceptual Site Model) – Variability in the quality of the assessments and conceptual site models being submitted. Many lacked the assessment of changing environmental conditions and, due to the development process, omitted assessments of soil stabilisation activities or impact of adjacent sites • Gas Risk Assessments (Gas Monitoring) – Insufficient or incomplete gas monitoring, or those which did not include falling pressure events indicative of worst-case scenario • Coal Authority – Perceived issues with data availability and accessibility, particularly on a site-specific basis, and benefits of closer collaboration with local authorities • Expertise – Local authorities acknowledge coal mine gas risk assessment is a specialist area. Loss of expertise is occurring as staff with mining industry experience retire. Financial constraints limit the use of external expertise to undertake peer reviews of reports submitted under Planning/Building Standards • Standards – Generally noted that the production of risk assessments and mitigation measures are targeted to meet the minimum functional standard. Local authorities try to provide a level playing field in interpreting the guidance, but some workshop attendees were not comfortable in determining if the current standards and guidance remain appropriate for mine gas assessment. They felt this area needs additional research and review at Scottish Government level • Communication – Some attendees felt their local authority required more of a joined up approach on these issues within departments. In others, they felt they already had this in place. There were some concerns raised on communication relating to planning conditions, gas risk assessments and mitigation measures between Planning, Environmental Health and Building Standards departments within local authorities • Ongoing Maintenance – Permitted developments and future maintenance issues that could affect the integrity of ground gas protection measures installed at the time of development.

7.3 Additional stakeholder engagement

Three local authorities have provided more considered responses or further relevant detail to the issues raised in the questionnaire as follows:

- Midlothian Council – we arranged follow up interviews with their planning teams to obtain further feedback
- North Lanarkshire Council provided reports related to methane seepages in the Chryston area which were first recorded in 1984
- Fife Council – their Land & Air Quality Technical Officer provided an additional written submission covering the issues raised and gas protection system verification.

Stakeholder meetings also took place with Northumberland County Council (NCC) and BGS and information was provided by University of Newcastle. Several publications in relation to experience of mine gas in the Northeast of England were reviewed including Sizer et al. (1996) and Robinson (2000).

NCC has extensive experience of dealing with mine gas related issues similar to those recorded in the Gorebridge IMT Report. This has led to increased vigilance regarding the risks posed by CO_2 for new developments. Two standard planning conditions requiring ground gas protection have been introduced by NCC as follows:

> Condition 1 – Ground Gas Protection:
>
> No buildings shall be constructed until a report detailing the protective measures to prevent the ingress of ground gases, including depleted Oxygen (<19%), to the CS2 standard specified in BS8485:2015 (Code of Practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings) have been submitted to and approved in writing by the Local Planning Authority.
>
> The report shall contain full details of the validation and verification assessment to be undertaken on the installed ground gas protection, as detailed in CIRIA C735 (Good practice on the testing and verification of protection systems for buildings against hazardous ground gases).
>
> Reason:
>
> In order to prevent any accumulation of ground gas, which may potentially be prejudicial to the health and amenity of the occupants of the respective properties.
>
> Condition 2 – Validation and Verification of Ground Gas Protection:
>
> No building shall be brought into use or occupied until the applicant has submitted a validation and verification report to the approved methodology in Condition 2*, which has been approved in writing by the LPA.

Reason:

In order to prevent any accumulation of ground gas, which may potentially be prejudicial to the amenity of the occupants of the respective properties.

Information relating to planning appeals concerning the protection for mine gas was also provided by NCC. The first is for the Arriva Garage site in Ashington where the site was developed without the required ground gas protection. Subsequently, the developer installed gas monitors in the areas of concern. The second appeal relates to a housing development near Cambois where the applicant submitted ground gas information which did not cover the low atmospheric pressure events. Subsequently, the developer submitted this information which showed no ground gas issues of concern at the site.

Generally, NCC were concerned about a lack of specific guidance relating to mine gas issues. This was partly negated by good contacts with Newcastle University, particularly Dr Jean Hall, who provided useful background information for this current project. That included several incidents in the Northeast of England related to CO_2 from abandoned mine workings. Experience in NCC in dealing with mine gas is extensive and there are also regular contacts with neighbouring LAs in the region. We would recommend further discussion with Environmental Health Officers in NCC who indicated they would find it mutually beneficial. Contact details will be provided to Scottish Government.

A key aspect of the incidence of CO_2 related incidents within the NCC area is the presence of shallow mine workings, sometimes only a few meters below ground level.

Consultation with the BGS focussed on the use of environmental data and supporting information to inform planning policy and in particular the issue of providing site investigation and other environmental data early in the planning process (Bonsor, 2018).

Work has been carried out by a sub-group of key agencies in Scotland, to examine what environmental information is potentially relevant to informing preparation of Local Development Plans (LDP), and how this information can be made more accessible.

This could be relevant to identifying within LDP's areas that may be of high risk of CO_2 emissions.

Contacts within the land contamination team at SEPA were also consulted, but they responded that they did not have much to contribute at this stage of the project.

8 Expert Consultation

8.1 Consultation Methodology

Working with industry experts we considered the issues related to CO_2 and mineral workings particularly in relation to the risk assessment process, mitigation measures and the verification and validation, the impact of construction techniques in relation to mine gas entry to residential developments and retrofitting of mitigation measure to existing properties.

The experts were selected on the basis of either being a known leader in a relevant field and/ or previous involvement in the development of relevant technical guidance or industry accreditation schemes. They were drawn from a range of sectors including environmental, engineering or specialist consultancies; designers, installers and verifiers of gas protection systems; a public sector 'developer'; a home construction warranty and insurance provider; and a major house-builder. An additional specialist was interviewed at the request of HPS and Scottish Government due to their knowledge of the Gorebridge IMT case.

We selected a range of experts to cover the full breadth of these issues as it is unlikely that many individuals would be able to cover all areas. The research specification requested that we collect an answer to each question from at least three experts and obtain their reasoning for the response. We consulted a total of ten experts with a range of six to nine responses per question stated in the brief.

The main objective of consulting the industry experts was to gain independent expert opinion to understand if there may be a case for Scottish Building Regulations to be updated or supplementary guidance to be provided. This is in order to minimise the likelihood and mitigate the risks of similar incidents to Gorebridge occurring in the future.

The interviews covered three main areas of interest, these being:

- An assessment of the effectiveness and limitations of the current mine gas risk assessment and mitigation design process and identification of any possible improvements
- The effect of different residential construction techniques on mine gas migration
- Any suitable mitigation measures that could be implemented for existing properties found to be affected by mine gas, as opposed to demolition of the properties.

The industry experts were consulted independently and sent in advance a series of questions, shown below as drawn from the Gorebridge IMT report, to serve as discussion topics.

8.2 Conflicts of interest

Scottish Government stressed the importance of obtaining unbiased views and avoiding those who have vested interests. However, where this was not possible, all vested interests were declared by the experts. A small number of the industry experts we approached declined our invitation to participate because of a conflict of interest in relation to a pending court case.

8.3 Arrangements for interviews

We conducted the interviews in late November/early December 2018, which were led by RSKW's Project Lead Andrew Gunning and supported by Dr. Tom Henman as technical specialist. The interviews took place by phone and lasted between one and two hours. They were carried out individually and followed a repeatable format structured around the three main areas of interest, as identified above, but also included supplementary questions where appropriate.

The industry experts that were consulted are noted in **Table 8-1 Expert Consultees** below. Each consultee was asked to respond to the IMT Building Standards questions shown in **Table 7-2 IMT Questions to Building Standards Stakeholders**. Their responses are collated within Annex 4.

Table 8-1 Expert Consultees

Expert Consultees
Peter Witherington Deputy Chairman, RSK
Peter Atchison, Director PA Geotechnical
Gavin Allsop, Principal Geo-environmental Engineer, NHBC
Barrie Ackroyd, Director MTS Ltd
Richard Boyle, Senior Technical Specialist Homes England
Stuart Borland, Director, RSK
Hugh Mallett, Technical Director, Buro Happold
Tom Parker, Director, Argentum Fox
Andrew Kram, Technical director, Fairhurst
David Steven, Technical Director Taylor Wimpey East Scotland

9 Data Analysis

9.1 Analysis Methodology

Following the stakeholder engagement and interviews with expert consultees, our meeting transcripts were collected and reviewed, and an issues/findings log was created. For stakeholder responses, see Annex 3 – Stakeholder Engagement

3(a) Issues log from Stakeholder Engagement workshop and 3(b) Stakeholder responses to questions. For industry expert responses, see Annex 4 the Findings log from the Consultation with Industry Experts is presented.

Our aim here was to distill all the issues and perceived solutions obtained on the day and identify the main patterns.

Additional reviews were completed by the RSK research team leaders carrying out a deductive approach to collate these themes. The responses were coded and assigned where possible to one of the eight issues relating to the IMT building standards questions.

The collation and analysis from each population type i.e. stakeholders and industry expert consultees were completed separately. Our overall process is shown in **Figure 9-1 Qualitative Data Analysis** below and the results of fact finding presented in Sections 9.2 and 9.3. Both the issues and findings were then compiled to generate a shortlist to assess the feasibility and subsequently the options for consideration.

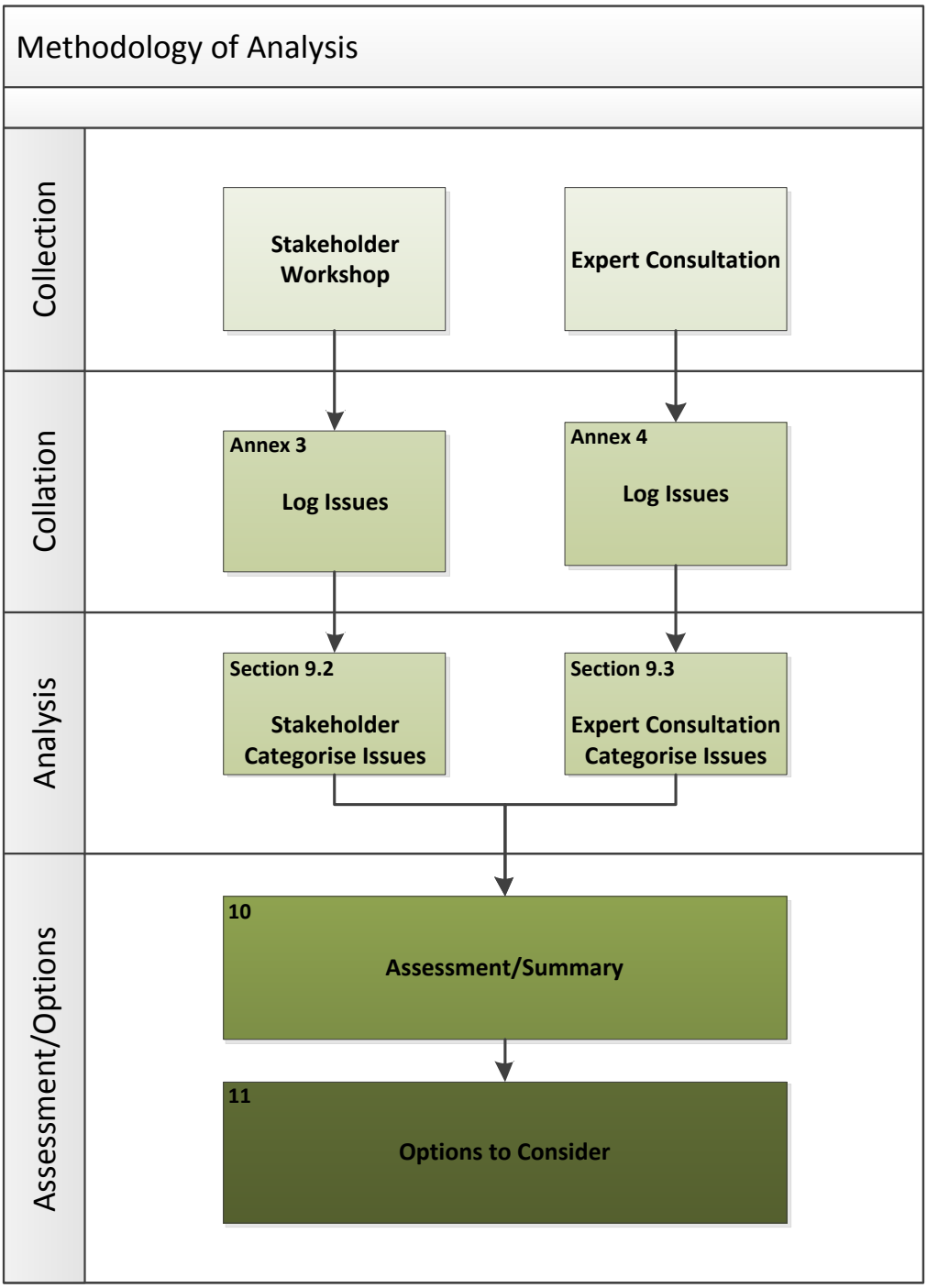


Figure 9-1 Qualitative Data Analysis

9.2 Stakeholder Analysis

The issues identified in the stakeholder analysis are summarized in **Table 9-1**.

Table 9-1 A summary of findings from the stakeholder analysis

9.2.1 Risk Assessments	
RA 1	There is a lack of experience/expertise in LAs to fully understand site risks and risk assessments
RA 2	There is lack of communication between planners, LA assessors and building standards departments
RA 3	There is no guidance on safe/unsafe levels for CO_2
RA 4	Gas monitoring on sites is insufficient
RA 5	The risk assessment is not 'future proof'
RA 6	The risk assessment does not include cumulative impacts
RA 7	Coal Authority Operations
RA8	Mitigation Measures for Existing Developments
RA 9	Site investigation boreholes are creating new pathways for CO_2
RA 10	Current construction techniques are increasing the risk of CO_2 ingress or accumulation.
RA 11	Lack of information on CO_2 sources and pathways related to colliery spoil, former open cast sites and peat.
RA 12	There needs to be more emphasis on mine gas information provided at planning permission stage
RA 13	Monitoring of gases after structural work/ground stabilisation had taken place are not included within risk assessments.
9.2.2 Energy Efficiency	
EE 1	The 'chimney effect' is increased within an airtight property
9.2.3 Mitigation Measures	
MM 1	Fixing a mandatory level of mitigation may cause further unintended issues.
MM 2	Gas Membrane Risk
MM3	Ventilated Sumps CO_2 parallel with Radon mitigation
MM4	Gas Ventilation subsequent blocking due to poor maintenance or lack of notification to owners

9.2.1 Risk Assessments

There was a general consensus from stakeholders that the current gas risk assessment is valid, but that it is frequently implemented poorly or not well understood. Submissions to LAs are noted to be highly variable and frequently suggesting mitigation measures which cannot be implemented until the development has begun. Although adhering to current guidance, the risk assessment fails to fully consider temporal change and/or cumulative effects.

RA 1 There is a lack of experience/expertise in LAs to fully understand site risks and risk assessments.

Feedback from stakeholders in some LAs indicated that there has been some loss of experience over the last decade. The main concern is that environmental health officer/contaminated land officer (EHO/CLO) has a good understanding of contaminated land practices and procedures and landfill assessment but not CO_2 mine gas in relation to former coal mining activity. In particular, a robust understanding of the source in the subsurface and the conceptual model.

Solution Option 1 - Support relevant LAs with compulsory training days on coal mine gas risk. The format of the training could involve expert consultants and the CA creating a workshop to improve understanding of the environmental risk and improvements on the guidance and assessment process.

Solution Option 2 - BGS, CA and former miners to assist LA with further information. Collaborate to create dedicated information about each coalfield and access to site-specific data, where available. Possibly culminating in a short document (2-4 pages) detailing the source material (type of coal), geology and style of mining including potential pathways, water levels and possible temporal changes. This could support more site-specific risk assessments and support regional planning by defining the risk areas with more precision and understanding. This could also be regarded as a peer review process.

RA 2 There is lack of communication between planners, LA assessors and building standards departments.

Stakeholders raised concerns that in some LAs there is not enough communication between the various departments involved in residential property development. The risk assessments are sometimes not being adhered to correctly because the development plans are not taking into account the gas risk correctly (although sometimes this is unavailable at an early stage). The responsibility for assessing the adequacy of the gas risk assessment and mitigation design is split between environmental health and the building standards personnel, who may or may not be fully aware of the level of gas risk and/or thus not authorising the correct level of mitigation. In some cases, relevant planning conditions recommended by EHO/CLO staff have not been acted on, or site assessment reports have been submitted. On other occasions

the risk is acknowledged but too late in the process and either the permission has been approved or development is already under construction.

Solution Option – Departmental liaison early and GIS risk mapping, particularly with regard to large scale residential developments. Building standards, planners, developers and the environmental health teams of an LA should have a meeting prior to planning applications being submitted in order to understand the gas risks. This would benefit all parties and pre-emptively reduce risk by being able to adapt building plans and potential site investigations from generating new pathways or constructing buildings in the more high-risk areas with insufficient mitigation.

Fife Council has taken a very proactive approach and is working with the Coal Authority to create advanced risk maps and candidate sites that are safer for new developments on brownfield areas (such as old coal fields). In addition to this they have built up a GIS database with this information and have retained a log of those properties constructed with gas mitigation measures. This approach should be a consideration for other local authorities.

This could be scaled to larger sites where an intermediate level of risk 'zoning' could take place with link to local development plans.

RA 3 There is no guidance on safe/unsafe levels for CO_2.

Current guidance does not specify a threshold of CO_2 to initiate mitigation measures or what is regarded as safe/unsafe for domestic properties. Standards and guidance tend to focus on short term acute risks from CO_2 and neglect longer term chronic risks of exposure.

Solution Option – Establish a nationwide threshold of CO_2/O_2 deficiency**.**

HSE currently provides workplace exposure limits (WELs) for CO_2 (EH40/2005). However, this is directed towards the working environment and enclosed spaces, not domestic dwellings. They provide a formula for the conversion of eight-hour time weighted average WEL to a continuous (24 hour) equivalent. EH40 provides guidance on standards for situations where occupational exposure is essentially continuous. In these cases, a continuous exposure limit is derived by dividing the eight-hour TWA exposure limit by a factor of five. Based on the eight-hour TWA for carbon dioxide (5000 ppm, 9150 mg/m^3), this would give a continuous exposure concentration of 1000 ppm or 1830 mg/m^3.

Dr Colin N Ramsay Health Protection Scotland has used this calculation with the Gorebridge IMT report to derive an outline acceptable domestic exposure threshold. This level of 1000ppm could easily be reached is some domestic circumstances i.e. within an occupied bedroom overnight. However, if levels above this threshold were being recorded within an unoccupied room it should trigger further investigation. Whilst some limitations exist around this approach, it

gives the most robust, scientifically-derived standard to use for continuous exposure.

Further research is needed. However, this would delineate a benchmark in Scotland, and possibly across the rest of the UK from which authorities would operate. A general blanket threshold value may help to isolate more chronic issues that may arise from persistent levels above a certain threshold exposure. The issue will still remain that a threshold value will not capture or help prevent sudden chronic events such as those in Gorebridge.

RA 4 Monitoring of sites is insufficient.

There was significant feedback that gas monitoring takes place over an inadequate time period(s), with insufficient frequency or limited coverage.

Solution Option 1 – Increased frequency or continuous monitoring (to include 'critical pressure drops').

BS8756: 2013 states sufficient monitoring should be carried out over a sufficient period to allow 'prediction' of worst-case scenario conditions. In order to capture a more robust dataset, monitoring should be continuous and cover a period that encapsulates three to four low pressure events (critical pressure drops CL:AIRE, 2018).

It can be difficult to capture a 'worst-case' scenario if such an event did not occur over the monitoring period. An example was cited that in the summer of 2018 there was a long dry spell of six to eight weeks of consistently high pressure. Any monitoring over this period would be inadequate because the conditions were unusual and would not have captured any rapid falling pressure event.

The solution is that the existing standards and guidance should be enforced, and site investigation and monitoring should commence earlier in the planning process.

Solution Option 2 – Introduce model planning conditions for areas affected by mine gas (see e.g. example of NCC). Model planning conditions, including covering aspects of mine gas risk assessment, for example as a pre-commencement condition.

RA 5 The risk assessment is not 'future proof'.

Several stakeholders were concerned that previous risk assessments may now be invalid as mine water levels rise and climate changes. These are factors which may increase the upward movement of CO_2. This is referenced to in standards and guidance, but no detail is provided on methods of assessment.

Solution Option – Temporal changes need to be logged and/or assessed.

Further research is required into the temporal changes within the former coal workings to understand any trends. These trends could be noted and added to support the conceptual site model by indicating an increased or lowered gas risk. The information could then be included in environmental risk assessments as part of the LDP process, and also used to supplement existing standards and guidance.

RA 6 The risk assessment does not include cumulative impacts.

It was identified in the Gorebridge IMT Report and confirmed by stakeholder engagement that cumulative impacts are not being documented or assessed. This includes the risk posed by a number of developments within the same former coalfield area but are assessed on an individual basis.

Solution Option – Cumulative risk assessment used at planning stage. Stakeholders suggested a cumulative impact assessment for specific former coal mining areas may be required. This could also be implemented in a similar way to the above issue by incorporating a cumulative assessment into the LDP process.

RA 7 Coal Authority operations

A significant number of stakeholder responses related to Coal Authority operations. These comprised the following:

- No risk is logged in a CA report if there is no monitoring or no past incident has occurred in the area
- There are not enough gas and groundwater monitoring points across former coal fields
- Coal mine maps are not detailed enough (therefore the risk source is poorly understood)
- The organisation is ‘reactive’ and not very proactive and will assist with data on request but is limited in its provision of data and scope of work.

Solution Option - The Coal Authority is a statutory body and have stated that it would require more financial support to begin to solve the above issues. At present the CA use the data they hold to inform their site-specific reports and the zoning of development in high risk areas. Site-specific data is not available to third parties. It was noted that Coal Authority representatives attending the workshop recognise the current limitations of their approach and are keen to explore opportunities for greater collaboration with LAs regarding mine gas issues.

RA 8 Mitigation measures for existing developments.

It is important to note that preventative mitigation installed at the time of construction is much more feasible than retrofitting. To quote from Sizer et al. (1996), “it is generally recognized that effective gas precautionary measures for developments are achieved by attention to structural details, which cannot be readily addressed post-construction.”

Stakeholders present from The Coal Authority identified that the organisation infrequently adopts retrospective mitigation measures such as membranes. The standard protocol was to demolish the properties to eliminate the risk, and therefore the liability, to the properties in question. On a large scale, however, this is costly and unsustainable and involves significant upheaval for the residents involved. The CA does passively and actively vent shafts and adits and is currently examining alternative methods to address this issue for residential properties.

Solution Option – Mitigation measures designed and fitted in new properties are much more effective than retrofitting similar measures. Where there are high risks to existing residential properties, there is uncertainty. It was stressed that one of the best overall mitigation measures would be more effective planning ensuring only suitable sites were selected for development. This would include more detailed risk mapping to prevent high risk sites being selected and requiring significant site investigation and mitigation measures which ultimately costs the LA and developer significant resources.

RA 9 Site investigation boreholes are creating new pathways for CO_2.

A ground investigation undertaken to understand the subsurface structures, land contamination (including ground gas), geotechnical/mining issues or other ground conditions can create preferential pathways between the surface and workings for gas migration. These can be lost or damaged over time or during site demolition and redevelopment.

Solution Option - All boreholes must be decommissioned properly. Boreholes drilled in any former coal mining area need to be decommissioned properly and in accordance with SEPA guidance. This could be included as a relevant planning condition. They would require proper capping and grouting if they are no longer being used for monitoring. In addition, a log of the location should be kept ensuring no properties are located directly over a potential pathway especially if the boreholes have reached shallow workings.

RA 10 Current construction techniques are increasing the risk of CO_2 ingress or accumulation.

The construction of concrete slab foundations with no ventilation, gas membranes which are subsequently punctured by service ducts, and also the limited verification for correct installation of membranes are increasing the risk of CO_2 ingress and/or accumulation.

Solution Option 1 – Construct properties with a ventilated solum. Stakeholders favoured the construction of a ventilated void solum. Although this does not eradicate the risk, it is easier to verify and is believed to be more effective overall than a gas membrane or sump.

Solution Option 2 - It was broadly accepted that developers consistently construct to minimum standards. Raising the minimum standards would be a simple solution although this may cause standards to be too prescriptive and thus restrict development.

RA 11 Lack of information on CO_2 sources and pathways related to former mining areas including colliery spoil and former open cast sites.

Solution Option – Further research required to update the risk assessment process in coalfield areas to distinguish between areas of high, medium and low risk. This work should include a detailed review of BGS and Coal Authority datasets.

RA 12 There needs to be more emphasis on mine gas information provided at planning permission stage and for LAs in general.

This issue was highlighted in CIRIA Report 149. Coal mine risks that are assessed in support of planning applications regularly relate more to structural issues rather than gas.

Solution Option – Include mine gas issues at LDP stage. A major update of planning legislation in Scotland is pending (Section 3.3). The Planning (Scotland) Bill was introduced to Parliament on 4 December 2017. The Bill is intended to strengthen the planning system's contribution to inclusive growth and empowering communities. Additional secondary legislation and guidance following on from this work would be required to strengthen the risk assessment process for new developments.

RA 13 Monitoring of ground gas after undertaking structural work/ground stabilisation is not being included within risk assessments.

Solution Option - Developers should be required to carry this out especially if groundworks involve piling or stabilisation of shallow workings. Such works are undertaken under a Coal Authority permit.

9.2.2 Energy Efficiency

It was generally regarded by stakeholders that air tightness is a potential contributing factor to potential CO_2 issues. Additional points were raised that suggested some properties are not built to the specified air tightness requirements or that where CO_2 (or ventilation) monitoring is to take place in the property then monitoring should be in specific rooms.

EE 1 The 'chimney effect' within properties.

The 'chimney effect' is a useful analogy to describe the vacuum effect where a small pressure gradient is created within a property where an upper level window is opened, and air is drawn up from beneath to replace the warm air discharged. A leaky property will exacerbate this effect.

If ground gas is getting into a property but the property is otherwise airtight, the gas will accumulate within the property which is a serious concern. However, if gas cannot get in in the first place, then having an airtight property is fine.

Generally, one of the poorest performing area within any airtight property's envelope are the service intrusions (soil pipes) in the slab within the ground floor toilet and kitchen. Therefore, if there has been significant accumulation of CO_2 beneath the subsurface of a house, then negative pressure here and reduced unintentional ventilation elsewhere could draw significant volumes into these areas of the property. This is particularly important if gas has built up below a membrane that has been punctured with service ducts.

It was noted that kitchens and bathrooms are also areas of the building which are fitted with mechanical extractor systems to remove warm moist air. These systems will induce a negative pressure within these rooms which may also draw in any CO_2 gases via the service ducting.

In addition, the lower levels of unintended background ventilation within airtight properties can allow CO_2 to accumulate.

Solution Option – Construct New Properties with a Ventilated Void Solum. Stakeholders suggested that air tightness should not be reduced because this is counter-productive in trying to improve energy efficiency. The main, albeit indirect solution, would be to construct a ventilated void solum as opposed to a gas membrane to mitigate the gas risk. The reason for this is that a ventilated void solum provides a buffer between the property and the ground, and gas at ground level will be dispersed. When a window is opened in the overlying property and the 'chimney effect' begins to establish, the air drawn up into the property will be less concentrated with CO_2.

It was also discussed that ventilation standards may require reexamination to ensure they are producing the correct results for the building design. This research has recently been undertaken highlighting that information dissemination on these issues might be the issue. A Scottish Government Report; 'Investigation of Occupier Influence on indoor Air Quality in Dwellings' was produced in 2014 (Sharpe et al.).

9.2.3 Mitigation Measures

MM 1 Fixing a mandatory level of mitigation may cause further unintended issues.

The issues raised by stakeholders relating to mandatory mitigation were:

- Having a minimum mandatory mitigation requirement may not be an adequate solution and insufficiently precautionary at some sites
- By fixing a mandatory level of mitigation it may give the developers a perception that the risk is mitigated, and emphasis will be reduced for the risk assessment and also the verification of gas protection measures
- There is already regular conflict between developers and LAs about the choice of mitigation, this regularly occurs when developer and LA timelines become poorly aligned
- Prescriptive standards may restrict development and/or cause blight
- The use of mandatory measures would still need to be accompanied by use of appropriate site-specific investigation and risk assessment, with additional mitigation being implemented where the minimum mandatory requirement is deemed to be insufficient.

Solution Option - There is no single solution that addresses the issue of mandatory mitigation. Although the suggestion of having a mandatory gas membrane fitted to properties with a high risk of CO_2 ingress was supported by some LAs, the fact remains that this would create uncertainty over whether or not the risk has in fact been mitigated.

In the Gorebridge area there is a requirement from the Local Authority for mandatory mitigation via a membrane on new properties. Other LAs noted they were not aware of this requirement or the authority used to request such a measure.

The general feeling of stakeholders is that if there were to be mandatory measures these should be a minimum for a particular area or site and the mitigation should possibly be a ventilated void solum as opposed to a membrane.

MM 2 Gas membrane risk

There was a general consensus that gas membranes have numerous risks relating to improper use, incorrect installation, damage after installation, insufficient verification and no sensible record to prevent future damage.

In addition to the current gas membrane issue, there are also legacy issues where properties claim to have mitigation fitted but have no paperwork or log of it happening. Fitting a gas membrane should also not be a substitute for a gas risk assessment.

Solution Option - Training and qualifications for installers are reported to be improving for the verification of membrane installations and LAs are focusing on ensuring verification reports are provided for all properties fitted with membranes. However, the stakeholders generally had a negative view of the quality and verification of membrane installation on site.

MM 3 Ventilated sumps CO_2 parallel with radon mitigation.

It was raised during the workshop that sumps have been used to mitigate against radon ingress and (along with membranes) used heavily in high risk radon areas such as Aberdeenshire.

Sumps/ventilation systems have been fitted to uninhabited domestic properties in Gorebridge and they are currently under testing. However, there is limited practical experience and evaluation of efficacy for this technique in conjunction with coal mine gas. Sumps by themselves in passive form can simply collect CO_2 and unless actively ventilated (which is not approved for domestic premises) by a fan would provide ineffective mitigation. Radon is also radioactive and therefore decays over time reducing the potential levels collected. In addition to this a sump may not mitigate against a sudden drop in pressure.

Solution Option - There was no singular issue regarding sumps that shone through from stakeholder feedback. There was a general belief that sumps work to a degree. In addition, the issues were more generalised around their effectiveness, for example, air needs to be ventilated to prevent the sumps filling up, however, an electric fan cannot be used in case methane has ingressed due to the explosive risk. If sumps are to be suggested as solutions for CO_2 ingress, then further evaluation and research would be required.

MM 4 Gas ventilation subsequent blocking due to poor maintenance or lack of notification to owners

There are issues surrounding ventilation regarded the subsequent blocking or lack of owner awareness. Various vents or trenches can be a good mitigation method for CO_2, however, these get blocked with plant material, objects or debris rendering them ineffective.

Solution Option - The house deeds or tenancy agreement should highlight the importance of the gas vents requiring the owner to keep them clear and maintained.

The caveat to this solution is that highlighting a gas issue at a property may reduce its market value or deter people from living in the property. Developers, agents and landlords may be reluctant to advertise such issues within the documentation.

9.2.4 Considerations for existing developments

It is important to note that preventative mitigation installed at the time of construction is much more feasible than retrofitting. To quote from Sizer et al (1996): “it is generally recognized that effective gas precautionary measures for developments are achieved by attention to structural details, which cannot be readily addressed post-construction.”

Stakeholders present from The Coal Authority identified that the organisation infrequently adopts mitigation measures such as retro-fitting membranes. The standard protocol was to demolish the properties to eliminate the risk, and therefore the liability, to the properties in question. This is, however, costly and unsustainable and involves significant upheaval for the residents involved. The CA does passively and actively vent shafts and adits and is currently examining alternative methods to address the issue for residential properties.

9.2.5 Additional Issues Raised

There were several issues raised by stakeholders which were outwith the scope of the eight building standards related questions. The full list is documented in Annex 4(b). These key issues, in summary, include the following:

- In relation to ground gas risk and mitigation requirements within buildings, which department within the LAs takes overall responsibility of the issue is muddled between building standards, contaminated land, environmental health etc.

- Process timelines are not communicated well enough causing stages of development and mitigation decisions to overlap which brings unnecessary delays to developments because information around gas risk is picked up too late in the process. This includes planning permission being granted in unsuitable areas

- Gas issues are only likely to be picked up if they are on the scale of Gorebridge

- No ground gas monitoring occurs for smaller properties or extensions
- More research is required into the understanding of CO_2 pathways to improve risk assessments and to supplement standards/guidance on ground gas assessment and mitigation
- Local Authorities are under serious pressure with time and resources.

9.3 Analysis of Expert Consultation Findings

9.3.1 Risk Assessments

In relation to the risk assessment process, most expert consultees highlighted the importance of developing a robust conceptual site model and of applying the Source-Pathway-Receptor (SPR) approach to risk assessment. Most consultees felt that adequate guidance was provided in BS8485, CIRIA C665 and other documents about applying this approach, but several noted that it was not always done effectively and that sometimes those developing the conceptual model might not have appropriate skills and experience.

The consultees were asked the eight questions highlighted in **Table 7-2 IMT Questions to Building Standards Stakeholders**. These responses are recorded in **Table 9-2** to **9-8**, and the questions are repeated above each table. One additional question about retrofitting was also added.

1. ***Consultees were asked to consider if the current mine gas risk assessment process is adequate at correctly determining the level of risk, especially in relation to assessing mine gas levels at sub-surface depths likely to be representative of gas migration potential from underground mine sources?***

Table 9-2 Topics discussed with consultees (Question 1)

Topics discussed	Responses
Is the current mine gas risk assessment process adequate to correctly determine the level of risk, especially in relation to the requirements for assessing mine gas levels at sub-surface depths likely to be representative of gas migration potential from underground mine sources?	General consensus amongst the experts consulted was that the existing standards and guidance is robust for assessment of ground gas. However, those experts with greater experience of mining-related sites felt that the existing guidance should be supplemented with additional considerations relating to mine gas sources and pathways.
What are the perceived gaps in the current mine gas risk assessment process? Is there too much reliance placed on measurements of gas concentrations and flow over a short time period?	Often spot gas monitoring may be limited and can miss the worst-case falling pressure events. A multiple lines of evidence approach should be used to inform the CSM and gas RA.

Should there be differences in approach to CO_2 versus methane e.g. to consider chronic risks?	Most consultees responded that both chronic and acute risks should be considered in the risk assessment, with the focus of current standards and guidance being on assessment of acute risks. Chronic risks of CO_2 exposure need further consideration.
Should further guidance be provided specifically on how to assess mine gas sources and pathways?	Several consultees considered more specific guidance around mine gas risk assessment would be useful as mentioned above.
What about for existing properties e.g. under Part IIA?	It was noted that there was little guidance available for assessment of gas risks to existing properties, where the GSV approach is not suitable. Often gas monitoring is required in properties which is invasive/disruptive for residents.

2. ***Is the current risk assessment process fit for purpose particularly in terms of taking account of future potential changes in mine gas dynamics and migration risk factors (e.g. due to ground stabilisation measures, additional developments, etc.) that could lead to an increased risk of gas migration into properties over the long term?***

Table 9-3 Topics discussed with consultees (Question 2)

Topics discussed	Responses
Is the current risk assessment process fit for purpose particularly in terms of taking account of future potential changes in mine gas dynamics and migration risk factors (e.g. due to ground stabilisation measures, additional developments, etc.) that could lead to an increased risk of gas migration into properties over the long term?	General agreement amongst the experts consulted was that this is referred to in current standards and guidance, but mixed views as to whether or not it is adequately considered in gas risk assessments.
To what extent do current standards and guidance consider the effect of future potential changes in the ground and the implications for future ground gas risk assessments? E.g. climate change, rising groundwater levels, mine grouting?	Current guidance does consider future changes within the red line boundary. There was a diversity of opinion about taking into account developments outwith the red line. Some consultees stated it was impossible, others noted that the responsibility lay with future

	developers of adjacent sites to consider the cumulative impacts. Consultees also mentioned the need to be precautionary and account for uncertainties. Some discussion about whether the use of the Quality Mark Scheme (NQMS) could be beneficial for such sites since this specifically requires consideration of uncertainties in risk assessments and their implications.
What additional guidance could be provided on this?	Recent papers related to climate change and ground remediation were mentioned which could be extended to provide guidance on rising groundwater levels and climate change.
Is research needed in this area to better understand the effects?	Gaps in current knowledge could be filled by further research.
How should the cumulative risk from multiple developments in mining areas be assessed? E.g. what are the implications for existing properties surrounding a new-build development if gas membranes are deployed (e.g. is there a need for venting trenches surrounding the site or buildings to prevent gas migration)?	Consultees noted that a precautionary approach should be adopted, and the cumulative risk of all developments should be considered when creating a new development. This could be linked to the planning process. The need for a 'responsible person' oversight of a development over time was mentioned.

3. ***Is there sufficient emphasis in the current mine gas risk assessment process on the potential for other interventions affecting the soils or substructures underpinning any building development, to alter the risk of mine gas migration and consequently to render any pre-development assessment redundant and inadequately precautionary to protect public health?***

Table 9-4 Topics discussed with consultees (Question 3)

Topics discussed	Responses
Is there sufficient emphasis in the current mine gas risk assessment process on the potential for other interventions affecting the soils or substructures underpinning any building development, to alter the risk of mine gas migration and consequently to render any pre-development	General agreement amongst the experts consulted was that consideration of these issues is a requirement of current standards and guidance, but responses were mixed as to whether it is adequately considered in mine gas risk assessments. There can be a disconnect between ground gas

assessment redundant and inadequately precautionary to protect public health?	and geotechnical/ structural assessments for building design.
Site specific mine gas risk assessments are based upon the current condition of the site. To what extent do potential changes to the site, related to the development, need to be considered in the risk assessment process?	Potential changes to the site, e.g. use of foundation methods which might alter pathways should be considered. There was a recommendation for the LA's approval of a risk assessment to be conditional, approved unless the site conditions change, then the risk assessment must be redone.
How can activities associated with the development that can affect the gas CSM, e.g. ground improvement, stabilisation, ground source heat pumps, be incorporated better into risk assessments?	The foundation design should consider the mine gas risk assessment. Sometimes the foundation design will be carried out sometime after the risk assessment which increases the risk to that development, and the gas RA should be revisited where a foundation design has changed.
What additional guidance could be provided on this?	In mining areas additional guidance is useful such as LA supplementary planning guidance. A flow chart or checklist was suggested for mining areas.

9.3.2 Mitigation measures

In relation to mitigation measures, two broad questions were asked of consultees and the discussions focused around several topics including the effectiveness of the available guidance, implementation and verification of mitigation measures.

4a. Are the current criteria used for deciding what constitutes a sufficiently precautionary approach to mitigation appropriate; particularly where there is known to be a potential risk of mine gas migration?

4b. Does the process adequately emphasise the need to take account of construction methods that may add to that risk (e.g. the use of vibro stone underpinnings or solid slab floors that are not separately vented to the outside atmosphere)?

Table 9-5 Topics discussed with consultees (Question 4)

Topics discussed	Responses
Are the current criteria used for deciding what constitutes a sufficiently precautionary approach to mitigation appropriate; particularly where there is known to be a potential risk of mine gas migration?	There was consensus amongst all the experts consulted that the mitigation design process in BS8485:2015 is precautionary if used correctly, however, this is reliant on a robust CSM and gas RA.
Is the risk assessment process precautionary and proportional?	The risk assessments are adequate where consultants have the experience and understanding of coal mine gas risk to include appropriate monitoring and assess the risks appropriately within the conceptual model.
To what extent is the existing process precautionary? Does the precautionary approach extend to design of mitigation measures?	The process should be precautionary if the guidance is followed. There is sometimes a question mark over the experience of the designers in understanding mine gas issues.
Does the process adequately emphasise the need to take account construction methods that may add to that risk (e.g. the use of vibro-stone underpinnings or solid slab floors that are not separately vented to the outside atmosphere)? Is the gas Risk Assessment and need for mitigation revisited when a change is made to building construction or foundation design?	Consultees agreed that the source-pathway-receptor (SPR) model should be updated right through the design and construction of the development and any changes to the design and construction reviewed in the light of the SPR model. However, consultees noted that this does not always occur. Problems are encountered when maintaining documents where a site is sold on for development by a third party and particularly when this takes place some time after the design was first completed.

5. ***In determining the need for mitigation measures, is the current scope for interpretation of the guidance open to developers at present appropriate****?*

Table 9-6 Topics discussed with consultees (Question 5)

Topics discussed	Responses
In determining the need for mitigation measures, is the current scope for interpretation of the guidance open to developers at present appropriate?	BS 8485:2015+A1:2019 and other guidance is robust but also generic. The guidance generally does not address specifics and therefore is not sufficiently prescriptive and sometimes open to interpretation/manipulation. Also, the lack of recourse for those not following the guidance was mentioned.
Is the standards and guidance on mitigation measures prescriptive enough?	
Are consultants/ developers interpreting the standards appropriately?	There was a consensus that developers rely heavily on consultants and other professionals such as architects for interpreting guidance. Issues identified with respect to consultants included a lack of experience in building and structural design. It was recommended that there needs to be more awareness/training.
To what extent are limitations in knowledge e.g. of building design from land quality professionals a constraint?	Concerns were reported about the failure to appreciate the implications of design in relation to the risks related to ground gas generally and mine gas in particular. Consultees stressed the importance of understanding the building/foundation design as it is often the pathway in the source pathway receptor model.
To what extent are poor installation of membranes and inadequate verification factors?	A ventilated void is seen as a first line of protection for mitigating risks associated with mine gas. In Scotland, recent housing developments use a slab construction with granular fill and perforated pipes to provide sub-slab ventilation. NVQ training and qualifications for installers is reported to be improving verification of membrane installations. Sealing techniques and technology for membranes have improved in recent years.

9.3.3 Construction techniques

The question posed to consultees in relation to construction techniques was:

6. ***Are construction methods that do not involve creating a ventilated solum beneath the ground floor of a property, inherently more liable to permit the transmission of mine gases to the inside of these properties compared to a traditional ventilated solum construction type?***

Table 9-7 Topics discussed with consultees (Question 6)

Topics discussed	Responses
Are construction methods that do not involve creating a ventilated solum beneath the ground floor of a property, inherently more liable to permit the transmission of mine gases to the inside of these properties compared to a traditional ventilated solum construction type?	Most consultees agreed that a ventilated layer is the first line of defence. Several remarked on the contrasts between construction practice in England and Wales, where a ventilated void solum is often utilised, and in Scotland where slabs underlain by granular fill and a perforated pipe are used. It was noted that where ventilated void solums were in place that it was rare for mine gas to gain access to a building.
What factors are driving the reduced use of a ventilated solum beneath domestic properties?	In Scotland since 2000 accessibility requirements have resulted in dwellings being designed with external ground levels at a similar level to the internal floor level. This lends itself to slab construction with granular fill and perforated pipes to provide sub-slab ventilation. The change also appears to be related to 'Modern Methods of Construction', which have been adopted more widely in Scotland than England.
To what extent is the issue addressed in existing standards and guidance e.g. BS8485?	The revision of BS 8485 in 2015 provided more detail about foundation design and particularly slab constructions and provision of ventilation.

9.3.4 Energy Efficiency

The question posed to consultees in relation to energy efficiency in modern buildings was:

7. ***Is the drive to improve the energy efficiency of modern properties by increasing the levels of insulation and ensuring they are less prone to uncontrolled air movement (draughts) and are consequently more air tight, a potential factor contributing to the retention of mine gas emissions that manage to penetrate a property?***

Three topics were covered in relation to this issue as shown in **Table 9.8 Topics discussed with consultees**.

Table 9-8 Topics discussed with consultees (Question 7)

Topics discussed	Summary of Responses
To what extent is the assumption correct that the drive towards air tightness and improved insulation contributing to the retention of mine gases within a property?	There was general consensus amongst the experts that this is correct although the best-informed opinions in this area indicated that there was a general problem with indoor air quality in Scotland and the UK as a result of insufficient ventilation. This problem would be exacerbated by entry of mine gas into a dwelling. However, it was noted by some that where there was less suction e.g. in an airtight house, there would be less gas drawn into the building through the slab and service entries. Several consultees mentioned that further research was required and that lessons could be drawn from Scandinavia.
To what extent is this considered in the standards and guidance e.g. BS8485?	BS8485:2015 doesn't cover this issue specifically; however, if gas protection measures have been designed, installed and verified correctly in accordance with the standard, then gas shouldn't be able to get into the building and the problem is avoided.
Are ambient levels of CO_2 from household sources understood as a 'baseline' to which mine gas emissions may increase?	Consultees indicated that ambient levels of CO_2 as a baseline appear to be poorly understood and that further research is required.

9.3.5 Mandatory Mitigation Measures

8. ***Would the simplest and most appropriately precautionary solution to the problems highlighted by the Gorebridge incident be to require mandatory gas risk mitigation measures in all new residential and similar developments in areas of Scotland defined by the Coal Authority as former coalfields?***

There were a variety of views expressed by consultees ranging from those supportive of mandatory measures to those who considered that such a step would be counterproductive as it could lead to complacency amongst developers and their consultants. There was some discussion as to how 'mandatory gas risk mitigation measures' should be defined in the context of BS8485:2015 e.g. CS2 or CS3. However, most consultees agreed that regardless of whether there was mandatory gas mitigation or not, a robust risk assessment and appropriate design, construction and verification of gas protection measures must still be carried out.

A view held by several consultees was that if the risk assessment process was followed correctly, then mandatory mitigation would not be necessary. There was also concern about mandatory mitigation being overly precautionary and overly expensive in some sites but not robust enough for other sites.

Other concerns related to how mandatory measures would be specified and implemented and whether or not mandatory measures could lead to inconsistencies in the implementation of mitigation measures.

There was also some contradictory feedback around the cost impact of mandatory measures. A housing developer consulted on this issue remarked that the key aspect was the establishment of a consistent 'level playing' field so that the cost of development was essentially the same for all potential developers of a site. As noted earlier, one local authority in Scotland has trialed mandatory gas protection measures (CS2) in a former mining area, and Northumbrian County Council have adopted this measure as part of their planning conditions.

A decision as to whether or not compulsory mitigation measures may be required could be linked to environmental risk assessment as part of the development of Local Development Plans.

9.3.6 Retrofitting

Views on the effectiveness of retrofitting of mitigation measures were sought from Consultees and particularly as to whether or not this can be carried out effectively as an alternative to demolition where existing properties have been found to adversely affected by ingress of mine gas.

Most responses provided on this issue indicated that retrofitting is technically feasible and dependent on building construction details and the level of gas risk, i.e. more suitable for low-moderate rather than high risk gassing sites. There is wide experience of undertaking this.

It was commented that retrofitting can be expensive, although this may still be cheaper relative to the costs of demolition and rebuilding. It also entails substantial disruption to residents if a property is occupied, for example temporary relocation. The same levels of workmanship and verification should be applied as for new build properties, i.e. adherence to BS8485:2015 and CIRIA C735 requirements. Neither document covers retrofitting specifically and as mentioned in section 6.4, CIRIA are due to commence a research project imminently to prepare good practice guidance on retrofitting.

A concern expressed by some consultees about retrofitting was the on-going duty of care it can place on the developer.

10 Assessment

The key findings and issues raised in the Stakeholder Engagement and Expert Consultation processes were reviewed in Section 9. Within this section they are integrated to provide a summary of all the issues raised with a potential solution for each, together with a comment on the impact, feasibility and timescale for ease of implementation of the solution.

These factors were assessed to provide an overall ranking regarding the potential solutions that were identified in the stakeholder engagement and expert consultation processes.

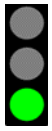
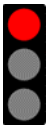
Our grading system for the assessment of the impact, feasibility and timescale for implementation of the solution is detailed within **Table 10-1**.

The full assessment of potential output summary showing all the graded solutions put forward is shown in **Table 10-2**.

This assessment and ranking are intended to be a simple measure of the effectiveness of a solution. We have highlighted several issues where there is no obvious immediate solution and further research is required to define a solution.

Within the research we also noted there were a small number of stakeholder derived risks/solutions which we scored as having no impact or change. This was due to them already being covered by the existing guidance and standards requirements. The identified solutions covering adherence to and further awareness of the existing guidance were noted as methods to mitigate these risks.

Table 10-1 Assessment Grading

Issue	Potential Solution	Impact	Feasibility	Timescale	Score
Description of the issue identified	Description of the potential solution identified	Comment on potential impact and score: **0** = limited change **1** = driver for change	Comment on feasibility and score: **0** = complex to implement or requiring additional budgets **1** = Easy to implement, no major budgetary implications	Traffic Light Symbol **Green** underway or effective in 2 years  **Amber** effective in 2 to 5 years  **Red** Possibly 5 years or greater to develop 	**0 to 2** **(Low to High)**

'Impact' was scored in terms of how effective the solution would be as an agent for change. If a solution would provide limited change, it would score a '0'. If it would provide major change, for example by promoting best practice or reducing risk, then it would score a '1'.

'Feasibility' was scored by the complexity of implementation. For example, a complex solution might involve interaction with many organisations, a lack of obvious ownership, or a requirement for legislative changes and would score '0'. A solution that might involve one or two organisations, has obvious ownership and/or changes to business or regulatory practice would score a '1'.

'Timescale' is not scored within the overall ranking. We have used a traffic light system to indicate a timescale to implement the solutions. Items were flagged as red (long term, greater than five years), amber (two to five years) and green (on-going or less than two years).

The issues are matched to specific solutions including consideration of impact, feasibility and timescales in **Table 10-2** below.

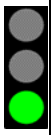
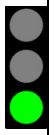
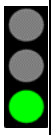
Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
Risk Assessment					
1/ Lack of experience and expertise in some Local Authorities (LAs) was indicated in both stakeholder engagement and expert consultation, limiting their ability to effectively peer review assessments against standards and guidance.	1A/ Support LAs with additional training and/or access to peer review support from external specialists.	1: This would help ensure that reports being submitted under planning and Building Standards are compliant with existing standards and guidance.	1: Feasible and is already being applied by some LAs. Funding constraints within local and central government departments may be a limiting factor.	Already underway for some LAs and could be rapidly procured by others through existing frameworks e.g. Scotland Excel. 	2
	1B/ Greater assistance/ engagement with other agencies e.g. CA, BGS, industry experts.	0: This could provide useful additional data for LAs in some areas but would not address the underlying issues.	1: Feasible. Low cost for LAs although funding and the availability of personnel in CA or BGS may be a limiting factor.	On-going process already initiated with LAs collaborating on this project and the Gorebridge IMT investigation. 	1
2/ Lack of consideration of the cumulative effects of multiple developments on	Departmental liaison within and between LAs at LDP stage. Stakeholders flagged up planning requires GIS risk mapping of former coal field areas into areas of high, medium and low risk based	1: Liaison and GIS identification would help identify areas of potential cumulative impact by stakeholders as	1: Feasible (subject to political will). Costs associated with internal LA GIS resource or procuring external support.	Can be implemented as part of LDP development. 	2

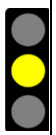
Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
former mining areas.	on parameters such as depth, age and type of mining or degree of groundwater rebound. Especially relevant with regard to large-scale developments and consideration of cumulative effects. Further consideration is required to assess where responsibilities should be assigned for cumulative impacts outwith a redline development boundary.	these are not being addressed currently.	Clarity required on responsibilities for cumulative impacts outwith a redline development boundary. The guidance does not clearly assign this responsibility to the developer of an existing site as opposed to the developer of a future adjacent site. Also, adjacent developments can occur concurrently.		
3/ There is no guidance on values for unsafe levels of CO_2 in domestic properties to initiate mitigation measures.	Establish a Scotland and or nationwide threshold for CO_2 /O_2 deficiency.	0: Although impactful, it would not on its own eliminate chronic events.	1: Feasible, low-moderate cost. A value of 1000 ppm or 1830 mg/m^3. has already been indicated based upon workplace exposure limits.	Medium term due to time to procure and undertake research. 	1

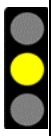
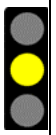
Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
			This may require additional research to verify.		
4/ For new developments the guidance around risk assessment is generally adequate but there is scope for more specific detailed guidance around mine gas issues.	Guidance specifically covering relevant sources and pathways for mine gas and uncertainties/ potential for future changes. This would need to be informed by further research to consider available case studies and data held by CA, stakeholders and experts. Similar Special Purpose Guidance has been provided to LAs in the past e.g. for Contaminated Land.	1: Would help address uncertainties and limitations in mine gas risk assessment process. Note linkage to solution 1 above.	1: Feasible, low-moderate cost, particularly if led by a single LA with expertise.	Medium term due to time to procure and undertake research. 	2
5/ Monitoring of sites to assess gas risk can be insufficient or poorly targeted.	Ensure adherence to guidance is enforced particularly with regard to worst-case scenarios (CL:AIRE 2018) which would capture potential Gorebridge-style events. Consideration of pre-commencement planning	1: Ensuring sufficient data collected in line with TB12 guidance would help address uncertainties and limitations in mine gas risk assessment results.	1: Feasible, at moderate cost. Practicality - the requirements to monitor through periods of low meteorological pressure drops will bring uncertainty into	Implementation could be low to medium term.  Impacted LAs may need to identify high risk areas and include the data requirement for monitoring in pre-	2

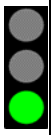
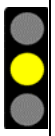
Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
	conditions to ensure that data collection for mine gas risk assessment commences early to maximize the ability to include the worst-case falling pressure events.	Note linkage to solution 1 above.	the data collection schedule.	commencement planning conditions.	
6/ There is limited specific guidance around the risk assessment of existing properties.	Detailed specific guidance for the risk assessment of existing properties (under Part IIA) is required. The planned CIRIA project on retro-fitting may cover this to some extent.	1: High impact as it would reduce uncertainty and may improve outcomes for properties in proximity to CO_2 events.	1: Low cost (assuming CIRIA guidance is published).	Short term. CIRIA is currently looking to appoint a research contractor for this project. 	2
7/ Future potential changes to sites need to be considered in the risk assessment process.	Adopt a precautionary approach as required by the standards and guidance. This should be linked to the planning process including improved information and enforcement by planning/ Building Standards/EHO staff.	1: Following best practice guidance would help address uncertainties and limitations in currently submitted mine gas risk assessment.	0: Guidance is in place, but supplementary guidance on considerations for sites affected by mine gas would be beneficial.	Medium to long term. Requires revision to guidance documents/ preparation of 	1

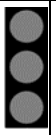
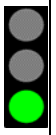
Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
	Issue of reports under the NQMS, which specifically requires consideration of uncertainties in the risk assessment process, would assist with improving the quality of reports, if this was requested by LAs.	Note linkage to solutions 1 and 4 above.		supplementary guidance.	
8/ What are the implications for existing properties surrounding a new-build development if gas membranes are deployed (e.g. is there a need for venting trenches surrounding the new development to prevent gas migration)?	Ventilation beneath the membrane should negate the potential for build-up of ground gas beneath a property. Venting should be to air. The guidance is clear that any risks associated with that venting should be considered in the risk assessment and mitigation design for a new development and LAs should require this to be done.	0: Ventilation measures designed in accordance with BS8485: 2015 should negate the potential for build-up beneath a property. Refer to item 2 re: cumulative development impact.	0: In general, additional venting should not be required.	Not applicable 	0
9/ Training and experience of those designing or installing mine gas mitigation measures can be inadequate.	Validation of the experience and qualifications of those designing mine gas mitigations measures is required by developers during	1: Improved compliance with design standards and effectiveness of gas protection measures.	1: Additional awareness/ rigour within the procurement process for specialist consultants.	A short to medium term solution requiring additional guidance to be provided to 	2

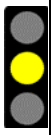
Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
Examples are cited by consultees of non-experts being appointed to carry out specialist work for which they were inexperienced.	the procurement process to appoint consultants. Note linkage to solution 4 above.		Design details would require sign off by a validated/qualified engineer confirming the details comply with current guidance.	developers by local authorities.	
10/ Revisions made in the overall design of a foundation or structure subsequent to the original design do not always consider the impact on mine gas mitigation measures e.g. the creation of preferential pathways during construction. This may be particularly the case where changes are made sometime after the original design due to a delay in the	The CSM developed in the risk assessment process needs to be reviewed when there is a change to the design. This is already covered by existing ground gas standards and guidance but needs better enforcement by planning/ Building Standards/EHO staff. A 'hold point' is needed to ensure that the gas risk assessment is reviewed and updated whenever design changes are made that could affect the assessment. This could be done through introduction and enforcement of model planning conditions for areas affected by mine gas (see e.g. example of	1: Enforcement of relevant planning conditions would be an effective way of mitigating this risk.	1: This is an extension to the existing planning and Building Standards system.	Short to medium term to develop. Consult and publish model planning conditions. 	2

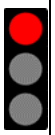
Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
development or a change of ownership.	NCC conditions). Planning guidance and Building Standards should also be amended to reference this issue.				
11/ Guidance related to the application of mitigation measures for ground gas is not specific to mine gas.	Specific guidance related to the design of mine gas mitigation measures should be considered e.g. in the form of a further Supplementary Planning guidance document and/or changes to Scottish Building Regulations and standards.	1: High - Revised technical guidance explicitly stating relevant standards and guidance documents will improve compliance by increasing visibility.	1: Feasible, low cost. Entails updates to already existing documentation within Building Standards and LAs.	Revision cycle for guidance documents vary from annual updates. LA document revision cycles will vary. 	2
12/ The verification system for gas membranes is not sufficient.	Independent verification on installation with supporting documentation. This should already be taking place and if not, there is a failure in the construction and possibly regulatory processes. A new NVQ for verifiers is currently being developed by the industry.	0: Should already take place if guidance is followed.	0: Numbers of qualified independent verifiers are low. Would require industry investment to improve the quality and capacity.	Long lead in time to roll out verification qualification to significant enough numbers to improve the situation. 	0
13/ Homeowners are unaware of gas ventilation mitigation	Details of installed gas protection systems should be provided when the property is	1: Public awareness and protection of existing mitigation	0: Existing systems and processes used. However, it may be	Medium –– there are existing 	1

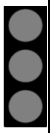
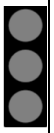
Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
on their property. Any future maintenance works, extensions etc. could damage the integrity of installed gas protection systems.	let or sold. Conveyancers should include such information in standard searches.	will reduce long term risks.	seen as a potential blight issue affecting property sale values.	processes amongst some developers.	
14/ The ventilation below a foundation is the 'first line of defence' in mine gas mitigation measures.	Application of a ventilated solum or granular fill with perforated pipe should be mandatory for future developments in areas of high risk of ingress of mine gas into a property.	N/A: This should already take place in modern developments if standards and guidance are followed (e.g. BS 8485).	N/A: This should already take place.	N/A: This should already take place. 	0
Construction Techniques					
15/ Developers will always build to the minimum required standards.	Independent verification of membranes required through planning and building regulation. See Issue 12.	0: Should already take place if guidance is followed and regulations through planning are robust.	0: Should already take place if guidance is followed and regulations through planning are robust.	N/A: Should already take place if guidance is followed and regulations through planning are robust. 	0

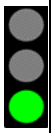
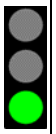
Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
16/ The use of granular fill with a perforated pipe below a foundation slab to provide ventilation has been used commonly in Scotland for over 20 years and consideration is required as to its effectiveness.	Further research is required to assess the long-term effectiveness of granular fill and perforated pipe ventilation systems in areas at high risk of mine gas emissions.	1: The perforated pipe ventilation system is extensively used in Scotland since 2000. It was primarily driven by mobility access regulations and without specific consideration of the long-term effectiveness in areas of high risk of ingress of mine gas into a property.	1: A research programme including long term monitoring is feasible albeit it would require budget and ownership to take forward.	Could be completed within a 12-month programme. 	2
17/ Site investigation boreholes are at risk of creating preferential pathways for mine gas migration to the surface.	Appropriate decommissioning and accurate log of borehole locations. This could be enforced by Planning/Building Standards/EHO staff through application of a standard supplementary planning condition. See link to item 10 above.	1: Enforcement of relevant planning conditions would be an effective way of mitigating this risk.	1: This is an extension to the existing planning and Building Standards system.	Short to medium term to develop. Consult and publish model planning conditions. 	2

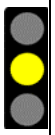
Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
18/ It is assumed that CO_2 would take the path of least resistance. Is it possible to create paths outwith affected buildings that would result in escape routes for the gas?	Current standards and guidance focus on ventilation and dilution of ground gas ingress into properties to acceptable levels. Venting systems external to buildings are routinely used for management of landfill gas emissions and in some cases for redevelopment of such sites. We are not aware of its uses for managing mine gas emissions and a key issue would be appropriate design of vents to reduce CO_2 concentrations to acceptable limits at ground level. It may be an approach to consider for multiple developments in former mining areas, but further research would be needed to consider the viability of such an approach.	1: A venting system may be an effective risk reduction mechanism in existing properties.	0: This may be an approach to consider for multiple developments in former mining areas, but further research would be needed to consider the viability of such an approach.	Would require significant time to carry out a trial and assess results. 	1
Energy efficiency and the air tightness of modern dwellings					
19/ Two lines of thought have emerged in relation	A long-term baseline study of CO_2 levels in modern properties may address this issue. A first step is a	0: Could eventually provide some	0: The major requirement for such a project would be either a property impacted by	A 12-month programme would enable long term 	0

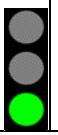
Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
to the impact of air tightness: 1. A general concern was expressed about air quality in modern housing generally and from CO_2 levels specifically. 2. The ingress of mine gas may be decreased in an air tight property because there is less suction.	specialist literature review to map current research in this area which would then indicate what further research may be required.	evidence on chronic assessment of CO_2. A research programme could be implemented within a 12-month programme to assess and report on the impact of air-tightness of a property.	mine gas or a simulation of this.	monitoring to be carried out.	
Mandatory Mitigation					
20/ Mandatory gas mitigation measures including ventilation	Mandatory gas mitigation measures. This is being successfully applied by one	1: If such an approach was to be adopted more widely across	1: This is being successfully applied by one LA in Scotland and	This could be implemented in 	2

Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
and membranes in areas at 'high risk'. Two lines of thought have emerged in relation to this: 1. This approach will be overly precautionary for some sites but unlikely to be precautionary enough for the higher risk sites, and there are potential risks of undermining the quality of gas risk assessments and design/ construction/ verification of gas protection measures. 2. There are inherent uncertainties in	local authority in Scotland via Building Standards for 'low risk' (CS2) sites, albeit on a small scale, without challenge by developers. NCC in England also have a process in place to require conditions in certain developments. Appropriate risk assessment and design/construction/ verification of gas protection measures in accordance with current standards would still be required and would need to be rigorously enforced. Arguably if this is being done effectively, the use of mandatory conditions should not be required. It is unlikely that such an approach could be practically adopted for 'high risk' sites since these require more detailed evaluation, risk assessment and mitigation design.	relevant areas of Scotland, more extensive consultation with stakeholders, particularly developers, would be required as well as more detailed consideration of how to apply this.	by NCC in England. It would require clear definition as to how areas would be identified and liaison with industry and developers.	a fairly short timescale.	

Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
gas risk assessment for mine gas sites, therefore a minimum level of protection (e.g. CS2) should be required to be precautionary.	It could potentially be applied to low-moderate risk sites in former mining areas. Further work would be needed in collaboration with the CA and LAs to identify and define areas where the mandatory approach could be applied. It is possible that these areas could be further differentiated, e.g. by geospatial studies of environmental risk, within Local Development Plans as will be required in the forthcoming Planning Act. This might be a way of reducing the scale of solution to areas where it is clearly necessary and make the solution more manageable to implement.				

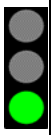
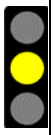
Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
Retrofitting of existing properties					
21/ What retrofitting works (e.g. gas membranes and/or ventilation/ pressurisation) can be carried out to existing properties that would give certainty to successfully 'managing' the presence of CO_2?	Several case studies have come to light where retrofitting of gas membranes have been successful. Therefore, it may be a viable alternative to demolition in some circumstances. Supplementary technical guidance is needed in this area, which is already being led by CIRIA.	0: Limited case history to estimate how viable this may be as a mitigation measure. Previously recorded CO_2 mine gas events generally relate to proximity of mine shafts with works carried out by the Coal Authority on venting the shaft were found to be effective.	1: Feasible (assuming CIRIA guidance is published).	Low (assuming CIRIA guidance is published). 	1
Regulatory Issues					
22/ Lack of communication between LA departments– planning, building standards,	Early departmental liaison and geospatial risk mapping linked to Local Development Plans so that information is readily available for analysis. Improved co-ordination and communication is needed	1: High in selected LAs where coordination on mine/ ground gas issues are required and coordination	0: Good practice processes already exist and could be shared between authorities; however, this would require additional resources to	Low to medium  Requires coordination and time for new processes/systems	1

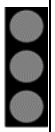
Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
environmental health.	between planning, Building Standards and EHO/CLO teams in some local authorities. The City of Edinburgh Council's Planning and Environmental Health protocol provides an example of this. Planning conditions recommended by EHO/CLO consultees should be acted on by planning officers.	issues have been noted.	develop which may not be practical for every local authority.	to become embedded.	
Other Issues					
23/ High levels of CO_2 may eventually become exhausted, are there any ways of determining how and when that might happen? Would there be any way of accelerating such a process?	In the context of the SPR approach, mine gas CO_2 should be considered as a ubiquitous source because it is created by the interaction of coal (C) and oxygen (O) in air. Complete submergence or infilling of old mine workings is not a viable option. Accelerating the process by	Not an applicable solution.	Not an applicable solution.	Not an applicable solution. 	N/A

Table 10-2 Assessment of Potential Outputs					
Issue	**Potential Solution**	**Impact**	**Feasibility**	**Timescale**	**Score**
	greater ventilation may risk spontaneous combustion.				

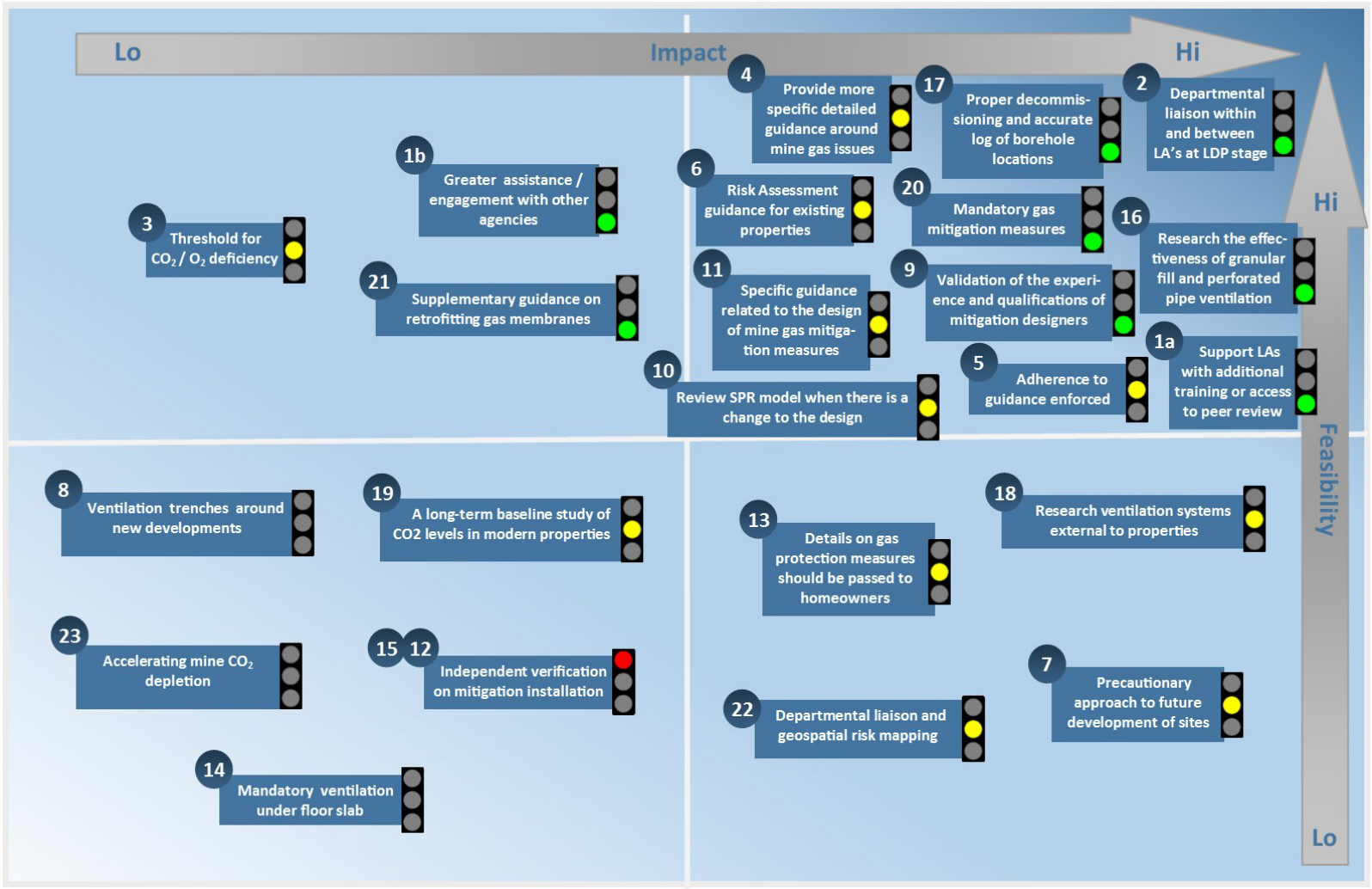


Figure 10-1 Potential Solutions Analysis

Figure **10-1 Potential Solutions Analysis** above summarises 'potential solutions' from **Table 10-2** in addition to scores for impact and feasibility as referenced in **Table 10-1 Assessment Grading**.

In **Figure 10-1**, those solutions with a positive combination of high feasibility and high impact are grouped within the top right quadrant. In addition, they are colour coded in the traffic light system to show the estimated timescale of each potential solution.

Those eleven solutions with the highest scores in impact and feasibility are included within the 'Options to Consider' in Section 11.2.

11 Conclusions & Options for Consideration

The general aims of this research project were to consider a range of issues relating to the assessment and mitigation of mine gas issues for new and existing developments in Scotland. The project has comprised a fact-finding exercise involving background research on previous incidents involving mine gas and CO_2, consultation with relevant stakeholders and industry experts, and detailed analysis of the findings.

11.1 Summary of Building Standards related questions

A specific objective of this project was also to explore the eight recommendations in the Gorebridge IMT report which related to Building Standards. Responses to these questions were tabled in Annex 3b Stakeholders and Annex 4 Expert Consultees.

In **Table 11-1** we set out the summary findings from the responses to these eight Building Standards related issues.

Table 11-1 Gorebridge IMT report questions which relate to Building Standards

IMT Building Standards Questions	Response Area
1/ Is the current mine gas risk assessment process adequate to correctly determine the level of risk, especially in relation to the requirements for assessing mine gas levels at sub-surface depths likely to be representative of gas migration potential from underground mine sources?	**Stakeholder Engagement –** Indicated that the risk assessment process should be adequate, however, it can be poorly implemented. **Expert Consultation –** Agreement with stakeholders that guidance is adequate if followed but is not always complied with or enforced. Recommended additional guidance and clarification specific to mine gas risk would improve the situation. **Analysis –** Better enforcement of current standards, development of supplementary guidance to enforce risk assessment requirements and further research is required in key areas. **Options –** For suggestions for improvement refer to Option 1 in Section 11.2.

Table 11-1 Gorebridge IMT report questions which relate to Building Standards	
IMT Building Standards Questions	**Response Area**
2/ Is the current risk assessment process fit for purpose particularly in terms of taking account for future potential changes in mine gas dynamics and migration risk factors (e.g. due to ground stabilisation measures, additional developments, etc.) that could lead to an increased risk of gas migration into properties over the long term?	**Stakeholder Engagement –** Indicated that the risk assessment process should take account for these issues, however, it can be poorly implemented. Assessment of the impact of adjacent future developments is difficult to include in conceptual models. **Expert Consultation –** Risk assessments should make an allowance for future change in the design life of the property but note that changes in groundwater levels due to climate change or cumulative development are uncertain and may be speculative. **Analysis –** Better enforcement of current standards, development of supplementary guidance to enforce risk assessment requirements and further research is required in key areas. **Options –** For suggestions for improvement refer to Option 1 and 3 in Section 11.2.
3/ Is there sufficient emphasis in the current mine gas risk assessment process on the potential for other interventions affecting the soils or sub structure underpinning any building development, to alter the risk of mine gas migration and consequently to render any pre-development assessment redundant and inadequately precautionary to protect public health?	**Stakeholder Engagement -** Indicated that the risk assessment process should take account of these issues, however it can be poorly implemented. **Expert Consultation –** The standards and guidance are clear on the need to consider interventions that could affect the CSM. Activities such as mine grouting are regulated by the Coal Authority and should consider risks of impact to existing development. **Analysis –** Better enforcement of current standards and development of supplementary guidance to enforce risk assessment requirements **Options –** For suggestions for improvement refer to Option 1 and 2 in Section 11.2.

Table 11-1 Gorebridge IMT report questions which relate to Building Standards	
IMT Building Standards Questions	**Response Area**
4/ Are the current criteria used for deciding what constitutes a sufficiently precautionary approach to mitigation appropriate; particularly where there is known to be a potential risk of mine gas migration? Does the process adequately emphasise the need to take account of construction methods that may add to that risk (e.g. the use of vibro-stone underpinnings or solid slab floors that are not separately vented to the outside atmosphere)?	**Stakeholder Engagement –** Indicated that the mitigation design is sufficiently precautionary, however it can be poorly implemented. A precautionary approach with conservative metrics is included in BS 8485:2015. It was noted that the gas risk assessment is usually carried out well ahead of final foundation design, so risk assessments should be revised any time there is a change. **Expert Consultation** - Interpretation of the guidance is to some extent open to developers. If guidance applied fully and appropriately by experienced individuals, and suitably enforced there would not be problems. **Analysis –** Better enforcement of current standards and development of supplementary guidance to enforce risk assessment and mitigation design requirements. **Options –** For suggestions for improvement refer to Option 1 and 2 in Section 11.2.
5/ In determining the need for mitigation measures, is the current scope for interpretation of the guidance open to developers at present appropriate?	**Stakeholder Engagement –** Views differed over the points-based system within the BS 8485:2015. Noted it is intended to be precautionary but is not designed to be prescriptive. Feedback was that some developers look for loopholes in the guidance rather than use them to assist in the risk mitigation process **Expert Consultation** – The points based system in BS8485:2015 seen as a generic solution. Developers tend to look a reducing cost via interpretation of the guidance on a site-specific basis. **Analysis –** Better enforcement of current standards and development of supplementary guidance to enforce risk assessment and mitigation design requirements. **Options –** For suggestions for improvement refer to O Option 1 and 2 in Section 11.2.

Table 11-1 Gorebridge IMT report questions which relate to Building Standards	
IMT Building Standards Questions	**Response Area**
6/ Are construction methods that do not involve creating a ventilated solum beneath the ground floor of a property, inherently more liable to permit the transmission of mine gases to the inside of these properties compared to a traditional ventilated solum construction type?	**Stakeholder Engagement –** General response was that a ventilated void under the floor was a very good defence against gas migration. However, there was debate over the long-term performance over the perforated pipe and granular fill solum used in Scotland over vented open voids. **Expert Consultation -** a ventilated solum is seen as the 1st line of protection in reducing the risk of gas ingress. **Analysis –** Indicated that further research was required to provide an evidence base for this view. **Options –** For suggestions for improvement refer to Option 5 in Section 11.2.
7/ Is the drive to improve the energy efficiency of modern properties by increasing the levels of insulation and ensuring they are less prone to uncontrolled air movement (draughts) and are consequently more air tight, a potential factor contributing to the retention of mine gas emissions that manage to penetrate a property?	**Stakeholder Engagement –** Response was mixed - airtightness will impact the retention of any gases able to enter a property but should also reduce gas ingress**.** Stakeholders suggested that air tightness should not be reduced because this is counter-productive in trying to improve energy efficiency. **Expert Consultation -** Agree that a draughty building will allow gas to escape out the building. Experts gave varied views on whether airtight buildings were riskier than older buildings. Agreement that best option is not to allow the gasses into the building. **Analysis –** Noted that mitigation measures or ventilation under the property were the best defence. **Options –** For suggestions for improvement refer to Option 5 and 6 in Section 11.2.
8/ Would the simplest and most appropriately precautionary solution to the problems highlighted by the Gorebridge incident be to require mandatory gas risk mitigation measures in all new residential and similar developments in areas of Scotland defined by the Coal Authority as former coalfields?	**Stakeholder Engagement –** This would be overly precautionary for some sites, and insufficiently precautionary for the high risk sites. Much debate over what mitigation would be mandatory. **Expert Consultation –** Views varied with most disagreeing but some agreeing with the statement. Many noted that generic mandatory measures would not necessarily resolve the issue and risk assessment and mitigation should be site specific. **Analysis –** Requires clear definitions and consultation on impact. **Options –** For suggestions for improvement refer to Option 6 in Section 11.2.

The consultees responses summarized in **Table 11-1** above were reviewed in full within Section 9 of this report. This ensured the related issues and the potential improvements highlighted were fed into our options assessment, the output of which is contained in Section 11.2.

From our review of the eight IMT Gorebridge Building Standards related questions, options to consider for improvement are addressed in Section 11.2 under options 1,3,5 and 6. Options 2, 4, 7 and 8 did not come directly from the eight IMT building standards related questions, but came out of stakeholder engagement and expert consultation, of which recommendations were made beyond the scope of the eight IMT questions.

11.2 Options to Consider

The options to consider in addressing mine gas issues identified in the Gorebridge IMT Report have been identified through the assessment conducted in Section 10. The data from the Stakeholder Engagement and Expert Consultation were analyzed and integrated to provide a summary of the issues in **Table 10-2** along with a potential solution for each. Potential solutions were assessed and scored based on their feasibility, impact and timescale of implementation which are ranked in **Table 10-2**.

The 23 potential solutions were assessed in Section 10 as having either

- high impact and high feasibility (upper right quadrant of **Figure 10-1**),
- high impact and low feasibility (lower right quadrant of **Figure 10-1**),
- low impact and high feasibility (upper left quadrant of **Figure 10-1**), or
- low impact and low feasibility (lower left quadrant of **Figure 10-1**).

Potential solutions are also colour coded in the traffic light system to show the timescale of implementation.

The eleven potential solutions within the upper right quadrant of **Figure 10-1** should be taken to action first which is why they are included as 'options to consider' below, see **Table 11-2 Options to consider with corresponding potential solutions from which they were derived**. These potential solutions taken forward were identified as having a high impact and high feasibility. Where there are similarities in terms of improvement actions, we have grouped solutions together to create the numbered options to consider below**.** Of note, potential solutions coded with a green traffic light will be the quickest to implement and may be chosen for prioritisation.

Table 11-2 Options to consider with corresponding potential solutions from which they were derived.

Option to Consider	Outcomes from Section 10 Analysis Fig 10.1
Option 1	5, 11, 17
Option 2	4, 6,11, 10
Option 3	2
Option 4	1A, 2

Option 5	16
Option 6	20
Option 7	2
Option 8	9

Solutions in the upper left, bottom left, and bottom right quadrants of **Figure 10-1** were not put forth as 'options to consider'. These potential solutions are significant recommendations for improvement, but they may not reduce the occurrence of acute events. We recommend the potential solutions in the upper left and lower right quadrants be reviewed and taken to action after all of the 'options to consider' have been addressed. We recommend that the potential solutions with low impact and low feasibility not be taken forward.

The eight final options to consider are set out below:

Option 1: The use and enforcement of model planning conditions as well as changes to Scottish Planning and Building Standards and guidance to cover adequate assessment of mine gas (including worst-case conditions) should be considered.

In accordance with standards, guidance and the NQMS, to remove uncertainties and provide future-proofing, the decommissioning of boreholes and other preferential pathways should be considered in the gas risk assessment, mitigation design and integrated within foundation and building design.

Risks and uncertainties created by additional pathways should be reassessed when there are significant changes to the foundation or building design.

What occurs at present:

Scottish Building Standards and guidance, e.g. 'Technical Handbook – Domestic', do not explicitly cover the assessment and mitigation of ground gas issues. Planning guidance, i.e. PAN33 and local authority supplementary planning guidance, contains reference to ground gas but not specifically to issues relating to mine gas. Planning conditions are imposed on a case by case basis with variations in approaches within and between different local authorities leading to a lack of consistency and potential for insufficient mitigation of mine gas related risks, as happened at Gorebridge.

Evidence of need for change:

Consultations with stakeholders and particularly experts (see section 9.3) have identified that many of the shortcomings in mine gas risk assessments, mitigation design and verification relate to a lack of compliance with existing standards and guidance relating to ground gas. In addition, the requirements of these documents have not been incorporated into relevant Scottish planning and building standards guidance. Model planning conditions recommended by the Scottish Government for developments in areas of former mine workings would be valuable in ensuring all relevant issues have

been addressed and achieving a more consistent approach across all relevant local authorities.

Next steps or where good practice can be found:

- Update PAN 33 and/or local authority supplementary planning guidance to make reference to key issues relating to mine gas and relevant standards and guidance to be followed. This could also refer to the role of the NQMS in such assessments to make sure all legislative requirements and necessary standards connected to the management of land contamination are met and uncertainties are adequately considered.
- Update relevant Scottish Building Standards and guidance, e.g. 'Technical Handbook – Domestic', to make reference to key issues relating to mine gas and relevant standards and guidance to be followed. Approved Document C applicable in England provides an example of this approach.
- Develop draft model planning conditions in consultation with CoSLA/relevant local authorities to cover:
    - adequate assessment of mine gas (including worst-case conditions) in accordance with relevant standards and guidance
    - gas risk assessment and mitigation design integrated with foundation and build design, and reassessment when there are significant changes
    - consideration of uncertainties/future-proofing
    - decommissioning of boreholes and other preferential pathways, and
    - verification of gas protection systems in accordance with BS 8484 and CIRIA C735.

Option 2: Further research and preparation of supplementary technical guidance relating to the assessment of risks to new and existing developments, specifically from mine gas.

What occurs at present:

Standards and guidance relating to ground gas reference mine gas as an issue of concern. However, the risk assessment approach does not consider explicitly some aspects relevant for mine workings, such as assessing the gas source, relevant pathways, changes over time and effect of cumulative development.

Evidence of need for change:

Several specialists consulted in the Expert Consultation phase of the project referred to a lack of specific guidance available relating to mine gas issues and relevant factors to consider in such assessments. This lack of specific guidance was also mentioned by Northumberland County Council. Within Scotland, several Local Authority staff consulted in the Stakeholder Engagement process commented on a lack of expertise and understanding around mine gas, which would be partially mitigated by specific guidance around the risk assessment process.

Next steps:

One immediate solution might be to develop Supplementary Planning Guidance or a similar document which provides a clear explanation of the issues. For example, similar documents have been prepared by various local authorities, supported by Environmental Protection Scotland, in relation to contaminated land assessment. Inclusion of additional emphasis that the CSM developed in the risk assessment process needs to be reviewed when there is a change to the design would be key in these guidance documents.

More generally there seems to be a decline in research activity into the issues arising from abandonment of mines. There was substantial activity from the 1990s onwards into the impacts of mine abandonment on the water environment; however, this is an issue that is now well understood. More recently research has addressed the impact of mine gas emissions as greenhouse gases in the context of climate change. The Gorebridge incident and the stakeholder engagement and expert consultation process, carried out as part of this project, suggests that there is a requirement for additional research into the sources of mine gas and CO_2 particularly, in the context of the Source-Pathway-Receptor model. This research should be geared towards improving the understanding of how emissions from former coalfields may change over time in response to issues such as mine-water rebound, mine collapse and climate change effects. A clear understanding of the source of mine gas and how that is likely to develop over time will enable a much clearer understanding of the current and future risks, as well as associated uncertainties.

Option 3: Include consideration of mine gas issues/constraints at local development planning stage, especially with regard to large-scale developments and consideration of cumulative effects.

What occurs at present:

Stakeholder consultation has indicated that mine gas issues are not considered as a constraint at local development planning stage. There is also no mechanism for considering cumulative effects, particularly where adjacent developments may be occurring in parallel.

Evidence of need for change:

Some areas of Scotland affected by former mine workings are currently undergoing rapid development, for example parts of Midlothian and Lanarkshire. There is a risk that such rapid development on a large scale could affect ground gas emissions and the effectiveness of designed mitigation measures due to cumulative effects and unintended interactions between developments. Such issues would be best considered at the time of updating LDPs where areas are zoned for development, such as residential use.

Next steps:

A major update of planning legislation in Scotland is pending (Section 3.3). The Planning (Scotland) Bill was introduced to Parliament on 4 December 2017. The Bill is intended to strengthen the planning system's contribution to inclusive growth and empowering communities. The Bill sets out proposed high level changes to the overall framework under which planning operates; in particular the Bill proposes a major update of the way local development plans are taken with a 10-year cycle as opposed to the current 5 years.

In section 7.3, we highlighted consultation with the BGS focused on the use of environmental data and supporting information to inform planning policy and, in particular, the issue of providing site investigation and other environmental data early in the planning process. Work has been carried out by a sub-group of key agencies in Scotland to examine what environmental information is potentially relevant to inform preparation of Local Development Plans (LDP) and how this information can be made more accessible. Liaison and GIS identification would help identify within LDPs areas that may be of high risk of CO_2 emissions and potential cumulative impacts.

Option 4: Improve co-ordination and communication between planning, Building Standards and EHO/CLO staff in some local authorities and provide additional budget for training or external specialist support where needed.

What occurs at present:

Within section 7.1 stakeholder engagement, some local authorities noted that on complex sites there was insufficient communication and handover between departments verifying assessments and compliance with regulations. Experience of the guidance and risks associated with coal mine gas varies within local authorities as does the use of external expert peer review submissions from developers.

Evidence of the need for change:

These issues could lead to insufficient checking and enforcement of standards and guidance through the mine gas risk assessment, mitigation design and verification stages.

Next Steps:

- Good practice was highlighted within Fife and Midlothian Councils and it was noted that The City of Edinburgh Council’s Planning and Environmental Health protocol cited as an example of best practice.
- Using existing lines of communication between Scottish local authorities’ good practice should be shared. Local authorities should consider reviewing their internal handover processes and lines of communication to improve consistency in the governance of regulations applied to development of sites identified as at risk.

- Provide additional budgets for training or use of external specialist support, where needed.

Option 5: Further research to assess the long-term effectiveness of granular fill and perforated pipe ventilation below slab construction as utilised in modern housing construction in areas where there is a high likelihood of mine gas emissions.

What occurs at present:

In Scotland, housing developments have tended to utilise a slab construction with granular fill and perforated pipes to provide sub-slab ventilation since 2000 in order to comply with mobility access regulations whilst avoiding the raising of buildings and to ensure that ramp access is not required.

Evidence of the need for change:

Several consultees questioned whether or not this construction technique may increase the level of risk in relation to mine gas particularly if a gas membrane was not emplaced correctly or if ventilation was subsequently blocked accidentally by operatives during construction or at a later date by home owners.

Next Steps:

Further research is required to test the effectiveness of granular fill and perforated pipe in both design and construction techniques and to consider if further regulation is required to ensure the operational effectiveness of the design as a mitigation measure in the long term.

Option 6: Consider further the implementation of mandatory mitigation measures in former coal/oil shale mining areas.

What occurs at present:

The application of mandatory mitigation measures in areas of former mine workings has been trialled by one local authority in Scotland on a limited basis and by NCC. Both have adopted an equivalent to Characteristic Situation 2 (CS2) as defined in BS 8485:2015, i.e. ‘low risk’ sites. The experts consulted in this project were not typically in favour of this option whereas views amongst the stakeholders were widely variable.

Evidence of the need for change:

If a mandatory approach was to be adopted, it is likely that the level of protection would be similar to CS2 to avoid an overly precautionary and costly approach that could form a barrier to development. All consultees in favour of this approach accepted that ground gas assessments, mitigation design and other considerations specific to mine gas would still need to be undertaken on behalf of developers and reviewed for adequacy by local authority staff. Therefore, while this appears a relatively straightforward option, the benefits appear to be more limited.

The next steps would involve:

- wider stakeholder consultation
- more detailed evaluation of how to identify areas of risk and the level of gas protection measures to implement.

Option 7: Liaise with NCC.

In parallel to the main stakeholder consultation we identified in section 7.3, our additional stakeholder liaison revealed that Northumberland County Council has extensive experience of dealing with mine gas related issues similar to those recorded in the Gorebridge IMT Report since at least the 1950s. This has led to increased vigilance regarding the risks posed by CO_2 particularly for new developments.

We recommend further liaison between Scottish Government, Scottish Local Authorities and NCC environmental health officers may be mutually beneficial, particularly in relation to progressing options 1-4 above.

Option 8: Validate consultants.

Validation of the experience and qualifications of those designing mine gas mitigations measures is required by developers during the procurement process to appoint consultants.

Evidence of the need for change:

Stakeholder at various levels within the industry have flagged up the lack of awareness within developers and consultants on mine gas issues and the requirements for risk assessing these issues. Examples are sighted by consultees of non-experts being appointed to carry out specialist work for which they were inexperienced.

Next Steps:

As with option one above, specific guidance in the form of Supplementary Planning Guidance or similar document which provides a clear explanation of the issues would be an initial step.

Requesting that developers require experience with mine gas assessment and mitigation during the procurement process to appoint consultants will assist in ensuring guidance and standards are being adhered to.

11.3 Conclusion

The fact finding research carried out for this project to investigate the prevalence of CO_2 from disused mineral mines and the implications for residential buildings has involved a very detailed process of literature review, stakeholder engagement, primarily with Local Authority staff in Scotland, and consultation with key technical experts with detailed knowledge of the issues. In addressing the eight building standards related questions in the Gorebridge IMT report, we have collated the published literature and the opinions of stakeholders and technical experts to provide solutions to the issues raised.

A number of options for further consideration have been presented above based on their effectiveness in improving knowledge in relation to the risks posed by CO_2 from abandoned mine workings. More robust enforcement, risk assessment and mitigation, will help to prevent further instances of ill-health in residential buildings from CO_2 associated with abandoned mine workings.

12 Bibliography

Abd-Elhamid, H. F. and Javadi, A. A. (2008). An investigation into control of saltwater intrusion considering the effects of climate change and sea level rise. Proceeding of 20th SWIM, June 23–27, 2008, Naples, FL, USA.

Adams, R. and Younger, P. L. (2005). A strategy for modeling ground water rebound in abandoned deep mine systems. Groundwater, 39(2), pp 249 - 261

Air Products. (2014). Dangers of oxygen-deficient atmospheres, Air Products Survey. [online] www.airproducts.com. [Accessed 08 Jan. 2019]. https://www.airproducts.com/~/media/Files/PDF/company/safetygram-17.pdf

Anon. (2018). “Gorebridge event was just maybe the tip of the iceberg.” Personal communication, project stakeholder workshop Nov 8th.

Appleton, J.D. (2011). User Guide for the BGS methane and carbon dioxide from natural sources and coal mining dataset for Great Britain, OR/11/054. British Geological Survey, pp 34.

Baker, K. et al. (2009). The VOC Handbook. Investigating, assessing and managing risks from inhalation of VOCs at land affected by contamination, CIRIA 682.

Banton, K., Kershaw, S., O’Connor, M. and Allan, D. (2015). Guidance on managing the risk of hazardous gases when drilling or piling near coal. The Coal Authority, HSE, etc.

BGS. (2018). Future Climates, climate change, discovering geology. British Geological Survey. [online] Bgs.ac.uk. [Accessed 14 Dec. 2018]. https://www.bgs.ac.uk/discoveringGeology/climateChange/general/futureClimates.html

BGS. (2019). Groundwater and climate change. [online] Bgs.ac.uk. [Accessed 15 Jan. 2019]. https://www.bgs.ac.uk/discoveringGeology/climateChange/general/groundwater.html

Bonsor, H. BGS. (2018). Current environmental information used to inform local development plan preparation and delivery, External Briefing Report, British Geological Survey, OR/18/040, pp 12.

Bonino. (2016) Carbon Dioxide Detection and Indoor Air Quality Control [online] ohsonline.com. [Accessed 08 Jan. 2019] https://ohsonline.com/articles/2016/04/01/carbon-dioxide-detection-and-indoor-air-quality-control.aspx

BSi. (1991). Ventilation principles and designing for natural ventilation, code of practice, BS 5925: 1991.

BSi. (2007). Code of practice for the characterization and remediation from ground gas in affected developments, BS 8485.

BSi. (2013). Guidance on investigations for ground gas – permanent gases and volatile organic compounds (VOCs), BS8576.

BSi. (2015). Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings, BS 8485.

Card, G. B. (1995). Protecting development from methane, R149. Construction Industry Research and Information Association (CIRIA) publications.

CL:AIRE. (2011). The utility of continuous monitoring in the detection and prediction of “worst case” ground gas concentration. CL:AIRE Research Bulletin, RB13.

CL:AIRE. (2012). A pragmatic approach to ground gas risk assessment. CL:AIRE Research Bulletin, RB17.

Coal Authority. (2017). Risk based approach to development management: guidance for developers.

Crowhurst, D. and Manchester, S. J. (1993). The measurement of methane and other gases from the ground, CIRIA R131.

Department of the Environment. (1996). Methane and other gases from disused coal mines: the planning response. Technical Report.

Department of the Environment, Transport and the Regions (DETR). (1997). Passive venting of soil gases beneath buildings: Volume 1 (Guide for Design) and Volume 2 (Computational Fluid Dynamics Modelling: Example Output).

DECC. (2011). Update of Estimated Methane Emissions from UK Abandoned Coal Mines, Department of Energy and Climate Change.

Ekström, M., Fowler, H. J., Kilsby, C. G. and Jones, P. D. (2005). New estimates of future changes in extreme rainfall across the UK using regional climate model integrations. 2. Future estimates and use in impact studies. Journal of Hydrology, (300)1-4, pp 234-251.

Falkirk Council. (2011). Development of land affected by contamination: guidance for applicants and developers supplementary planning guidance note.

Fischer, E. M. and Knutti, R. (2015). Anthropogenic contribution to global occurrence of heavy-precipitation and high-temperature extremes. Nature, (5), pp 560-564.

Government of the U. K. (1997). The Town and Country Planning Act (Scotland) 1997, amended in 2006.

Harries, C. R., Witherington, P. J. and McEntree, J. M. (1995). Interpreting measurements of gas in the ground, CIRIA R151.

Hartless, R. (1991). Construction of new buildings on gas- contaminated land, BRE 212.

Hendrick, D. J. and Sizer, K. E. (1992). "Breathing" coal mines and surface asphyxiation from stythe (black damp). BMJ, 305(6852), pp 509-510.

Herrera-Pantoja, Hiscock, K. M. (2007). The effects of climate change on potential groundwater recharge in Great Britain. Hydrological Processes, (22)1, pp 73-86.

Hooker, P. J. and Bannon, M. P. (1993). Methane: Its occurrence and hazards in construction, CIRIA R130.

Jackson, C. R., Meister, R. and Prudhomme, C. (2011). Modelling the effects of climate change and its uncertainty on UK Chalk groundwater resources from an ensemble of global climate model projections. Journal of Hydrology, (399)1-2, pp 12-28.

Johnson, R. (2001). Protective measures for housing on gas-contaminated land, BRE 414.

Joint Scottish Contaminated Land Regulatory Officers. (2010) An Introduction to Land Contamination and Development Management revision 4, Joint Scottish Contaminated Land Regulatory Officers Publication.

Lagny, C., Lafortune, S., Charmoille, A, Pokryszka, Z., Degrelle, F. and Kimmel, M. (2013). Understanding CO2 Gas Production Above a Partly Flooded, Former Coal Mining Area. 14. International Symposium on Water-Rock Interaction (WRI 14), Avignon, France. 7, pp 455-458.

Mallet, H., Cox, L., Wilson, S. and Corban, M. (2014). Good practice on the testing and verification of protection systems for buildings against hazardous ground gases, CIRIA 735.

Met Office Hadley Centre Climate Programme. (2009) UK Climate Projections (UKCP09).

Min, S., Zhang, X., Zwiers, F. W. and Hegerl, G. C. (2011). Human contribution to more-intense precipitation extremes. Nature, (470), pp 378-381.

NHBC, (2007). Guidance on Evaluation of Development Proposals on Sites where Methane and Carbon Dioxide are Present. Report. (04).

NHS Lothian. (2017). Carbon Dioxide Incident in Gorebridge Midlothian, April 2014. Final Report of the Incident Management Team.

O'Riordan, N. J. and Milloy, C. J. (1995). Risk assessment for methane and other gases from the ground, CIRIA R152.

Owen, R. and Paul, V. (1998). Gas protection measures for buildings: Methodology for the quantitative design of gas dispersal layers. Proceedings of the Fifth International Conference – Polluted and Marginal Land.

Qi, X., Wang, D., Zhong, X. and Xu, Y. (2009). Oxygen consumption of coal at low temperatures. Procedia Earth and Planetary Science, 1(1), pp 366–370.

Raybould, J. G., Rowan, S. P. and Barry, D. L (1995). Methane investigation strategies, CIRIA R150.

Robinson, R. (2000). Mine gas hazards in the surface environment, Trans. Inst. Min. Metall. Sect. A Min Technol. 109, A228-A236.

Safi, A., Rachid, G., El-Fadel, M., Doummar, J., Abou Najm, M. and Alameddine, I. (2018). Synergy of climate change and local pressures on saltwater intrustion in coastal urban areas: effective adaptation for policy planning. Water International, (43)2, pp 145-164.

Scivyer, C. (2015). Radon: Guidance on protective measures for new buildings, BRE 211.

SEPA. (2019). The effects of climate change. [online] sepa.org.uk [Accessed 16 Jan. 2019].
https://www.sepa.org.uk/environment/climate-change/the-effects-of-climate-change/

Sharpe, T., McQuillan, J., Howieson, S., Farren, P. and Tuohy, P. (2014). Investigation of occupier influence on indoor air quality in dwellings. The Scottish Government.

Sherif, M. M. and Singh, V. P. (1999). Effects of climate change on sea water intrusion in coastal aquifers. Hydrological Process J (13)8, pp 1277–1287.

Sizer, K., Creedy, D. and Sceal, J. (1996). Methane and other gases from disused coal mines: the planning response technical report. London: Wardell Armstrong.

Teasdale, C. J., Hall, J. A., Martin, J. P. and Manning, D. A. C. (2018). Discriminating methane sources in ground gas emissions in NW England. Quarterly Journal of Engineering Geology and Hydrogeology.

The Environment Agency. (2004). Model Procedures for the Management of Contaminated Land. Contaminated Land Report Number 11 (CLR11).

The Scottish Government. (2006). Environmental Protection Act 1990 – Part 11A contaminated land: statutory guidance edition 2.

The Scottish Government. (2014). The Scottish Planning Policy (SPP). Edinburgh.

The Scottish Government. (2000). Planning advice note PAN 33 development of contaminated land.

The Scottish Government. (2019). Planning and Architecture. [online] gov.scot [Accessed 15 Jan. 2019]. https://www.gov.scot/policies/planning-architecture/overseeing-planning-system/

The Scottish Government. (2005). The Contaminated Land (Scotland) Regulations.

The Scottish Government. (2014). The National Planning Framework 3 (NPF3). Edinburgh.

Welburn, P., Baker, K., Borthwick, K. and MacLeod, C. (2012). Remediating and mitigating risks from volatile organic compound (VOC) vapours from land affected by contamination, CIRIA 716.

Wilson, S. (2017). Complete continuous monitoring in underfloor voids, CL:AIRE Technical Bulletin TB16.

Wilson, S. A. and Card, G. B. (1999). Reliability and risk in gas protection design. Ground Engineering, February 1999 and Ground Engineering News Section of Ground Engineering, March 1999.

Wilson, S. and Lucas, J. (2018). Ground gas monitoring and 'worst-case' conditions, CL:AIRE Technical Bulletin TB17.

Wilson, S., Card, G. and Haines, S. (2008). The Local Authority Guide to Ground Gas. Chartered Institute of Environmental Health.

Wilson, S. and Mortimer, S. (2017). Piled foundations and pathways for ground gas migration. Environmental Geotechnics. Journal of Environmental Geotechnics.

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

Wrona, P., Różański, Z. and Pach, G. et al. Closed coal mine shaft as a source of carbon dioxide emissions; Environ Earth Sci (2016) 75: 1139. https://doi.org/10.1007/s12665-016-5977-7

Yawson, D. O., Adu, M. O., Mulholland, B., Ball, T., Frimpong, K. A., Mohan, S. and White, P. J. (2019). Regional variations in potential groundwater recharge from spring barley crop fields in the UK under projected climate change. Groundwater for Sustainable Development, (8), pp 332-345.

Yuan, L. and Smith, A. C. (2011). CO and CO_2 emissions from spontaneous heating of coal under different ventilation rates. Int J Coal Geol, 88(1), pp 24-30.

Zhang, X., Wan, H., Zwiers, F. W., Hegerl, G. C. and Min, S. (2013). Attributing intensification of precipitation extremes to human influence. Geophysical Research Letters, (40)19, pp 4977-5336.

13 Annex List

Annex 1 - Table of past incidents

Annex 2 - Table of Standards and Guidance

Annex 3 – Stakeholder Engagement

3(a) Issues log from Stakeholder Engagement

3(b) Stakeholder responses to questions

Annex 4 - Findings log from Expert Consultation

Annex 1 – Table of Past Incidents

Summary of past incidents (The Coal Authority data was generated from an incidents database and is not publicly available)

Date	Location	No. of people/units affected	Detail	Source
Issues in Scotland				
03/11/1994	Coalburn, South Lanarkshire	1 residential property	Blackdamp emission at a residential property during the winter of 1994 lowered the O_2 levels to a reported 12%. Two vents were installed into shaft 280634-003 and the shaft fill was grouted.	Coal Authority, 2018
30/05/1995	Coalburn, South Lanarkshire	No data	Ongoing gas monitoring carried out by British Coal regarding O_2 deficient atmosphere, transferred to the Coal Authority. Upper section of shaft 280634-003 drilled and grouted to a depth of 12m. Shaft re-drilled through the grout plug and a passive vent installed into shaft to protect the building. Vent attached to side of building to vent above eaves level.	Coal Authority, 2018
08/08/1999	Kirkconnel, Dumfries and Galloway	Number of animal fatalities	Low O_2 within dry stream bed (dead animals). Gas venting undertaken and continual monitoring.	Coal Authority, 2018
09/08/1999	Kirkconnel, Dumfries and Galloway	Number of bird and small animal fatalities	Possible gas emission at site of old shaft. Several dead birds and small animals in the vicinity. Shaft excavated to depth of 4m, no evidence of shaft lining found. Filled with concrete and reinforced cap constructed. Void above cap filled.	Coal Authority, 2018

Date	Location	No. of people/units affected	Detail	Source
12/08/1999	Kirkconnel, Dumfries and Galloway		Suspected gas emissions. Records showed no mine entries at this location but discussions with local residents suggested unlawful coal working. Sealing works were undertaken by Coal Authority.	Coal Authority, 2018
28/06/2001	Dysart, Fife	1 harbour store	O_2 deficient atmosphere found in old store at Dysart Harbour. New security grille with access door installed and gap between top of wall and rock face sealed with security mesh. Building vented.	Coal Authority, 2018
25/10/2002	Fife (no village listed)	1 Elderly woman (1 residential property)	Gas service engineer called out due to the inability of woman to light her gas boiler. After investigation it was found they could not light a match due to serious O_2 depletion. Mine gas incursion into the property was a probable cause. She contacted LA environmental health team and CA was called out. During discussions with the woman it emerged she had "been sleeping more than usual" over the previous few weeks (of unsettled/stormy weather) and the decision was taken to install a 24-hour O_2 monitor in the property to gauge the scale of the problem. A press release was issued, and a targeted leaflet-drop arranged jointly by EH and the CA to warn of the potential for mine gas in the village.	Stakeholder Engagement
01/04/2004	Thornton, Fife	Multiple residential properties	Unable to light gas appliances–mine gas suspected. Issue affected multiple properties in the locality. Site investigation boreholes drilled. Site then drilled and grouted. Two underfloor fans installed, and a monitor alarm left in house, ventilation into affected workings installed to alleviate issue.	Coal Authority, 2018

Date	Location	No. of people/units affected	Detail	Source
10/11/2010	Coalburn South Lanarkshire	1 property	CO_2 at very high levels entered previously treated building through a mine entry. The building underwent a change of use from commercial to residential and previous remediation altered. The property was subsequently demolished and ventilation into the shaft improved.	Coal Authority, 2018
April 2014	Gorebridge, Midlothian	165 people (22 for healthcare)	See IMT report	NHS Lothian, 2017
Anecdotal evidence in Scotland				
1950's	Cowdenbeath	No data but allegedly several properties	Reports in local press of people 'suffering from mystery symptoms'. Subsidence at the sites also recorded and both sites were vacated and demolished.	Expert Consultation
	Lochgelly			Expert Consultation
Other CO_2 or O_2 deficient events in the rest of the UK				
1960s	NW England	4 (3 children, 1 fireman) dead	Asphyxiated in poorly sealed surface entrance to adit (blackdamp).	Sizer et al., 1996
1971-76	No detail	2 dead	Walked into old workings.	Unwin and Phil, 2007
1977	Portobello, Birtley, near Gateshead, 1977	2 dead	December 1977 two persons found dead from carbon monoxide poisoning in bungalow. Investigation showed that the gas had travelled some 200 meters underground in permeable, fissured strata from burning fill in an abandoned shaft.	Robinson, 2000

Date	Location	No. of people/units affected	Detail	Source
1979	Low Fell, NE England	0 (1 household)	Poorly capped mineshaft found in garden, although no methane and little blackdamp found.	Robinson, 2000
1979	Sunnybrow, County Durham	1 family, rehoused	Random testing revealed low O_2 levels (below 14%). House had been built above stopping to seal off surface drift to abandoned mine. Council officials stated that the family had been living there for four years and had frequently complained of ill health.	Robinson, 2000
1980	Cramlington	2 families (and further 8 properties)	Complaints of breathlessness, low O_2 (circa 11%) discovered on investigation. Further 8 properties were found to have problems. An improved ventilation system was installed under floor spaces, removal of suspended floor, insertion of plastic membrane (all unsuccessful).	Robinson, 2000.
1987	Seaton Sluice, Northumberland	15 properties on an estate	Emergency service called out by council officials after drop in pressure resulting in O_2 deficient atmosphere. Cause possibly rising water levels and low pressure. A ventilated system emplaced with boreholes allowing gas to be released at the surface.	Robinson, 2000
1987	Newcastle-upon-Tyne	1 property	Woman and helpers moving into property suffered dizziness, nausea and headaches which passed on moving to fresh air. High CO_2 and low O_2 were recorded. Maximum CO_2 recorded in the property was 7.05%. Spikes in CO_2 found to be associated with drops in atmospheric pressure. A shallow venting shaft sunk into soil in property (ineffective), then new shafts sunk into the mine itself for ventilation.	Hendrick and Sizer, 1992
December 1993	Pegswood, Northumberland	Evacuation of number of homes	Falling atmospheric pressure caused problems with blackdamp. Fan stopped from a connecting colliery that had shut down.	Robinson, 2000

Date	Location	No. of people/units affected	Detail	Source
31/12/1994	Pegswood Nr. Morpeth	Number of properties	Properties were affected by the ingress of blackdamp from shallow mine workings. Cavities grouted up and vents installed into the shallow pillar and stall mine workings and mine entries in the locality. Monitoring indicated that the level of blackdamp had been significantly reduced, properties still affected were treated through installation of retrospective gas membranes.	Coal Authority, 2018
11/02/1995	Widdrington	1 fatality, 'major incident' at 1 property	An uncontrolled release of blackdamp through a mine entry causing a fatality. The building effected occupied a former pit head baths built over the mouth of the mine entry. A trench was excavated across the drift and backfilled with concrete and the old drift entrance within the factory was backfilled with concrete. A borehole was drilled into the drift inbye of the stopping and a ventilation chimney erected. Following discussions with the LA and HSE further works were undertaken to infill an inspection chamber with mass concrete which was left in the floor of the property.	Coal Authority, 2018
07/03/1995	Widdrington, Northumberland	1 (non-residential) property	O_2 deficient atmosphere recorded within the property attributed to the presence of a mine shaft beneath the property. Works were undertaken to seal the mineshaft and a gas collecting system was installed into the shaft beneath the sealing works. A gas vent was constructed on the outside of the property to vent the shaft.	Coal Authority, 2018
No date	Cresswell, Northumberland	1 commercial property	Evidence of blackdamp entering commercial building. Treatment of mine entry undertaken, and ventilation introduced.	Coal Authority, 2018

Date	Location	No. of people/units affected	Detail	Source
1995	Widdrington, Northumberland	1 house	Occupants of privately-owned house showed symptoms of blackdamp exposure. House was a former fanhouse above a shaft. Shaft grouted, and vent pipe installed.	Robinson, 2000
1995	Widdington, Northumberland	1 and 1 dog dead	Disused mine entry in factory, makeshift stable in brick shed possibly due to dewatering allowing pathway in old drift.	Hansard, 2016
1995	Cramlington Primary School	0 (school)	Fan failure in old mine ventilation system. Police, mine rescue and environmental health officers called out. No health impacts noted.	Hansard, 2016
01/02/1997	Pegswood, Nr. Morpeth	Number of residential properties	CO_2 detected in property. Existing vents from old workings enlarged. These were subsequently collected together in a combined manifold to enable the gas to be discharged from a common installation. Gas membranes fitted into affected houses.	Coal Authority, 2018
09/07/1997	Rhymney, South Wales	Commercial property	CO_2 detected in the commercial premises. A 600mm diameter pipe installed from the existing pipe in the stoppings for the length of the adit beneath the properties. This was vented to a ventilation stack on land adjacent to the adit entrance.	Coal Authority, 2018
1998	Barnsley	1 dead (1 collapse)	A man collapsed while laying sewer pipes, son died rescuing father from trench. Blackdamp had seeped in from disused colliery.	Humphries, 2001

Date	Location	No. of people/units affected	Detail	Source
02/06/1999	Low Moor, Bradford, Yorkshire	1 residential property	Elevated levels of blackdamp (up to 9%) and low levels of O_2 (down to 10%) found by Transco within the basement of the property after electrician working within the property complained of breathing difficulties. Drilling works identified an unrecorded shaft filled with pea gravel and the remaining shaft void was filled with high strength foamed concrete to the underside of the capping plate. A ventilation fan was temporarily installed in the cellar but was removed after the sealing works to the shaft were completed.	Coal Authority, 2018
23/06/1999	Low Moor, Bradford, Yorkshire	1 property (non-residential)	Shaft depression found to contain elevated CO_2. 150mm pipe with monitoring facility placed into the excavation prior to backfilling.	Coal Authority, 2018
09/07/1997	Rhymney, South Wales	No specific data	CO_2 detected in the premises. It was decided to install a 600mm diameter pipe from the existing pipe in the stoppings for the length of the adit beneath.	Coal Authority, 2018
28/08/1997	North Shields	Residential property(ies), no specific data	CO_2 detected in property. Consideration of possible remediation works concluded that the problem was too widespread to solve by individual property treatment/venting etc. A fan test on a borehole sunk to the workings proved that it would be possible to control the gas emissions by installing a mechanical ventilating system to extract the gas in controlled manner.	Coal Authority, 2018

Date	Location	No. of people/units affected	Detail	Source
11/10/2000	Great Broughton, Cumbria	1 property (residential)	Residents of bungalow not able to light gas appliance. CO_2 in general body up to 2.9%, 17.5% O_2. Problem ongoing for 18 months. Monitoring suggested a good pathway from shallow unrecorded mine workings and driving force for the movement of gases appears to be changing atmospheric conditions. Remedial works undertaken.	Coal Authority, 2018
30/10/2000	Cockfield, County Durham	1 property	Ingress of elevated CO_2 into a property causing ill health and inability to light appliances. Sealing works were undertaken on all passages between the underfloor area of the property and the living areas above. Extra sealing around skirting boards was also undertaken and service entry points sealed with foam. Two large diameter boreholes were sunk to these workings. A ventilation scheme was initially put in place at the property. This passive ventilation system was adjusted to connect the subfloor area to a vent arrangement in the birdbath in the front of the property.	Coal Authority, 2018
11/12/2000	Hunwick, County Durham	Number of residential properties	CO_2 entering cottages from abandoned mine entries. The drifts were vented, and gas disappeared.	Coal Authority, 2018
11/12/2000	Hunwick, County Durham	1 Commercial property	CO_2 entering factory canteen from shaft partially beneath building. Shaft treated and vented.	Coal Authority, 2018
26/01/2001	Crook, County Durham	No specific data	Mine entries emitting elevated CO_2. Mine entries treated and vented.	Coal Authority, 2018
02/08/2001	Crook, County Durham	No specific data	Gas emission within woodland showed up to 16% CO_2 present. Depression dug out and reinstated with on-site material.	Coal Authority, 2018

Date	Location	No. of people/units affected	Detail	Source
21/09/2001	Biddulph, Stoke on Trent	No specific data	CO_2 concentrations up to 0.8% were detected within general body of living areas under steady atmospheric conditions. Ingress believed to be associated with shallow workings. Active ventilation installed at the property.	Coal Authority, 2018
12/11/2001	Moira, Derbyshire	Commercial property	Identified elevated CO_2 leaking at industrial units. Passive ventilation installed.	Coal Authority, 2018
16/10/2002	Stoke on Trent	No specific data	Possible emission of CO_2 and O_2 deficiency. Gas monitoring unit removed from property, constructed new ventilation system.	Coal Authority, 2018
01/04/2004	Woolley, Wakefield, Yorkshire	Several residential properties	Long standing mine gas issue in residential properties. CO_2 and smell when pressure low and wind from west. Venting fissures and filling in cellar have alleviated the problem, but low concentrations of gas still present in kitchen. A fan was installed beneath the living room floor but provided only a limited air flow. Two boreholes were drilled into Woolet Edge rock and nearby workings to vent and monitor. Cellar fitted with foam concrete, fissure sealed under the solid part of the lounge floor before sealing the whole room with a gas membrane and concrete floor. This subsequently caused smells in other rooms and a trench was excavated in the patio area to the south of the property to expose two fissures. Allowing these to vent outside the house appeared to have alleviated these problems.	Coal Authority, 2018
11/01/2005	Coleford, Forest of Dean	None identified	Discharge of O_2 deficient air from mine entry. Removal of concrete capping, filling of void using clean stone. Excavation to formation and placement of RC shaft cap.	Coal Authority, 2018

Date	Location	No. of people/units affected	Detail	Source
01/03/2005	Tankersley, South Yorkshire	None identified (area extensively used by public)	Shaft cap over void shaft with 3” pipe in cap. 12% CO_2 and low O_2 gas readings within the pipe. The shaft cap was further secured by erecting 5m x 5m square 2.4m high palisade fencing with warning notices. Site monitored annually to ensure the fencing remains secure.	Coal Authority, 2018
15/07/2005	Ashington, Northumberland	None identified (potential effects to public area– museum)	Elevated CO_2 leaking from shaft cap within museum. Remedial works undertaken, and shaft regularly monitored.	Coal Authority, 2018
14/02/2007	Pegswood, Nr. Morpeth	1 property	Continued blackdamp detected at property from shallow mine workings. Property retrospectively sealed.	Coal Authority, 2018
28/06/2007	Elescar, Barnsley, Yorkshire	Several residential properties	Residents complained of difficulty lighting fires in the house, caused by ingress of CO_2 from shallow mine workings. Property demolished, including garage at rear and foundations grubbed out. Site was cleared and surrounded with timber and shiplap fencing.	Coal Authority, 2018
23/10/2008	Pegswood, Nr. Morepeth	1 residential property	Retrospective sealing works undertaken to property following ingress of elevated CO_2 from shallow mine workings. Workings and nearby mine entries also vented.	Coal Authority, 2018
08/09/2009	Halfway, South Yorkshire	Several residential properties	Elevated levels of CO_2 affecting properties on housing estate. Shallow workings vented in multiple locations across the estate.	Coal Authority, 2018

Date	Location	No. of people/units affected	Detail	Source
08/07/2010	Cwmbran, Monmouthshire	1 person (anecdotal)	Open adit in open land where low O_2 levels have reportedly affected member of the public. The adit was sealed and access restricted.	Coal Authority, 2018
17/04/2012	Lower Brynamman, Ammanford, South Wales	1 commercial property	Elevated CO_2 and methane entering commercial property from mine entry. Mine entry treated and vented, and monitoring facilities installed. Further sealing done at the monitoring point within a manhole chamber where CO_2 and methane were entering the building.	Coal Authority, 2018
18/03/2014	Spennymoor, County Durham	None reported	Mine gas (blackdamp) issuing under pressure from manhole chamber over treated mine shaft at housing development. Shaft vented.	Coal Authority, 2018
21/01/2016	Rhymney, Tredegar, South Wales	Several properties	CO_2 from abandoned mine entry affecting properties vegetation. Mine entries treated, and a number of ventilation stacks installed to remediate issue.	Coal Authority, 2018
28/02/217	Heanor, Derbyshire, East Midlands	Several residential properties	Ingress of elevated CO_2 into property from shallow adit roadway beneath the property. Lower levels of CO_2 also detected in neighbouring properties. Temporary venting installed into roadway to alleviate problem affecting neighbouring properties. Ventilation has reduced issue in affected property but not to an acceptable level. Consideration will be given to demolition and permanent ventilation.	Coal Authority, 2018
Anecdotal evidence or lacking data				
1950s	NE England	No specific data	Number of mine gas surface incidents in domestic properties. Not just CO_2 but O_2 deficient (blackdamp).	Robinson, 2000

Date	Location	No. of people/units affected	Detail	Source
1995	Northumberland	Health of 1 woman	Anecdotal: woman falling asleep when blackdamp had reached level of sofa.	Hansard, 2016
No date	Hunterfield	1 fatality	Young boy fell into shallow ground collapse and overcome by CO_2.	NHS Lothian, 2017
No date	No detail	1 collapse from exposure	Anecdotal evidence from HSE: one person overcome retrieving football from mine entrance.	Health and Safety, Executive. Personal communication. 31 March 2016.
No date	No detail	1 fatality	Anecdotal evidence from HSE: one death from someone exploring old mine. Overcome and could not be rescued.	Health and Safety Executive. Personal communication. 31 March 2016.
No date	No detail (possibly Yorkshire)	1 fatality	CO_2 from old chalk quarry with 2-3m of chalk and soakaways put in for the roof drainage. Couple came to buy houses second hand. One man went into subsurface void and collapsed followed by second. Firemen called out and even he collapsed. O_2 was brought down but sadly one man died.	Expert Consultation
No date	No detail	3 fatalities (anecdotal)	About three incidents where people have died in excavation on former open cast sites or chalk sites	Expert Consultation

Date	Location	No. of people/units affected	Detail	Source
Worldwide significant CO_2 events				
1953	Menzengraben mine, East Germany	Mine shaft roof shattered, 3 deaths (2 from asphyxiation)	Salt mines had unexpected explosion ("outburst") of CO_2 (common in salt mines). Two died of CO_2 asphyxiation. One at 100m, one at 350m distance. Asphyxiation symptoms recorded at 530m distance.	Hedlund, 2012
1986	Lake Nyos, Cameroon	1,700 Fatalities, 3,500 livestock	Limnic eruption (lake overturn) ½ million tonnes of CO_2 released.	BBC, 2018
Unknown/ late 1990s	Lorraine, France	Number of persons/ properties	Former iron and coal mines. Faulty gas appliances and symptoms of CO_2 recorded. 8% CO_2 and 7% O_2 at times of pressure drop.	Lagny, 2015
1999	Rome, Italy	30 cows	Asphyxiated due to CO_2 exposure.	Beaubien et al., 2003
1980s-2003	Lazio Region, Italy	10 fatalities (over 20 yrs.)	Fatalities from asphyxiation.	Beaubien et al., 2003
2000	Cava del Selci, Italy	1 person and multiple livestock/ animal fatalities	Home owner and grazing farm animals were asphyxiated by CO_2 gas cloud arising from natural volcanic activity near Cava del Selci, Italy.	Chartered Institute of Environmental Health, 2008

Date	Location	No. of people/units affected	Detail	Source
2000	Lawrence County, Pennsylvania, USA	4 people in 3 homes	Numerous properties affected by low O_2 and high CO_2 near and on old strip mine. Sub slab positive pressure ventilation seemed successful mitigation.	Ehler, 2002
2001	West. Virginia, USA	2 people	Reports of dizziness and fatigue while in basement. Very high CO_2 and low O_2. CO_2 level 9.5% and O_2 level 14% recorded in crawlspace adjacent to basement.	Center for Disease Control, 2004
2002	Lawrence County, Pennsylvania, USA	73 properties	Low O_2 and elevated CO_2. Same case as above. Reaction of acidic minewaters with limestones. Three other sites in Western PA also investigated and showed elevated CO_2 and reduced O_2 in homes. Site 1: CO_2 3.52%, O_2 16%. Site 2: CO_2 > 25%. Site 3: CO_2 14.7%, O_2 6.8%. Remediation successful.	Laughrey and Baldassare, 2003
2002	Derry, Pennsylvania, USA	1 home	Two daughters with bedrooms in the basement awoke several times with increased hearth rate and difficulty breathing. CO_2 levels recorded >10%, O_2 levels <10%, on occasion CO_2 exceeded 20%. House located on area with past surface and deep mining. CO_2 higher following rainfall.	Laughrey and Baldassare, 2003

Date	Location	No. of people/units affected	Detail	Source
2006	Indiana, USA	3 properties	Elevated CO_2. Maximum daily concentration of CO_2 2%. Mitigation measure taken, but in one house the effects remained. Three mitigation measures attempted: block-wall depressurisation, block-wall and sub-slab depressurisation, and block-wall and sub-slab pressurisation, but none achieved safe CO_2 levels. Excavation of an open trench and sub slab positive pressure ventilation seemed successful Risks remained at a drop in pressure.	Robinson, 2010
May 2006	Sullivan Mine, Kimberly, BC, Canada	4 fatalities	Zinc and iron mine. Over three days, four individuals died at a water monitoring station at toe of number one shaft waste dump.	Sullivan Mine Incident Technical Panel, 2010
Other mine gas issues (not CO_2 or O_2 deficient) in Scotland				
14/07/1986	Chryston, N Lanarkshire	Possible leakage to series of properties	Report of methane accumulation in the area and in the Berryknowe housing estate on above shallow unworked coal and fractured sandstone	Expert consultation
24/10/2002	Leven, Fife	No data	Hole appeared in field issuing smoke. Spontaneous combustion materials dug out and cold edges sealed with sand barrier.	Coal Authority, 2018
10/11/1999	Leven, Fife	No data	Alleged burning in a coal seam. Excavation carried out and 4 monitoring boreholes drilled.	Coal Authority, 2018

References for Annex 1:

BBC. (2018). On this day in August 21, 1986: Hundreds gassed in Cameroon lake disaster. [online].

Beaubien, S., Ciotoli, G. and Lombardi, S. (2003). Carbon dioxide and radon gas hazard in the Alban Hills area (central Italy). Journal of Volcanology and Geothermal Research, 123(1-2), pp. 63-80.

Center for Disease Control. (2004). Brief Report: Investigation of a Home with Extremely Elevated Carbon Dioxide Levels – West Virginia, December 2003. 53(50).

Chartered Institute of Environmental Health. (2008). The Local Authority Guide to Ground Gas. London.

CL:AIRE. (2018). Ground gas monitoring and 'worst-case' conditions. CL:AIRE technical bulletin. TB 17.

Coal Authority. (2018). Coal Authority Report.

Ehler, W.C. (2002). Dangerous Atmosphere created by Strip Mine Soil.

Hansard. (2016). Mine workings. Northumberland.

Health and Safety Executive. (HSE). Personal communication. 31 March 2016.

Hedlund, F. (2012). The extreme carbon dioxide outburst at the Menzengraben potash mine 7 July 1953. Safety Science, 50(3), pp. 537-553.

Hendrick, D. and Sizer, K. (1992). "Breathing" coal mines and surface asphyxiation from stythe (black damp). BMJ, 305(6852), pp. 509-510.

Humphries, P. (2001). Deep concern: The risk of gas leaks from disused mines. The Guardian. [online].

Lagny, C. (2015). Noxious gas emissions above former coal and iron mines in Lorraine due to the presence of iron sulphides. Environmental Earth Sciences, 74(7), pp. 6303-6313.

Laughrey, C. and Baldassare, F. (2003). Some applications of isotope geochemistry for determining sources of stray carbon dioxide gas. Environmental Geosciences, 10(3), pp. 107-122.

NHS Lothian. (2017). Carbon Dioxide Incident in Gorebridge Midlothian, April 2014. Final Report of the Incident Management Team.

Rippon, J. H. (2002). Coal. In: Trewin, N. H. (ed.) The Geology of Scotland. The Geological Society, London, pp. 449-454.

Robinson, R. (2000). Mine gas hazards in the surface environment. Mining Technology, 109(3), pp. 228-236.

Robinson, B.A. (2010). Occurrence and attempted mitigation of carbon dioxide in a home constructed on reclaimed coal-mine spoil, Pike County, Indiana. US Department of the Interior, US Geological Survey.

Sizer, K., Creedy, D. and Sceal, J. (1996). Methane and Other Gases from Disused Coal Mines: The Planning Response Technical Report. London: Wardell Armstrong.

Sullivan Mine Incident Technical Panel. (2010). Sullivan Mine Fatalities Technical Investigations Summary Report: Mine waste respiration-induced air quality risks March 2010.

Unwin, I.D. and Phil, M. (2007). Mine monitoring for safety and health. Monograph.

Annex 2 – Table of Standards and Guidance

Summary of published and planned technical guidance and standards on ground gas assessment and mitigation

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
1	Construction of new buildings on gas-contaminated land, BRE Report 212	Building Research Establishment (BRE)	1991	Guidance	Reference sources but largely superseded by later guidance.	Ground gas risk assessment (RA) and mitigation design. Contains basic technical advice on the design of gas-protection measures for new buildings on land affected by hazardous gases such as methane.	Not covered explicitly.
2	Ventilation Principles and Designing for Natural Ventilation, Code of Practice, BS 5925:1991	British Standards Institution (BSi)	1991	Standard		This British Standard gives recommendations on the principles which should be observed when designing for the natural ventilation of buildings for human occupation.	Not covered explicitly.

[1] Includes relevant notes from CLR11, 2004

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
3	Methane: Its occurrence and hazards in construction, R130	CIRIA	1993	Guidance		Methane properties, sources, hazards and migration. Reviews all aspects of methane generation and associated hazards, including factors relevant to methane generation and migration, and circumstances in which methane may present a threat to the built environment.	Focus on methane but other gases inc. CO_2 considered. Landfill primary focus but coal mining areas considered.
4	The measurement of methane and other gases from the ground, R131	CIRIA	1995	Guidance	Reference source but largely superseded by later guidance.	Measurement and monitoring methods	Focus on methane but other gases inc. CO_2 considered. Landfill primary focus but coal
5	Protecting development from methane, R149	CIRIA	1995	Guidance		Mitigation design methods. Contains similar but more detailed advice than BRE 212. Includes case studies of practical design measures in different applications. Provides a categorisation scheme for sites that have different gassing regimes.	

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
6	Methane investigation strategies, R150	CIRIA	1995	Guidance		Site investigation and monitoring methods	mining areas considered.
7	Interpreting measurements of gas in the ground, R151	CIRIA	1995	Guidance		Ground gas investigation and assessment. Includes advice on the interpretation of results of ground gas investigations, including the effect of factors as temperature and pressure, fluctuating groundwater levels, etc.	

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
8	Risk assessment for methane and other gases from the ground, R152	CIRIA	1995	Guidance	Reference source but largely superseded by later guidance.	Ground gas RA. Sets out a risk assessment procedure that incorporates both qualitative and quantitative assessment techniques. The quantitative methodology uses fault-tree analysis to predict the probability of an unacceptable outcome (such as an explosion) by assigning probabilities to various components of the source–pathway–receptor relationship (e.g., the potential for gas generation and/or migration, failure of a membrane, presence of an ignition source, etc.).	Focus on methane but other gases inc. CO_2 considered. Landfill primary focus but coal mining areas considered.

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
9	Methane and other gases from disused coal mines: the planning response. Technical Report	Dept. of Environment	1996	Technical report	No longer available	Aimed at identifying a suitable planning response to reduce mine gas emission risks in respect of new development, without placing unnecessary constraints on land use. The principal objective was to provide advice suitable for use by planners, developers, land and property owners, insurers and others.	The study has relevance to the detection, investigation and treatment of mine gas emissions affecting existing development.
10	Passive Venting of Soil Gases Beneath Buildings: Volume 1 (Guide for Design) and Volume 2 (Computational Fluid Dynamics Modelling: Example Output)	Dept. of Environment, Transport and the Regions (DETR)	1997	Technical bulletin	Reference source but largely superseded by later guidance.	Mitigation design. Sets out a methodology to assess the risks to buildings posed by soil gases, and to design appropriate passive gas venting measures.	Referred to as a source, but not covered explicitly.

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
11	Gas protection measures for buildings. Methodology for the quantitative design of gas dispersal layers. Proceedings of the Fifth International Conference – Polluted and Marginal Land	Owen, R. and Paul, V.	1998	Published paper	No longer available, but referenced in other guidance.	Mitigation design	Not known as no longer available.
12	Reliability and risk in gas protection design, Ground Engineering, February 1999 and Ground Engineering News Section of Ground Engineering, March 1999 (this contains points of clarification that must be read in conjunction with the February paper)	Wilson, S. A. and Card, G. B.	February / March 1999	Published paper	No longer available, but referenced in other guidance.	Mitigation design, building on CIRIA report R149	Not known as no longer available.

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
13	Protective measures for housing on gas-contaminated land, BRE 414	BRE	2001	Guidance	Reference sources but largely superseded by later guidance.	Mitigation design. A practical guide to good practice for the detailing and the construction of passive soil gas protective measures for new and existing residential development. It does not contain advice on the design of passive or active protective measures for specific gas regimes, nor does it provide information on active gas protective systems or external in-ground protective measures.	Includes methane and carbon dioxide from sources including coal measures and/or underground mine workings.
14	Model Procedures for the Management of Contaminated Land. Contaminated Land Report Number 11 (CLR11)	Environment Agency	2004	Guidance	Reference	Overarching guidance on assessment and remediation of land contamination.	Includes consideration of ground gas sources but not specifically mine gas.

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
15	Assessing risks posed by hazardous ground gases to buildings, C665	CIRIA	2007	Guidance	Reference	Good practice guidance covering methods of investigation, the adequacy of monitoring, the methods of risk assessment and the selection of options for remediation.	Includes methane and carbon dioxide from sources including coal measures and/or underground mine workings.
16	Guidance on Evaluation of Development Proposals on Sites where Methane and Carbon Dioxide are Present	NHBC	2007	Guidance	Current but due to be updated in 2019.	Good practice guidance covering methods of investigation, adequacy of monitoring, risk assessment and suitable design of protection measures for residential developments. Developed NHBC 'traffic light' risk assessment approach for low rise housing.	Covers methane and carbon dioxide only, including mine gas related sources.

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
17	The Local Authority Guide to Ground Gas	Chartered Institute of Environmental Health	2008	Guidance	Current. This is being updated with interim issue of Ground Gas Information Sheets by EPG.	This document provides practical guidance for Environmental Health, Contaminated Land and Building Control Officers along with others who need to undertake, manage or review ground gas assessments and design appropriate protection measures.	Yes, covered explicitly.
18	The VOC Handbook. Investigation, Assessing and Managing Risks from Inhalation of VOCs at Land Affected by Contamination, C682	CIRIA	2009	Guidance	Current	Good practice guidance on the investigation, assessment and remediation of risks associated with VOCs.	Limited to VOCs which may be present within mine gas.

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
19	A Pragmatic Approach to Ground Gas Risk Assessment. CL:AIRE Research Bulletin RB17	CL:AIRE	2012	Technical bulletin	Current	This Research Bulletin proposes a pragmatic approach to ground gas assessment for low risk sites using data that can be collected quickly and at low cost.	Not intended for sites affected by mine gas sources.
20	BS8576:2013. Guidance on investigations for ground gas – permanent gases and volatile organic compounds (VOCs).	BSi	2013	British Standard	Current. BSI committee EH4 reviewed whether BS8576 required revision earlier in 2018 and decided that it was not necessary at present. The next review will be c. 2023.	Good practice guidance covering site investigation and monitoring methods for ground gases and volatile organic compounds (VOCs), with particular reference to development sites and the risks posed by gassing sites to neighbouring land and developments.	Covers methane and carbon dioxide, including from mine gas sources.

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
21	Good practice on the testing and verification of protection systems for buildings against hazardous ground gases, C735	CIRIA	2014	Guidance	Current	Good practice guidance for the designer, installer, verifier and regulator on the verification and integrity testing of gas protection systems.	Not covered explicitly but is applicable to sites affected by mine gas sources.
22	Radon: Guidance on protective measures for new buildings, BR211	BRE	2015	Guidance	Current	Mitigation design. This report gives guidance for reducing the concentration of radon in new buildings, extensions, conversions and refurbishment projects to reduce the risk to occupants of exposure to radon.	Limited to radon which may be present within mine gas.
23	The utility of continuous monitoring in the detection and prediction of worst-case ground gas concentration, RB13	CL:AIRE	2011	Technical bulletin	Current	Ground gas RA. Technical bulletin that aims to show how the impact of temporal variability in gas concentrations and flow and uncertainties can be reduced by continuous monitoring, thereby reducing uncertainties in ground-gas risk assessment.	Incudes an example case study for old mine-workings.

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
24	Remediating and mitigating risks from VOC vapours from land affected by contamination, C716	CIRIA	2012	Guidance	Current	Good practice guidance covering remediation and risk mitigation for VOCs.	Limited to VOCs which may be present within mine gas.
25	Guidance on Managing the Risk of Hazardous Gases when Drilling or Piling Near Coal	Coal Authority, HSE and others	2012	Guidance	Current	This document is stated to be designed and published in order to provide guidance with respect to hazardous gases for the safe drilling and piling through Coal Measures up to a maximum depth of 200m.	Yes. Gases considered include methane, hydrogen sulphide, carbon dioxide and carbon monoxide but also less common gases such as hydrogen. It also includes oxygen deficient air.

26	BS8485 Code of practice for the design of protective measures for methane and carbon dioxide ground gases for new buildings	BSi	2015	British Standard	Originally published in 2007 and fully updated in 2015. Under review. A1 2019 currently in prep.	Code of practice covering gas risk assessment and mitigation design. It is intended to be used by designers of gas protection measures and by regulators involved in the assessment of design solutions. It recognizes that there are a number of factors requiring consideration which affect the sensitivity of a development to the effects of ground gas, and that there is a range of design solutions available for different situations. The framework, developed in line with CLR11, provides designers with information about what is needed for an adequate ground gas site investigation. It also provides an approach to determine appropriate ground gas parameters that can be used to identify a range of possible design solutions for protection against the presence of methane and carbon dioxide on a development	Yes. Both mine workings and mine gas sources and pathways are considered

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
						site. The framework is not prescriptive, and professional judgement may be made as to the acceptability of risk and whether there might be benefit in undertaking a more rigorous site assessment or adopting conservative measures in design. Emphasis is placed on the justification and recording of risk assessments and design decisions throughout the process.	

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
27	User Guide for the BGS methane and carbon dioxide from natural sources and coal mining dataset for Great Britain, Open Report OR/11/054	British Geological Survey (BGS)	2011	Guidance	Current	This report presents a description and review of the methodology developed by BGS to produce an assessment of the potential hazards from methane and carbon dioxide from natural sources and coal mining. The purpose is to enable those licensing this dataset to have a better appreciation of how the dataset has been created and therefore a better understanding of the potential applications and limitations that the dataset may have.	Yes
28	Risk based approach to development management: Guidance for developers	Coal Authority	2017	Policy document	Current. Next revision scheduled for December 2018	Presents a risk-based approach developed by the Coal Authority for safe development in former coal mining areas and consultations required.	Yes

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
29	Piled foundations and pathways for ground gas migration	Wilson, S., Mortimer, S., Journal of Environmental Geotechnics	November 2017	Published paper	Reference	This paper discusses the different types of pile construction and considers how they may or may not influence gas migration.	Not specifically but applicable to assessment of mine gas.
30	Complete Continuous Monitoring in Underfloor Voids, TB16	CL:AIRE	December 2017	Technical bulletin	Current	This bulletin explains a best practice approach using complete continuous monitoring to assess the performance of ventilated voids.	Not specifically but applicable to assessment of mine gas.
31	Ground Gas Monitoring and 'Worst-Case' Conditions, Technical Bulletin TB17	CL:AIRE	2018	Technical bulletin	Current	Guidance on critical barometric pressure conditions that influence gas monitoring results and provides a framework to risk assessors to determine when they have sufficient gas monitoring data to evaluate risks with confidence.	Not specifically but applicable to assessment of mine gas.

Item No.	Title/Report No.	Author/ Publisher	Publication Date	Type	Status	Summary of scope of guidance[1]	Applicability to mine gas?
32	Retro-fitting of gas protection measures, CIRIA report TBC	CIRIA	TBC	Guidance	In prep.	New research project commencing late 2018/early 2019.	Not specifically but applicable to assessment of mine gas.

Annex 3 – Stakeholder Engagement

(a) Issues Log

Table of issues logged from stakeholder engagement meeting on 8th November 2018 and external responses received from Local Authorities.

Issue Number	Category	Perceived Issue
1	Construction techniques	"The Building Regulations are only the minimum standard the public would expect in terms of gas mitigation matters."
2	Construction techniques	Concern that the methodology within the building/construction documents is no longer appropriate given the situation that occurred at Gorebridge.
3	Construction techniques	Building Standards practitioner noted that they were not comfortable in commenting on the appropriateness of current standards and guidance and suggested that perhaps further research is now required.
4	Construction techniques	"The construction industry will always work to the minimum building standards" LA stakeholder concerned if these standards were appropriate in this area.
5	Other	"We have a range of discussion groups and formal forums within the environmental health groups (which would discuss mine gasses). These would not include the Building Standards department. So, there are no formal multidepartment discussions covering mine gas risk."
6	Other	"The subject matter under discussion today (mine gas) is not one that's regularly brought up or discussed within stakeholder groups i.e. LABSS." Suggestion there was no forum for discussions between Building Standards, Planning and EH.

Issue Number	Category	Perceived Issue
7	Risk assessment	“The guidance in this (gas risk) area is so specialised that a local authority verifier would tend to get risk assessments peer reviewed/ externally reviewed”.
8	Construction techniques	“It is fair to say that building regulations are not prescriptive, they are functional standards which set the intention for the mandatory standard and then point towards the guidance documents which sit beneath these.” Issue - Building standards departments can only require the developers to look to the standards and guidance documents. They cannot request additional mitigation if this is not detailed in the standards and guidance.
9	Construction techniques	“Prescriptive standards would restrict development.” The Stakeholder noted that while a more prescriptive standard would assist with mine gas risk, it may also prevent development in these areas.
10	Risk assessment	Discussed local authority oversight and understanding of the issues. It was noted that the specialised guidance in this area is outside the expertise of LA staff: “Ground gas risk and fire risk assessments are generally sent for external peer review.”
11	Risk assessment	Noted that budgets and availability can be an issue when reviewing risk assessments. Consensus that within the individual authorities there is a varied approach in terms of the management and available budget to carry out reviews.
12	Risk assessment	“Fundamental issue that there is no clear guidance on what unsafe levels of CO2 in properties.”

Issue Number	Category	Perceived Issue
13	Mitigation measure	“It’s not sustainable to just demolish affected properties.” Noted that research may be required to test remediation of existing properties. Comments that insurance companies and the Coal Authority require certainty that measures will work and protect the occupants.
14	Construction techniques	“There has been other contaminated land (not building standards) issues where there has been changes in guidance down south that the Scottish Government has chosen not to pick up on.” Concern that best practice developed in England is not being applied here.
15	Other	“I don’t see this as just a building control issue. It’s multi agency. The problem is the system in which we work and the way we interact within departments.” Issue raised that responsibility on gas risk lies between separate departments within the LAs which makes it more difficult to ensure that developers are taking gas risk into account.
16	Construction techniques	“There have been instances where individual local authorities have tried to instigate their own guidance to suit specific conditions within their area. National developers come along, and it turns into a scrap over whether the local authority has the authority to add additional measures.” Perceived issue is that LAs don’t have the power to request any more that the minimum required by standards and guidance.

Issue Number	Category	Perceived Issue
18	Other	“As a contaminated land specialist, if I say at the planning stage there should be a membrane in there, and down the line during the building standards verification they discover there’s no membrane included, it’s often too late to flag this up.” It was noted that planning consent requirements are being edited or scaled back during the planning process without reference back to the contaminated land specialists.
19	Other	Comments from other local authorities about developments going ahead before mitigation is signed off and approved. Noted that risk assessment/mitigation comes late in the development process and properties are already built before these are reviewed. Concern that developments are built and occupied without suitable mitigation of the risks. “There are some issues, but it’s difficult for us to discuss these openly as no one wants to shame their own local authority when something goes wrong.”
20	Other	“Some developers will push the system and work within the existing frameworks to see what they can get away with.” Concern raised about the capacity of LAs to require sufficient gas monitoring.
21	Construction techniques	“Concrete slab with no ventilation beneath is perhaps part of the issue.” LA response to the IMT question relating to traditional ventilated solum.

Issue Number	Category	Perceived Issue
22	Energy efficiency	LA response to the IMT question relating to energy efficiency–concern over poor ventilation within modern properties. "There is also an issue with houses becoming more air tight. We have got to the point where we are specifying CO_2 monitors in bedrooms."
23	Energy efficiency	LA response to the IMT question relating to energy efficiency–concern over poor ventilation within modern properties. "Airtight houses would appear to be a contributory factor in CO_2 issues."
24	Energy efficiency	LA response to the IMT question relating to energy efficiency–concern over airtightness/lack of ventilation. "Agree it is a fundamental problem at the moment."
25	Energy efficiency	LA response to the IMT question relating to energy efficiency–concern over airtightness/lack of ventilation "Lack of recognition in the industry that proper ventilation/air infiltration within a property is an important factor".
26	Energy efficiency/ construction techniques	Issue raised that stakeholder has seen "new build properties coming in under the designed air tightness value." Raised concerns over higher risk from mine gas related to new build properties compared with older properties.
27	Energy efficiency/ construction techniques	Stakeholder raised issue with the chimney effect within an airtight property. "If you crack the bedroom window open you create this natural draught, which in older properties would have drawn air up from the solum, but in new properties may just draw in any mine gases trapped under the unventilated concrete slab."

Issue Number	Category	Perceived Issue
28	Energy efficiency	Stakeholder raised issue in ventilation and air circulation standards/models. "Air circulation estimates can vary from what was used in the ventilation design model. Some people will not open windows, some properties will be fully occupied throughout the day."
29	Energy efficiency	Stakeholder raised issue with the chimney effect within an airtight property. Negative pressures creating "a chimney effect with CO_2 coming through the service ducts."
30	Other	Stakeholder discussed response to research project request for previous incidents/info on concerns raised over CO_2. They stated that "it would likely be via the GP's/NHS board rather than a complaint put to a council planning/ environment department".
31	Risk assessment	Stakeholders in LA noted that council contaminated land specialists are comfortable with risk assessment reviews from landfill, but with mine gas it is not their area of expertise.
32	Risk assessment	Comment from contaminated land specialist on lack of guidance/ understanding of the pathways: "We need more research on how this is happening/what are the pathways we need to look out for?"
33	Risk assessment	Comment from contaminated land specialist on lack of guidance/ understanding of the pathways. Stakeholder raised example of landfill over mining area: "how do you monitor how much CO_2 comes from landfill compared to how much comes from mines without very expensive lab tests?"

Issue Number	Category	Perceived Issue
34	Mitigation measure	Stakeholder discussed retrofit mitigation of radon sumps. They raised the issue that, “this goes against the current regulations as it is an active ventilation system in a dwelling,” adding that if fitted it may be acceptable if the property is “managed” i.e. a housing association.
35	Mitigation measure	Discussed retrofit mitigation and active ventilation: “There is similar technology available for schools to monitor CO_2 and ensure forced ventilation, but for domestic properties the equipment is just not available”.
36	Mitigation measure	Stakeholder discussed similarities/ differences with CO_2 vs radon. “Radon is a low-level bleed. With CO_2 there could be a low-pressure weather event. So you need research to prove that this (radon) system could cope with a large volume CO_2 spike”
37	Mitigation measure	Would radon sumps be an appropriate solution for CO_2? “If there is any suggestion of firedamp then an electric fan is not the way to go.” “Installation (retrofit active measures) would need to come back to a precautionary risk assessment.”
38	Mitigation measure/ risk assessment	Stakeholder discussing developers trying to reduce costs on gas mitigation/fitting membranes. During site zoning “a developer was pushing for certain areas within a site to not require mitigation, when in fact they whole area has the same underlying structure/strata, but gas monitoring was only carried out in one area.” Stakeholder noted that risks due to the very oldest shallow mine workings are unknown: “As they are very old, there are no records, so you just don’t know what’s down there.”

Issue Number	Category	Perceived Issue
39	Mitigation measure	Stakeholder comments on gas membranes: “fine if installed correctly.” But would be against them being used as “mandatory mitigation” as stakeholder perceived this would provide the developers with a reason not to carry out a proper gas risk assessment.
40	Mitigation measure	Stakeholder comments on gas membranes: “quality of installation is an issue, the expectation these will be fitted well and validated is variable.” “Some developers will get in expert installation contractor, but some will leave it to any general labourer to install a gas membrane.”
41	Mitigation measure	Stakeholder comments on gas membranes: “Verification after fitting is difficult.”
42	Mitigation measure	Stakeholder comments/concern on gas membranes and the resource available to check/verify these. “On the verification, are these requirements going to be pushed onto already stretched building standards departments?”
43	Mitigation measure	Stakeholder comments/concern on gas membrane protection: “When a membrane is fitted are the homeowners made aware of this? Will they be advised not to drill or cut the membrane?”
44	Risk assessment	Stakeholder comments on risk assessments received within their local authority: “Some are really good/ some are barely acceptable. Very variable.”

Issue Number	Category	Perceived Issue
45	Risk assessment	Stakeholder comments on risk assessments received within their local authority: “Some come in too late, if you already have the walls going up, the information provided may not allow the council to make the correct decision.”
46	Risk assessment	Stakeholder comments on risk assessments received within their local authority: “the developer provides the minimum standard in terms of risk assessment and monitoring, and the council cannot send it back because that would be unreasonable.”
46	Risk assessment	Stakeholder raised additional concern relating to the issue of CO_2 being generated in developments where peat or colliery spoil may be present. “This is not mentioned in the IMT report.”
47	Risk assessment	Stakeholders commented that the situation requires “long-term monitoring encompassing a wide range of environmental events and application of continuous monitoring techniques as a more standard approach to robustly characterising ground gas conditions in such areas.”
48	Risk assessment/ mandatory mitigation	Concern was raised that any minimum mandatory CO_2 ground gas protection may be unnecessary in some coal reporting areas. Noted that it should not be applied in place of a robust risk assessment. Also, any minimum ground gas protection may not be sufficiently protective.
49	Risk assessment	Stakeholder noted, “There is adequate guidance available on the ground gas risk assessment process. However, it is rare to review a report that understands that the conceptual site model should be considered in the ground gas investigation strategy, risk assessment and protection, system design.”

Issue Number	Category	Perceived Issue
50	Risk assessment	Stakeholder commented that the “gas risk assessment process is probably adequate, but I would suggest it is being wrongly applied.” “Under the development system, time and money is often a critical factor and risk assessments aren't being carried out properly and monitoring is often a hit and miss.” “It may be that developers do not understand the time taken to adequately assess ground gas regimes” and/or are “not willing to pay” and/or “the consultants employed are not experienced enough to undertake such monitoring.”
51	Risk assessment	Stakeholder comment/concern on risk assessments was that “the current risk assessment tends only consider current conditions under Part IIA/PAN33.” They stated that, “quite often future development plans are unknown at the site investigation stage, the consultant doesn't know e.g. finished ground levels, building/foundation designs etc.” Concern that the site conceptual model cannot take adjacent sites or foundation design into account.

Issue Number	Category	Perceived Issue
52	Risk assessment	Concern raised that larger sites can be developed by different companies with different consultants. Quite often information not passed on/shared, details overlooked, sites sold, etc. The stakeholder noted that these “details” may be flagged up by the regulator (if involved), but generally different officers within the regulatory system can deal with various planning applications and this can lead to things being overlooked.
53	Risk assessment/ mitigation measures	Gas Risk/Mitigation comment: “no holistic approach to either on-site proposals or off-site in the adjacent or wider area.”
54	Risk assessment	LA stakeholder noted that a significant proportion of CSMs (submitted via planning/building standards) fail to provide sufficient level of detail in regard of the potential pollutant linkage (PPL) associated with mine gas.
55	Risk assessment	LA stakeholder noted that data gaps and uncertainties in the conceptual site model is common in reports submitted to local authorities.
56	Risk assessment	LA stakeholder noted that as per issue above the sampling duration needs to be consistent with the conceptual site model, the exposure mechanism(s) and possible temporal/environmental effects. This is not always covered in the reports we receive.
57	Risk assessment	LA stakeholder noted that “some ground gas risk assessments fail to consider mine gas issues as highlighted by CIRA Report 149.”

Issue Number	Category	Perceived Issue
58	Risk assessment	LA stakeholder noted the potential for other interventions affecting the soils to alter the risk of mine gas migration and consequently to render any pre-development assessment redundant. Stakeholder commented that research/guidance was required: “I do not believe there are other significant literature sources for the risk assessor to seek guidance on such issues.”
59	Mitigation measure	Comment on gas membrane suitability as protection measure. “It is easy to fit ground gas protection badly. Good integrity across the whole floor area in average weather conditions on a building site is difficult to achieve, and few installers are suitably trained.” “Even at the design stage, mistakes are made relating to the specification of gas protection because this is new for many house builders.”
60	Mitigation measure	Comment from stakeholder on gas protection design suitability. “Gas protection systems have to remain effective for the lifetime of the building. I have seen proposals for gas vent trenches and drain-like air vents that would become clogged or covered up with a plant pot within a few years of construction.”
61	Mitigation measure	Comment from stakeholder on gas membranes. “They have to survive the installation process, which means every worker on site needs to understand the importance of their continued integrity.” “Examples of accidental subsequent penetration of membranes are commonplace.”

Issue Number	Category	Perceived Issue
62	Mitigation measure	Comment from LA building standards inspector on quality of verification reporting. “I am one of a very small number of people in Scotland who has attended the CL:AIRE Membrane Verification course in Doncaster. As a result, I am in the uncomfortable position of being unable to accept at face value any verification reporting I have reviewed (visual/photographic inspection is no verification at all).”
63	Risk assessment	Concern raised related to gas monitoring and that any discrete monitoring rounds may miss significant changes in the atmospheric conditions. The stakeholder commented that, “It is my feeling that worst-case conditions may only occur every three to five years and monitoring for this is impractical.” Their view was that a suitable conceptual site model is the best tool.
64	Risk assessment/ construction techniques	Stakeholder commented that, “One thing that is rarely done properly on site is the decommissioning of existing site-investigation boreholes. This risks leaving a preferential pathway for ground gas.”
65	Risk assessment/ construction techniques	Stakeholder commented that local authority contaminated land staff are not necessarily qualified to understand foundation design drawings. Care and collaboration required with our colleagues in building standards to ensure submitted drawings show the correct details. Stakeholder noted that “Builders or their agents often submit drawings that do not conform to the remedial action.”
66	Risk assessment	Stakeholder raised concern on lack of research/guidance on groundwater rebound. Similar issue with climate change generally.

Issue Number	Category	Perceived Issue
67	Other	Stakeholder commented that, “we have uncovered a situation in Gorebridge by unhappy accident.” Concern was to what extent might this problem affect other mining areas?
68	Risk assessment	Stakeholder comment on risk assessments was that, “there are representatives of other councils who have nobody in posts within contaminated land that are qualified enough to understand whether these reports are good enough or not.”
69	Risk assessment	Stakeholder comment on gas risk Assessment: “We deal with the difficult ones and ones that are needed to be done quickly in house, but the sheer volume of work is immense.”
70	Risk assessment	Stakeholder comment on gas risk assessment: “We get a variable quality in reports that come in (some good, some awful). Smaller developers and smaller consultants aren’t willing to do the extra work or don’t have the experience.”
71	Risk assessment	LA stakeholder commented that small developments don’t understand the process leading to many delays in their developments leading to increased costs.
72	Risk assessment	LA stakeholder commented that, “I think there should be planning officers here (at workshop) and not building standards officers because that’s the first line of defence. It’s planning applications that give the planning conditions for SI, remediation, everything else. By the time it gets to Building Standards, it’s too late.”
73	Risk assessment	LA stakeholder commented that if the risk assessment/mitigation is not appropriate it may not get picked up at planning "permitted stage". Once Building Standards pick up on this it is too late.

Issue Number	Category	Perceived Issue
74	Risk assessment	LA stakeholder comment on risk assessments: “The reports not as good as they can be, but they’ve improved over the years.”
75	Risk assessment/ mitigation measure	Concern raised on extensions. Attendee mentioned they were aware of two large councils in coal mining areas where they have stopped consulting on extensions because they do not have the time.
76	Mitigation measure	Concern raised on extensions: “Quite often there won’t be planning permission required, so the first stop in identifying there is a problem is building standards and we get all the hassle.”
77	Mitigation measure	Comment that the overall trend is a drop in standards. “In the future, more buildings will not need planning and there’s an indication that some work might not need a building warrant in the future. That might be a problem if there are no checks at all.”
78	Other	“The key role of a planning department is to determine if the ground in that proposed area is suitable for proposed future use. I don’t think that always happens. There’s some land you probably just shouldn’t build on.” Stakeholder noted that, “Planning permission is given in some areas it shouldn’t be.”
79	Other	Concern raised on gas risk was that the planning authority need to appropriately condition a development. This is quite important, and it depends a lot on the experience of the individual planner.
80	Risk assessment	Comment on gas risk assessments. “We get a distinct variation in the quality of information that is submitted to us. Some can be appallingly bad.”

Issue Number	Category	Perceived Issue
81	Risk assessment	Comment on gas risk assessments from LA stakeholder: “Within the last six months we had a housing developer submit a report which had less than 10% of the gas monitoring required. That’s a significant failing.”
82	Risk assessment	Comment from LA stakeholder that they get developers stating they will install a membrane on all properties to avoid carrying out gas monitoring and a conceptual model. The LA stated that “We tell them you still have to do your monitoring, risk assessment and conceptual site modelling, because a membrane might not be enough.”
83	Risk assessment/ mitigation measure	Comment from LA, “there is the assumption that when developers agree to put in gas protection measures, they think that is enough, and they don’t have to gas monitoring and do validation and verification.”
84	Mitigation measure	There is a legacy issue relating to all the houses and hundreds of sites where verifications were expected or where membranes were fitted, but LAs have never received a report. Several sites where membranes were required have no evidence that the membranes were fitted.
85	Mitigation measure	Developers have an expectation that membrane verification is to be completed over a very short time period.
86	Other	Both communications between departments and the quality of responses from developers needs to be improved.
87	Construction techniques	Site investigation boreholes are a potential pathway if they are not decommissioned and they are routinely lost on site.

Issue Number	Category	Perceived Issue
88	Mitigation measure/ risk assessment	Mitigation measures are frequently inadequately designed for the long-term especially when the risk assessment does not cover an extended time period.
89	Mitigation measure	Ventilation design for vents and trenches needs to be checked as these can become blocked or filled over long timescales. This should be compared with the lifespan of the property.
90	Mitigation measure	Ground gas ventilation measures are not notified to homeowners. A consequence of this is that vents are becoming blocked. There is a lack of notification because brokers do not want to advertise that a property may have a ground gas issue.
91	Mitigation measure	Homeowners require notification of mitigation measures such as vents so that they can be maintained and kept clear. A housing association might be able to enforce this, but other organisations may be limited.
92	Mandatory mitigation	The implementation of a mandatory membrane is good in practice but ensuring installation and verification procedures could prove difficult.
93	Mandatory mitigation	Creating rules that make installation of gas membranes mandatory is dangerous because it creates an expectation that this is sufficient for the risk. There is a large variety in sites and some may require a much higher level of assessment and mitigation.
94	Risk assessment	Extremely important that your initial risk assessment is accurate because it supports monitoring, further assessment and mitigation implanted afterwards.
95	Risk assessment	Gas risk assessments are highly variable, and many monitoring timeframes are too short.

Issue Number	Category	Perceived Issue
96	Risk assessment	Some consultants will just conduct six weeks of monitoring. However, this is not necessarily enough time. Occasionally there will be evidence of three or four incidents of spot monitoring. This is unlikely to be robust enough and continuous monitoring should be considered.
97	Risk assessment	There are issues that consultants are not conducting monitoring correctly. They report that monitoring is complete; however, according to the reports the data is insufficient e.g. three of their six boreholes are flooded for most of the monitoring time, or they couldn't find a borehole.
98	Risk assessment	On occasion, developers have submitted plans for monitoring which are artificially low knowing that they are substandard.
99	Risk assessment	There is no nationwide limit or threshold for CO_2. A threshold may help to determine the outcome of a risk assessment or mitigation measures.
100	Mitigation measure	The verification of mitigation measures is non-existent (particularly with regards to membranes).
101	Mandatory mitigation	There are no mandatory mitigation measures in our LA.
102	Mitigation measure	As a method of mitigation, a membrane is limited in the current building standards.
103	Other	Building standards and planning teams within LAs rarely meet to understand the requirements of a development.
104	Risk assessment	Focus of coal mine risk is mainly towards structural issues rather than that of mine gas.
105	Risk assessment	Information from the CA is relied upon to inform planning decisions and frequently this is lacking detail.

Issue Number	Category	Perceived Issue
106	Risk assessment	There is an education gap in councils and LAs, personnel are not experienced enough to scrutinise planning and/or risk assessments
107	Risk assessment	CA may not have a monitoring point or previous gas incident in an area, but that does not mean there is no risk from mine gas (this issue must be iterated in consultants mining reports).
108	Risk assessment	CA data is limited to what currently exists and what is currently reported. More data is required to support consultants reports and ultimately risk assessments.
109	Risk assessment	Mining reports requested from the CA frequently state there is 'no record of mine gas,' but the report does not clarify this statement. ‘No record’ does not necessarily mean that there is no mine gas risk.
110	Risk assessment	CA does not have enough personnel to deal with the issues surrounding mine gas.
111	Risk assessment	CA does not have enough gas monitoring and groundwater monitoring points to support a robust risk assessment.
112	Risk assessment	CA coal mine maps are not detailed enough to understand the gas risk and to generate a robust conceptual model.
113	Risk assessment	The results from consultant’s reports related to mine gas risk are not joined up to the developers plans (for mitigation).
114	Construction techniques	There is currently testing on properties for noise and tightness, but there is no verification in building standards for the verification of mitigation measures.
115	Risk assessment	There are currently no specific personnel within an LA that are prepared to deal with mine gas risk. The issue tends to fall to contaminated land personnel.

Issue Number	Category	Perceived Issue
116	Risk assessment	Mine gas risk is given enough emphasis in the planning permission.
117	Risk assessment	There is a lack of knowledgeable people within local authorities/ councils to understand the mine gas risk assessments.
118	Risk assessment	Mine gas risk is transient, and the monitoring process will not always pick up the environmental changes.
119	Risk assessment	Gas flow paths are likely to be changed or altered by further developments.
120	Risk assessment	Risk assessments are reviewed by EHO or contaminated land officers that may lack experience to correctly scrutinise the data.
121	Risk assessment	There has been loss of experience for councils. Former mine surveyors and other personnel have moved on or to other departments.
122	Mitigation measure	Generally, the CA's primary mitigation technique was to demolish a property after a gas 'event'.
123	Mitigation measure	The developer is not incumbent to check whether the services installation is likely to puncture a membrane (disrupt any mitigation measure in place). A check of the services installation and how this matches up to the mitigation that is installed is required.
124	Risk assessment	CA mining reports rarely have enough information about mine gas issues.
125	Risk assessment	The risk assessment is not future proof (not incorporating environmental change).
126	Risk assessment	Changing environmental conditions are not considered in the risk assessment: climate change, water levels, atmospheric pressure changes.

Issue Number	Category	Perceived Issue
127	Risk assessment	The risk assessment process is not incorrect, but it is implemented incorrectly, either at the wrong time or for wrong duration.
128	Risk assessment	There is significant time pressure on the consultant to monitor for ground gas when it should be conducted over a longer period over periods of lower pressure.
129	Risk assessment	There is not enough information provided to LAs on the change in ground conditions e.g. site scrape, piling etc. For developments with lengthy development timelines, the conditions are likely to change to adjacent properties.
130	Risk assessment	There is no monitoring implemented for smaller properties or extensions.
131	Mitigation measure	The risk assessment relies on the developer to correctly implement the correct gas mitigation measures, and these are not always checked.
132	Risk assessment	It is possible that mine gas issues are only picked up when there is a large event like Gorebridge.
133	Risk assessment	Is the current gas risk assessment considering the cost-benefit of demolition as a mitigation method?
134	Risk assessment	The CA is a ‘reactive’ organisation. This is not the preferred stance for mine gas issues, but more financial support is required if the CA is to provide additional support in this field.
135	Risk assessment	The CA does not have enough resources to support mine gas monitoring and assessment.
136	Risk assessment	There is no repository for ground gas data that the CA holds which the LAs can access. All the information comes from the CA reports or information 'on request'. No monitoring data is readily available.

Issue Number	Category	Perceived Issue
137	Risk assessment	Often the development has already begun before all the gas risk information has been compiled. This prevents the LA assigning certain mitigation measures because they do not have all the information available to make an informed decision.
138	Risk assessment	An LA is unable to rectify deficiencies in a development (such as installing a membrane) if gaps are found within the risk assessment or building plans once construction has started.
139	Risk assessment	There is a conflict between site investigation (SI) reports and council requirements e.g. an SI is undertaken, and the conclusion is that no membrane is required. The council suggests a membrane is required, but once this detail has been raised there is a disagreement as to which choice of membrane based on limited information available/collected.
140	Mandatory mitigation	There is frequently a conflict between the developer's choice of mitigation and what the council believe is required. However, there is not enough information to support a particular type or standard of membrane.
141	Mitigation measure	There is no robust verification process of the mitigation measures or who is taking responsibility for it and who is undertaking the work.
142	Risk assessment	Information regarding ground gas is frequently submitted too late in the planning process. Any changes, therefore, cannot be implemented.
143	Risk assessment	LAs struggle to enforce gas monitoring in advance i.e. before planning applications/development plans are submitted.
144	Risk assessment	The gas risk assessment needs to include parameters such as: climate change, future environmental scenarios, groundwater levels etc.

Issue Number	Category	Perceived Issue
145	Risk assessment	Consultants need to utilise and implement the guidance that is available. Currently work that is conducted is substandard.
146	Risk assessment	Cumulative effects not being taken into account in the gas risk assessment.
147	Risk assessment	Adjacent develops are generally not considered in the risk assessment.
148	Risk assessment	Mine gas risk areas need to be identified at the LA planning stage. Frequently there is not enough pre-emptive work completed at the front end of the planning system.
149	Risk assessment	There is not enough awareness in LAs relating to ground gas risk.
150	Risk assessment	The risk assessment does not extend to incorporate ground design and the effect of disturbance, piling, etc.
151	Risk assessment	Gas monitoring should be completed post ground stabilisation.
152	Risk assessment	CA has no repository of information to be accessed by LAs. The data the CA holds is limited and mainly only available upon the request of the consultants mining report.
153	Risk assessment	CA monitoring is more general rather than site-specific. The consultant reports issued rarely help to define the site-specific gas risk.
154	Risk assessment	Groundwater data is not available on a site-by-site basis. However, this is because there is not a borehole or gas monitoring point nearby.
155	Risk assessment	CA monitoring data is mainly only available on request.
156	Risk assessment	Ground improvement and piling assessments are not being reviewed in relation to ground gas.
157	Construction techniques	Developers are regularly building to the minimum standards.

Issue Number	Category	Perceived Issue
158	Mitigation measure	The CA has used membranes as a gas mitigation measure, but they have raised the issue that installations have been inadequate.
159	Construction techniques	Constructing a solum is frequently easier and more reliable than a membrane as a gas mitigation measure.
160	Risk assessment	There is significant variation in the quality of reports received from consultants. Much of the work fails to meet the minimum requirement of the guidance. Additional work and evidence are often requested from applicants.
161	Risk assessment	Off-site gas migration needs to be considered as this is an area currently lacking detail. Measures used for ground stabilisation need to be delineated as these are potential pathways.
162	Other	Is the training of the professionals sufficient enough that that the chemical and physical processes that influence mine gas are fully understood?
163	Risk assessment	“Is there sufficient knowledge of the differences in composition/behaviour of mine gas vs ground gas?” More research is required into the characteristic differences between mine gas and ground gas.
164	Risk assessment	Consultants regularly include gas monitoring as part of the SI, as an assumption, which indicates a failure in the initial CSM development. Gas monitoring may ultimately be required for the site by the CSM, but the potential of mine gas might warrant more sophisticated methods such as continuous monitoring, flow monitoring or sampling for composition.

Issue Number	Category	Perceived Issue
165	Risk assessment	TB17 (CL:AIRE, 2018) is a good document but mainly refers to ground gas. The impact of sharply falling barometric pressure is potentially very significant when dealing with mine gas.
166	Risk assessment	Validation reports are frequently inadequate, and the properties are already completed or inhabited upon discovery of this information. In addition, the planning authorities do not have the resources to chase this issue.
167	Risk assessment	Concern raised about the responsibility of determining installed mitigation measures on existing adjacent developments.

Annex 3(b) Stakeholder Question responses

WS = General response collected from workshop

R= Written response sent from LA

Q1	Is the current mine gas risk assessment process adequate to correctly determine the level of risk, especially in relation to the requirements for assessing mine gas levels at sub-surface depths likely to be representative of gas migration potential from underground mine sources?
Q1WS	The results from the risk assessments process and the reports being produced are variable in quality, councils often find that small developers and smaller consultants aren't willing to do the extra work (monitoring) or don't have the experience within this area. Risk Assessments come in too late if you already have the walls going up, the information provided may not allow the council to make the correct decision. In some cases, the developer provides the minimum standard in terms of risk assessment and monitoring, and the council cannot send it back because that would be unreasonable. There needs to me more work on the understanding of the conceptual site model, the risks and pathways. Monitoring requirements are not long enough–need to cover low pressure events. There is an assumption from some developers that when they agree to put in gas protection measures, they think that will be sufficient and they don't have to do gas monitoring, validation and verification.

Q1	Is the current mine gas risk assessment process adequate to correctly determine the level of risk, especially in relation to the requirements for assessing mine gas levels at sub-surface depths likely to be representative of gas migration potential from underground mine sources?
	Concern raised regarding extensions not being risk assessed/ constructed with no requirement for building warrant. General acknowledgement when dealing with development risks that some councils have robust verification, peer review and good practice policies in place. There was also a concern about a lack of communication between planning, building standards and environmental health departments in this area. Concerns also raised regarding resourcing issues and coal mine gas expertise. Noted that colleagues from planning should be involved in this project as they are key within all of this. Noted that Council Contaminated Land specialists comfortable with risk assessments from landfill, but mine gas is not their area of expertise. We need more research/understanding on the pathways we need to look out for.
Q1R1	There is adequate guidance available on the ground gas risk assessment process (for new developments). However, it is rare to review a report that understands that the conceptual site model (for the scenario of the development and proposed foundation design) should be considered in the ground gas investigation strategy, risk assessment and protection system design. Suitable training courses for practitioners and regulators are required. Technical bulletins are required for raising awareness of mine working issues and for other significant ground gas generation sources (landfill, peat, colliery spoil, radon). Guidance/Technical bulletins on best practice for ground gas protection system design specifications (i.e. material specifications, foundation schematics etc) and how to verify their installation. More information on retrofitting of ground gas protection measures is required. Procedures for Part 11a ground gas investigations and assessing risk are required.
Q1R2	No.
Q1R3	The current mine gas risk assessment process is probably adequate, but I would suggest it is being wrongly applied. Under the redevelopment system, time and money is often a critical factor and risk assessments aren't being carried out properly and monitoring is often a hit and miss. It may be that developers do not understand the time taken to adequately assess ground gas regimes, are not willing to pay and/or the consultants employed are not experienced enough to undertake such monitoring.
Q1R4	BS 8485 notes the framework of ground gas risk assessment (i.e. CLR 11, CIRIA C665, BS 8485 etc) is not prescriptive and professional judgement is required to determine the acceptability of risk and whether there is benefit of more site assessment versus adopting conservative measures in design. Unfortunately, it is the local authority's experience that the justification and recording of risk assessment decisions throughout the process is often lacking. The key factor to determine if a mine gas risk assessment process is adequate is the appropriateness of the CSM (Conceptual Site Model). From the LA's perspective, for an

Q1	Is the current mine gas risk assessment process adequate to correctly determine the level of risk, especially in relation to the requirements for assessing mine gas levels at sub-surface depths likely to be representative of gas migration potential from underground mine sources?
	area that has been historically heavily mined (at surface and at depth), a significant proportion of CSMs (submitted via planning/building standards) fail to provide sufficient level of detail in regard of the potential pollutant linkage (PPL) associated with mine gas. In consideration of the generation potential of the source mine gas, this may represent a very low to high risk (as per BS 8576 Figure 6). However, there is often minimal detail presented within the CSM on the nature of such mine workings. In order to provide greater level of confidence in the determination of the generation potential then a detailed CSM is required. The goal to reduce the uncertainty of the CSM, is often absent in reports submitted to local authorities. It is this failure, which causes PPL's, such as mine gas, to be absent in contaminated land reporting to local authorities. The failure to address data gaps and uncertainties in the CSM is commonly overlooked in reports submitted to local authorities. The output of the ground gas risk assessment is only reliable if data, and other information (e.g. geology) about the site is sufficient in terms of quality, quantity and appropriateness (BS 8485 section 6.1). It is noteworthy that BS 8485 section 6.1 highlights that any uncertainty (from the CSM/risk assessment) should be reflected in the design of the gas protection system. Sources and pathways associated with mine gas are highlighted throughout BS 8485 and Environment Agency, Guide to Good Practice for the Development of Conceptual Models and the Selection and Application of Mathematical Models of Contaminant Transport Process in the subsurface, NC/99/38/2, section 3.4.2 and Table A1. This highlights the importance of artificial pathways, such as mine workings, within the CSM. However, reports submitted to the local authority often lack data and discussion on the pathways, e.g. the groundwater system encompassing geology, water table and unsaturated and saturated zone flow and transport. There is often a lack of acknowledgment in ground gas risk assessments that the sampling duration needs to be consistent with the CSM, the exposure mechanism(s) and possible temporal/environmental effects. Therefore, if the design of the sampling programme is flawed, then the subsequent risk assessment may not be fit-for-purpose (BS 8576 section 10.8.2.1). It appears some ground gas risk assessments fail to consider mine gas issues as highlighted by CIRA Report 149. A re-issuing/ updating of such reports may assist in raising awareness to those undertaking ground gas risk assessments. CIRA 149 section 2.5.5 succinctly notes:

Q1	Is the current mine gas risk assessment process adequate to correctly determine the level of risk, especially in relation to the requirements for assessing mine gas levels at sub-surface depths likely to be representative of gas migration potential from underground mine sources?
	The reliability of measured gas concentrations and emission rates and the uncertainty of predicting future changes is probably the greatest influence on the design and application of gas protection measures. Without detailed knowledge of the gas regime and the long-term behaviour, gas protection measures cannot be fully designed or their performance guaranteed. This is one reason which has led to the adoption of high margins of safety on gas concentrations, the over-design of gas protection measures and the adoption of control systems based on a combination of individual measures. However, it is worth noting that the standard approach of conducting spot monitoring (empirical, semi-quantitative) of sites to determine a gas screening value has a number of inherent conservative assumptions. It is based on the assumption of directly relating gas monitoring standpipe emission measurements to future gas emissions from a fixed volume of ground around the standpipe (BS 8485 section 6.2.1.1).
Q1R5	It is felt that the current risk assessment process is satisfactory with adequate notification and contact between our department and Planning. However, the quality of reports from consultants vary with a lot requiring further work due to not meeting minimum requirements as per the guidance. We often must request additional works and evidence from applicants. There is a worry that Permitted Developments and garden 'homes' may be missed from being notified to EH to consider risk factors.
Q1R6	Only if there is sufficient knowledge/expertise within the industry to undertake competent assessments.

Q2	Is the current risk assessment process fit for purpose particularly in terms of taking account of future potential changes in mine gas dynamics and migration risk factors (e.g. due to ground stabilisation measures, additional developments, etc.) that could lead to an increased risk of gas migration into properties over the long term?
Q2WS	The risk assessment should consider the potential for offsite migration of gas but doesn't always. Adjacent developments are generally not considered in the risk assessments. Where the risk assessment considers the potential migration and identifies that certain measures need to be carried out, the concern is that this may not be effectively completed where a large site is being developed in phases or by different developers. Guidance and implementation should be stronger. Difficult for cumulative effects (adjacent developments) to be processed into planning applications, would be very hard to deny a planning application based on cumulative risks.

Q2	Is the current risk assessment process fit for purpose particularly in terms of taking account of future potential changes in mine gas dynamics and migration risk factors (e.g. due to ground stabilisation measures, additional developments, etc.) that could lead to an increased risk of gas migration into properties over the long term?
Q2R1	See Response to Q1
Q2R2	No, an additional environmental cause of mine gas risk uncertainty relates to future change in precipitation associated with predicted climate change in Scotland. It is possible that climate change may cause alterations in rainfall patterns in the future; how this will be reflected in groundwater levels is currently unclear. As ex-mining areas complete their groundwater rebound phase, the relative impact of any such change will increase over time. The consequential impact of any climate change related effect on mine gas migration risk is uncertain but could act to increase the overall risk. This is therefore yet another source of uncertainty making mine gas risk prediction more imprecise and another reason for advocating for the adoption of a more highly precautionary stance to future proof mine gas mitigation measures.
Q2R3	No, current risk assessment tends to only consider current conditions under Part IIA/PAN33 and quite often future development plans are unknown, the whole plans for the site are unknown at the site investigation stage, or the consultant doesn't know the finished ground levels, building/foundation designs, etc.
Q2R4	The risk assessor is directed to consider such dynamic and future factors (e.g. flooding, changes in groundwater levels, global warming, extreme weather conditions, the closure of mines, and possible changes to the gas regime caused by future development) by BS 8576 section 6; CIRA R149 section 2.5.5 and EA NC/99/38/2 section 3.3.1 & 3.7. Such factors should therefore be considered within a defensible and robust CSM, where appropriate, by the risk assessor.
Q2R5	Again, we don’t see major issues with the guidance available, rather adherence to this and poor quality of consultant reports which have not considered all factors. Off-site migration is a factor to consider but can be lacking in exploration/detail. Perhaps the ground stabilisation measures area could be flagged more.
Q2R6	I am not aware that sufficient research has been undertaken to identify/quantify these risks, particularly since the closure of the mining industry effectively 20 years ago in Scotland.

Q3	Is there sufficient emphasis in the current mine gas risk assessment process on the potential for other interventions affecting the soils or substructures underpinning any building development, to alter the risk of mine gas migration and consequently to render any pre-development assessment redundant and inadequately precautionary to protect public health?
Q3WS	Concerns raised on site investigation boreholes not being decommissioned correctly, and foundation design becoming a pathway for gasses. Councils suggested more coal authority involvement in identifying risks required where interventions include permits to break down into coal mines/grouting.

Q3	Is there sufficient emphasis in the current mine gas risk assessment process on the potential for other interventions affecting the soils or substructures underpinning any building development, to alter the risk of mine gas migration and consequently to render any pre-development assessment redundant and inadequately precautionary to protect public health?
Q3R1	See response to Q1
Q3R2	No
Q3R3	No as per response to Q2
Q3R4	Further to the response provided for point two, I do not believe there are other significant literature sources for the risk assessor to seek guidance on such issues. However, the risk assessor should be cognisant that the CSM is a representation of a real-world dynamic system subject to constant influences via, natural (e.g. geological/atmospheric/biological) and anthropogenic sources.
Q3R5	We feel information on this could be expanded.
Q3R6	I suspect not.

Q4	Are the current criteria used for deciding what constitutes a sufficiently precautionary approach to mitigation appropriate; particularly where there is known to be a potential risk of mine gas migration? Does the process adequately emphasise the need to take account of construction methods that may add to that risk (e.g. the use of vibro-stone underpinnings or solid slab floors that are not separately vented to the outside atmosphere)?
Q4WS	Comments as per Q3 above. Workshop also discussed long term suitability of mitigation measures/ongoing maintenance. Issues where gas trenches are present. Ventilation structures left blocked or not maintained would increase the future risk. Suggestion raised covering Building Standards continuing requirements on building warrant. Noted that within risk assessments we do see risks related to construction methods on ground improvement and piling for ground contamination, but not covering coal mine gases. Suggestion is contaminated land and ground gas risk assessment should be combined.
Q4R1	See response to question one
Q4R2	No
Q4R3	No. Although the current criteria allow for mitigation measures to be implemented to the next risk assessment level, pre-construction risk assessment is independent of development. Larger sites/development areas can be redeveloped by different developers with different consultants. Quite often information not passed on/shared or details overlooked, sites sold on, etc. This may be flagged up by the regulator (if involved). Different officers within the regulatory system can deal with various planning applications and this can also lead to details being overlooked.
Q4R4	This first point (criteria used for deciding what constitutes a sufficiently precautionary approach to mitigation) relates to the robustness of the

Q4	Are the current criteria used for deciding what constitutes a sufficiently precautionary approach to mitigation appropriate; particularly where there is known to be a potential risk of mine gas migration? Does the process adequately emphasise the need to take account of construction methods that may add to that risk (e.g. the use of vibro-stone underpinnings or solid slab floors that are not separately vented to the outside atmosphere)?
	CSM and risk assessment process. For example, is the precautionary approach based upon a robust data set and detailed logs? Or various unquantified assumptions? There are multiple sources of guidance within the literature which direct the risk assessor to consider construction methods within their risk assessment framework, e.g. BS 8576 section 6; BS 8485 section A.2 and CIRIA C665 section 2.7.
Q4R5	Yes

Q5	In determining the need for mitigation measures, is the current scope for interpretation of the guidance open to developers at present appropriate?
Q5WS	The guidance under the building regulations is the minimum standard the public would expect in terms of gas mitigation matters. It's the best published guidance we have now, and it's those minimum standards that we in local authorities look to when applying the Building Regulations. There is perhaps a further question as to whether the methodology within those documents is appropriate given the situation that has occurred at Gorebridge. Perhaps we need some research, but, as a building standards practitioner, I would not feel comfortable in commenting on whether the guidance is now appropriate or deficient in any way. Acknowledgement that the construction industry will work to those minimum building standards.
Q5R1	See response one
Q5R2	No
Q5R3	Yes. However, there is no holistic approach to either on-site proposals or off-site in the adjacent or wider area.
Q5R4	It is understood that the responsibility for the developer to design (and in doing so interpret the guidance) appropriate mitigation measures. This originates from Scottish Government Planning Advice Note 33 (section Development Control, 4). Therefore, this is a policy question, which is considered out with the technical remit of CLO's and should therefore be considered by competent Scottish Government/Local Authority Policy Officers.
Q5R5	The guidance appears appropriate. It depends on consultants recognising that this is now a possible pathway.
Q5R6	Yes

Q6	Are construction methods that do not involve creating a ventilated solum beneath the ground floor of a property, inherently more liable to permit the transmission of mine gases to the inside of these properties compared to a traditional ventilated solum construction type?
Q6WS	Solum is always easier and more reliable than a membrane for gas mitigation. Point raised that with suspended timber floors ventilation was fortuitous–it was in place to stop the timber becoming damp–but has now been found to mitigate this other issue. Noted that there is no research into CO_2 in existing housing stock so no evidence on solum preventing CO_2 in properties.
Q6R1	Unknown–depends on the design and conceptual site model. The ventilated solum is a layer of protection, without it you are relying on the design specification of the other components of the ground gas protection system to compensate (BS8485:2015).
Q6R2	There are other possible methods for gas accumulation and ingress routes.
Q6R3	Possibly yes. However, it is a complex issue and would depend on the quality of workmanship/construction of the floor slab, quality of any membrane installed and its installation.
Q6R4	It is considered likely that the provision of a ventilated solum provides a preferential pathway for gas migration, thereby decreasing the likelihood of direct transmission to the inside of the property.
Q6R5	This is perhaps out with the expertise of Environmental Health, but a ventilated solum can be easy to install in the design stage and monitor thereafter compared to other measures which are more difficult to install and assess.

Q7	Is the drive to improve the energy efficiency of modern properties by increasing the levels of insulation and ensuring they are less prone to uncontrolled air movement (draughts) and are consequently more air tight, a potential factor contributing to the retention of mine gas emissions that manage to penetrate a property?
Q7WS	Airtight houses would appear to be a contributory factor in CO_2 issues. Larger issue with ventilation in general and a lack of recognition in the industry that proper ventilation/air infiltration within a property is an important factor. Energy efficiency targets lead to lots of new build properties coming in under the designed air tightness value.
Q7R1	Also, issues with build-up of indoor air pollutants. The building design needs to provide adequate air circulation and ventilation for optimal human health.
Q7R2	Yes, potentially.
Q7R3	Potentially yes. However, it is a complex issue and may depend on air pressure differences being created as the driving forces.
Q7R4	As a CLO, this question is out with my area of expertise. However, the basic premise that increased air tightness within a property could be a potential contributing factor to the retention of mine gas emissions appears sound.
Q7R5	Yes, the increased airtightness is a potential factor.
Q7R6	Whilst modern houses are effectively more airtight, the simple action of opening an upstairs window can institute the chimney effect resulting in a

Q7	Is the drive to improve the energy efficiency of modern properties by increasing the levels of insulation and ensuring they are less prone to uncontrolled air movement (draughts) and are consequently more air tight, a potential factor contributing to the retention of mine gas emissions that manage to penetrate a property?
	lowering of pressure within the property, thus increasing the likelihood of gas entering the dwelling. Closure of the window then means that the gas is likely to remain for longer periods.
Q8	Would the simplest and most appropriately precautionary solution to the problems highlighted by the Gorebridge incident be to require mandatory gas risk mitigation measures in all new residential and similar developments in areas of Scotland defined by the Coal Authority as former coalfields?
Q8WS	Sounds good in practice but uncertain how this would be implemented. Could pose higher risk with expectation that one solution is appropriate in every situation. Some areas might need much more risk measures than others. In summary, don't jump into mandatory risk measurements without understanding the specific risk at the site. From the building standards perspective, everything that we do is evidence based so there has to be evidence for a mandatory requirement.
Q8R1	If it is deemed necessary by the Planning Authority to have areas with minimum level of ground gas protection (CS2?) it must be demonstrated by the developer that this level of protection is adequate. There would need to be a much more rigorous verification process with competent and qualified installers/verifiers being a mandatory requirement.
Q8R2	Yes
Q8R3	Possibly yes. The advantage of this would be that developers/ consultants and regulators would be aware and know what is required. The disadvantage would be that it may not be required in some areas and not be adequate enough in others. It would also depend on the quality of the membrane and its installation.
Q8R4	The proposal does represent a precautionary approach. However, if it was enforced, i.e. mandatory gas risk mitigation measures in all new residential and similar developments in areas of Scotland defined by the Coal Authority as former coalfields, how is the decision derived that the 'mandatory gas risk mitigation measures' provide sufficient protection? What is meant by 'mandatory gas risk mitigation measures'? What specific protection components are mandatory? It is also not evident what is defined as a 'former coalfield' by the Coal Authority.
Q8R5	Mandatory measures should be backed up by a robust site-specific investigation which accounts for the source-pathway-receptor analysis whilst considering off-site migration and changes to ground structure during exploration, preparation and installation.
Q8R6	It is nonsensical to require a risk assessment and then ignore its conclusions. If coal workings are found at a depth of 500m under a site, is it necessary to install gas protection measures? Very unlikely unless close to a shaft or drift that intersects those workings.

Q7	Is the drive to improve the energy efficiency of modern properties by increasing the levels of insulation and ensuring they are less prone to uncontrolled air movement (draughts) and are consequently more air tight, a potential factor contributing to the retention of mine gas emissions that manage to penetrate a property?
	What would mandatory gas protection measures consist of? Would there then be a temptation to skimp on the risk assessment as a membrane was to be installed anyway? Would there then be a danger of not installing sufficiently robust mitigation measures or not refusing development altogether? This suggestion in the Gorebridge report is the equivalent of advocating mass medication to reduce the chance of disease (generally resisted by the health authorities). To continue the medical analogy–there may also be side effects!

Annex 4 – Expert Consultation

Summary of answers form expert consultees. **NB**: Consultees answered the questions related to their area expertise hence not all consultees have a response logged to every question. **Question 1: Is the current mine gas risk assessment process adequate to correctly determine the level of risk, especially in relation to the requirements for assessing mine gas levels at sub-surface depths likely to be representative of gas migration potential from underground mine sources?**

1) Sub-question/ discussion points	A) What are the perceived gaps in the current mine gas risk assessment process? Is there too much reliance placed on measurements of gas concentrations and flow over a short time period?
Geotechnical Specialist	Existing standards and guidance don't require a holistic approach, they just imply it. The problem is that it should be done but is not required. Risk assessment, design and planning, and construction all done separately.
Insurers	Process is adequate, but implementation is of variable quality. Variable quality of conceptual site model by consultants and developers. Monitoring variable quality as well. Too much guidance on risk assessments. Recommendation to clarify guidance in a short paper, training of local authorities and consultants, or big game change.
Geotechnical Specialist	Process is adequate, but in mine gas R.A. further lines of evidence need to be considered. Further guidance around application of conceptual models and SPR approach and an addendum on guidance on mine gas would be useful.
Developer	Much guidance published (which is clear about the conceptual model and having lines of evidence), but it is applied and interpreted of varying quality. From a developer's perspective, need to check experience of consultants. Often monitoring done over too short of a period of time. Spot monitoring misses the atmospheric event. Mining areas should be flagged to make sure quality monitoring data collected there. The risk assessment should be done knowing what type of building is being constructed because building type will affect the risk.
Developer	Yes, but the expertise with which to use the guidance sometimes is not adequate. If CIRIA C665 & Wardell Armstrong guidance is followed, it is unlikely that an incident will occur. Deviation and lack of understanding leads to incidents.

Consultant 2	BS8576, BS8485, CIRIA C665 etc. are not specifically about mine gas, they're about all ground gas. The process is adequate if you follow the guidance, but the guidance is not being applied. It's been difficult (especially in last 10-15 years) to get everybody to understand the importance of the conceptual site model. If you look at the conceptual site model, then the process is adequate because you are considering the whole potential for ground gas generation. The guidance does lead one to consider the potential for gas to be generated and/or to move in ways specific to that particular site, but too often people will put in shallow wells, measure nothing, and report everything is all right without thinking about how gas might be generated or move. Assessment must consider what will happen if flow rates increase, if monitoring did not measure the maximum. Sensitivity analysis should always be carried out. People should not rely solely on GSV's. In CIRIA C665 there are examples of GSV being wrong. Steve Wilson and Geoff Card have stressed to not rely on GSV but consider the conceptual site model. • Sometimes the local authority officer does not understand the guidance and applies it incorrectly. • The guidance is there if one chooses to use it. In the original BS8485, in one of the appendices, there was a list of qualifying questions to be considered when deciding on protection measures including the complexity of the subfloor and the liability of the data. The flow chart in section 7.1 of CIRIA 665 captures the important questions to consider. Recommendation: There would be benefit in supplementary guidance being developed to look specifically at mine gas sources and pathways. When outside of competence, consider third party review. 3rd party review has been very valuable to use on multiple occasions.
Consultant 1	No real guidance on the risk assessment process. The only true guidance is the NHBC document traffic light system. Having a conceptual side model is very important. In terms of the SPR approach, there is no adequate methodology on how to do the process. Assessments must be site specific. Baseline monitoring is not effective unless you have designed it specific to the site. Worst case scenarios must be considered (like the NHBC and CIRIA guidance say), a 1-in-50-year event atmosphere condition. More than one line of evidence must be used, and the source needs to be well understood. CIRIA 152 has quite a lot of discussion about the sources of gas, not exclusive to landfill, and has a conceptual model which includes mines.

Local Authority	Local authorities vary in approach to the risk assessment. Risk assessment can be challenging because guidance is lacking on mine gas.
1) Sub-questions/ discussion points	**B) Should there be differences in approach to CO2 versus methane e.g. to consider chronic risks?**
Geotechnical Specialist	-
Insurers	Should consider chronic risks.
Geotechnical Specialist	Should measure both CO_2 and methane in the risk assessment.
Developer	Chronic risks are considered for standard contaminated land issues but not for ground gas.
Consultant 1	-
Consultant 2	The approach was developed initially for methane and expanded to include CO_2. But the lower level chronic risks are not adequately considered. The subsequent guidance has tried to address that where it talks about VOC. People might need to consider third party reviews when outside of scope.
1) Sub-questions/ discussion points	**C) Should further guidance be provided specifically on how to assess mine gas sources and pathways?**
Geotechnical Specialist	The guidance is very good, it's the implementation that gives us problems. Mine gas doesn't feature strongly in much of the guidance. The guidance tends to focus on ground gas in relation to landfills. However, mines are unique and can create a massive volume of gas very quickly. The way in which the industry calculates GSVs has never been proven to be correct. Site investigation and gas protection design are not absolute because calculating GSV is not absolute.
Insurers	-
Geotechnical Specialist	-
Developer	Further guidance about GSV values and how they are applied would be beneficial. The risk assessment must incorporate the design and construction techniques.
Consultant 1	Source must be understood.
Consultant 2	-

1) Sub-questions/ discussion points	D) What about for existing properties e.g. under Part IIA?
Geotechnical Specialist	-
Insurers	-
Geotechnical Specialist	-
Developer	If you are building new houses, you must consider how new developments will affect old ones (typically not done but should be). Gas risk assessment for existing properties is very disruptive. A different approach will be required in the future to make it successful.
Consultant 1	Very little guidance for existing properties, just have to demonstrate that there is not a risk.
Consultant 2	Guidance is completely adequate for existing development as opposed to a new development. The approach is the same.

Question 2: Is the current risk assessment process fit for purpose particularly in terms of taking account of future potential changes in mine gas dynamics and migration risk factors (e.g. due to ground stabilisation measures, additional developments, etc.) that could lead to an increased risk of gas migration into properties over the long term?	
2) Sub-question/ discussion points	**A) To what extent do current standards and guidance consider the effect of future potential changes in the ground and the implications for future ground gas risk assessments? E.g. climate change, rising groundwater levels, mine grouting?**
Geotechnical Specialist	Risk assessments don't consider the worst-case scenario. It should be considered earlier in the planning process. With regards to climate change, greater levels of groundwater, rate of change is relatively modest compared to instantaneous changes you get from low pressure weather events, but it's all worth noting, and climate change is especially going to increase the risks.
Geotechnical Supplier	The guidance is appropriate, it just comes to accuracy of reports on the site. Often uncertainty is not addressed. Former coal mining sites must be considered differently because there are more uncertainties (groundwater, stabilization, etc). There are lots of uncertainties and you must put in proper mitigation to account for those uncertainties. If the risk cannot be rules out, then you need to be precautionary. It's probably quite common to not consider future uncertainties and just do spot monitoring in a shallow well and have a bad CSMI.
Insurer	The guidance is appropriate, it just comes to accuracy of reports on the site. Often uncertainty is not addressed. Former coal mining sites must be considered differently because there are more uncertainties (groundwater, stabilization, etc). There are lots of uncertainties and you must put in proper mitigation to account for those uncertainties. If the risk cannot be rules out, then you need to be precautionary. It's probably quite common to not consider future uncertainties and just do spot monitoring in a shallow well and have a bad site model.
Geotechnical Specialist	Grouting of shafts for geotechnical purposes should include a vent pipe. Rising groundwater levels and consequences of climate change need to be considered, possibly by the coal authority. They are not considered at present.
Developer	Current Guidance does consider future changes within red line boundary, but outside of this is less robust. Potential climate change impacts or rising groundwater not really considered. The local authority should be the one considering implications of turning off the pumps of mines. Limited knowledge in how information the groundwater levels in a mine is acquired.

Developer	The ground gas risk assessment guidance does not ask you to look forward to the future. It asks you to consider the site at the time of assessment. The conditions that will be represented post-construction may be much different to those present during the risk assessment (vibrostone columns, etc). The current guidance doesn't ask you to potentially consider the design life of the property or if changes to the property occur. Recommendations: • Guidance should take into account your risk assessment site being a preferential pathway for ground gas migration. • Should take into account the design life of the property or if changes to the property occur. • Foresight: if building council housing with design life of 60-100 years, the RA should consider, are there any sources at the site in the 60-100-year period that are going to change? With current guidance, RA considers a 10-year plan.
Consultant	In old mines where there has been regional pumping for decades where the water table has been depressed 100m plus and the pumping stops, then the water table comes up and at one mining site for example, the water table came up 60m in a few years. Implications for the ground gas regime must be considered.
Consultant	Someone assessing a site can only deal with what's in front of them. It's the responsibility of people creating new developments to assess that their construction won't affect existing developments. It is unreasonable to consider how your development might change in 50 or 100 years, it is too uncertain. People should just consider what is foreseeable. If there is specific knowledge such as evidence for rising groundwater levels, that should be taken into account as part of the assessment and conceptual site model. Foreseeable issues should be taken into account, but implications which are speculative should be left along. The gas risk assessment originally should be conditional and based upon X, and if X changes, then the risk assessment must be re-done. For the developer to appoint someone right through the process to keep an overview of these types of issues would be impractical and likely ignored. Half the time a site ends up getting developed out by somebody different than it started with, and all with different teams.
Building sciences consultant	Seal should last at least 25 years if not exposed to weather (but may need checking periodically).

	Expanding foam quality sealant for penetrations of slab to emplace services with life time guarantee, UV will destroy the foam. Construction techniques may decrease quality. Damp proof membrane will provide sealant for gas migration. Degree of sealing will vary with emplacement of membrane. CO_2 would flow out rather than up so increased levels of ventilation have no impact.
Local authority	A national strategy is required for mine water recharge.
2) Sub-question/ discussion points	**B) What additional guidance could be provided on this?**
Geotechnical Specialist	-
Geotechnical Supplier	-
Insurer	-
Geotechnical Specialist	-
Developer	Knew of recent paper on climate change and remediation that would be relevant.
Developer	See 2A
Consultant	-
Consultant	See 2A
Building sciences consultant	-
Local authority	There is a lack of guidance specific to mine gas.
2) Sub-question/ discussion points	**C) Is research needed in this area to better understand the effects?**
Geotechnical Specialist	-
Geotechnical Supplier	-
Insurer	-
Geotechnical Specialist	-
Developer	There are gaps in current knowledge.

Developer	See 2A
Consultant	-
Consultant	See 2A
Building sciences consultant	-
Local authority	-
2) Sub-question/ discussion points	**D) How should the cumulative risk from multiple developments in mining areas be assessed? E.g. what are the implications for existing properties surrounding a new-build development if gas membranes are deployed (e.g. is there a need for venting trenches surrounding the site or buildings to prevent gas migration).**
Geotechnical Specialist	-
Geotechnical Supplier	-
Insurer	If you have many developments over a coal mining area, there might be pathway over pathway. This is covered in the guidance. The whole site must be considered.
Geotechnical Specialist	Cumulative risk of multiple developments should be assessed using a precautionary approach
Developer	-
Developer	See 2A
Consultant	Must look at cumulative effects of developments
Consultant	See 2A
Building sciences consultant	-
Local authority	-

Question 3: Is there sufficient emphasis in the current mine gas risk assessment process on the potential for other interventions affecting the soils or substructures underpinning any building development, to alter the risk of mine gas migration and consequently to render any pre-development assessment redundant and inadequately precautionary to protect public health?

3) Sub-question/ discussion points	**A. Site specific mine gas risk assessments are based upon the current condition of the site. To what extent do potential changes to the site related to the development considered in the risk assessment process?**
Geotechnical Specialist	Too often the structural design is done in isolation. Vibrostone columns are a good structural engineering solution, but massively increase the risk. All of the professionals involved in the construction of a site must understand the risk of ground gas and consider it in their design.
Insurer	Vibro-stone columns increase risk. This is definitely covered in ground gas risk assessment, even in CS1. Consultants need to be more aware. There is currently variable quality in awareness.
Geotechnical Supplier	In foundation design, mines should flag as higher risk. There is a lack of awareness and training. Consultants need to be more aware. Planning conditions would require a developer to assess foundation design to consider how it will be impacted by ground gas.
Developer	Do need to consider foundation design. Use of vibrostone columns might not be taken into account in ground gas assessment. There's a disconnect between ground gas and geotechnical/ structural assessments. More linkage is required
Developer	Problems occur when risk assessment done far before development—miss that maybe vibrostone columns might be added or that additional sites will be added which then elevates risk. Recommendations: • The conceptual model needs to consider the final design • RA needs to be reviewed throughout the process to see if it's still applicable • Would be useful to have geo-environmental consultant and environmental consultant collaborating • Responsibility lies with the developer to ensure site is suitable for use, not the local authority.
Consultant	In mining areas, there has to be a checklist or flowchart of things that have to be considered.
3) Sub-question/ discussion points	B. How can activities associated with the development than can affect the gas CSM, e.g. ground improvement, stabilisation, ground source heat pumps, be incorporated better into risk assessments?
Geotechnical Specialist	-
Insurer	See 3A
Geotechnical Supplier	-
Developer	NHBC should cover this as part of the 10-year insurance cover.
Developer	See 3A

Consultant	See 3A
3) Sub-question/ discussion points	C. What additional guidance could be provided on this?
Geotechnical Specialist	-
Insurer	See 3A
Geotechnical Supplier	-
Developer	LA Guidance in Scotland varies (although supplementary planning guidance in Central Belt).
Developer	See 3A
Consultant	See 3A

Question 4a: Are the current criteria used for deciding what constitutes a sufficiently precautionary approach to mitigation appropriate; particularly where there is known to be a potential risk of mine gas migration?	
4a) Sub-question/ discussion points	**Is the risk assessment process proportional?**
Geotechnical Specialist	SPR model not applied properly and not looked at early enough in the design process.
Geotechnical Supplier	Yes
Insurer	Where uncertainty in site, you must adopt a precautionary approach and adopt mitigation measures.
Geotechnical Specialist	Should adopt the same approach as in volatile organics.
Developer	A precautionary approach with conservative metrics is in the guidance. Scoring system is effective. Consultants adopt a tick box approach.
Developer	Interpretation of the guidance is open to developers. If guidance applied fully and appropriately by experienced individuals, there would not be problems.
Consultant	Yes, if they are followed. The broad guidelines in BS8485 for ground gas conditions do not apply in difficult situations. On routine sites, a simple and straightforward system is easy to follow, but nearly

	impossible at a complex site. A good risk assessment and a good site conceptual model are important. At high risk sites, a risk-based approach is needed which must be quantified.
Consultant	Up to interpretation. The point system of BS8485 was meant to help people reach a competent system for gas protection. The scope for interpretation is there and it is a good thing, it just needs to be improved properly (e.g. there are some words in there about being unnecessarily conservative).
Local Authority	-
4a) Sub-question/ discussion points	To what extent is the existing process precautionary? Does the precautionary approach extend to design of mitigation measures?
Geotechnical Specialist	The approach should be precautionary. If guidance was used appropriately, it would be sufficiently precautionary. Ground gas management protection often seen as over precautionary by solutions providers. The regulations are good but should be managed and policed better. A problem we've seen since we produced BS8485 is that if people are less confident in their risk assessment, then they resort to a more over engineered mitigation method. It all relies on the risk assessment process. And a risk assessment is site specific and dependent upon what is being built (residential or non-residential building).
Geotechnical Supplier	-
Insurer	-
Geotechnical Specialist	-
Developer	Often more cost-effective to install mitigation measures. Membranes, if installed, require verification.
Developer	-
Consultant	-
Consultant	People often take a precautionary approach and install gas protection systems they don't need. Then they take no care at installation and do not get any gas protection. When a site actually needs a gas protection measure, it should be installed and verified properly.
Local Authority	Two methods of precaution are required. The quality of mitigation can vary. There is a two-part planning development standard approach in CS2 and validation and verification in CIRIA.

Question 4b: Does the process adequately emphasise the need to take account of construction methods that may add to that risk (e.g. the use of vibro stone underpinnings or solid slab floors that are not separately vented to the outside atmosphere)?	
4b) Sub-question/ discussion points	**Is the gas RA and need for mitigation revisited when a change is made to building construction or foundation design?**
Geotechnical Specialist	There is a lack of holistic thinking in maintaining the source pathway receptor model and applying it to various types of construction. Problems in risk assessments tend to be picked up at the last minute. If it is picked up at the last minute, then decisions have often already been made in the design process. Again, too often the design of the building structure is done in isolation. The industry should go back to how it was done in the 1980s, where engineers designed, they constructed, and the contract was built. It's been a progressive problem of the design-build scenario of the work being isolated across different groups of professionals. The highest cost of membrane solutions is the cost of sealing them around penetrations and awkward corners and changes in levels etc. A simple flat membrane that runs across a foundation and goes to the outside of the building, BRE414, is relatively inexpensive to install and can be done fairly well. At buildings with very complex designs, the installation of the membrane is very complex and almost impossible to achieve without highly experienced people.
Geotechnical Supplier	Different method of construction (standard block floors) in Scotland than in the rest of the UK. In England use a lot of concrete beam and block floors with a ventilated void below. In Scotland there are some floor slabs being constructed above granular fill. It is fairly common for membranes to be damaged through the installation and construction process. The industry should be looking at the construction process when designing gas mitigation measures. With granular fill with 10mm plastic pipes, ventilation capacity on vented solum is much improved. With granular fill, angular material will block up all of the voids whereas rounded won't. Some of the pipes don't go from one side of the building to the other which could create a negative pathway that it draws gas into the pipe itself. Sometimes we have seen the interweaving of the perforated pipes - so air has to pass through the granular fill to get to the other side of the building. We need to confirm what is the most efficient system for protection. In Scotland builders are still building with pipes and granular fill and expert not confident in its performance
Insurer	Sites often sold on using consultants reports with many caveats covering risk and their own liabilities.

Developer	Information can be lost over development lifecycle. A mandatory reports register would help here. Quite a lot of the time contamination assessment is done by one party, the geotechnical assessment is done by another party, and the foundation design is completed at the end. This is a potential problem and it is the developer's job to understand the linkages.
Consultant	A risk assessment has to asses that the proposed mitigation methods will work. Any time there is a change, there should be a re-evaluation of the risk. The local authority could make their approval conditional, approved unless something changes.
Consultant	How you will be constructing your building should be an integral part of the risk assessment project. If how the building will be built changes, then the RA and mitigation measures must be reconsidered. Recommendation: When reports talk about the gas protection system, they should be in general principal terms, so they are understandable for the structural engineer and architect. Coordination, discussion, and cooperation between consultants, structural engineers, and architects on gas protection systems, and the ultimate design of what the building looks like and how it will work.
Building sciences consultant	Slabs and timber frame provide greater thermal mass. Timber frame construction has been around a long time in Scotland. They heat and cool quickly. Solid slab floors stabilise heat flow. This construction type has been driven by cost efficiency and regulation (e.g. disabled access). Timber frames provide more insulation: higher thermal standards Section 6 of Building Standards Regs (Part L in England & Wales). Block and beam with raised timber, provided all are sealed, with a ventilated void will enable gas to be driven out of structure. A continuous membrane under slab should also do this, but penetrations for services may not be sealed so may be a problem in high risk areas. There should be more education/training as there is a lack of understanding by guys on site. A problem in high risk area School at Cumbernauld provides examples of best practice: piles onto peat bog, gas membranes sealed and welded. Manufacturers of membrane provide validation–very rigorous as they provide a 10-year guarantee. Small housing developers might take more risks.
Developer	Our company uses 100% manufactured timber kit construction, driven by mobility access issues which requires external and internal ground levels to be similar. This lends itself to slab construction, partly for aesthetics e.g. otherwise ramps required.

	Our company uses granular fill and perforated pipes, with 3 m centres below the slab is typical. The granular fill is typically 20mm gravel. An active system of ground gas dispersal has been used but is not the ideal solution as there is a requirement for long term maintenance with associated liabilities. Mobility access has been a big regulatory driver since 2000, albeit not using slab at ground level would avoid a number of flooding issues. The weight of the structure is not an issue, there is a marginal decrease in weight from using a timber frame which is not significant in terms of overall loadings.

Question 5: In determining the need for mitigation measures, is the current scope for interpretation of the guidance open to developers at present appropriate?	
5) Sub-question/ discussion points	**A) Is the standards and guidance on mitigation measures prescriptive enough?**
Geotechnical	It's more the application. The regulations are adequate. BS8485 is a relatively slim document and was designed to provide guidance. A lot of engineering practices have varying levels of knowledge and experience. More commercially oriented groups frequently found gaps/loopholes in the guidance, rather than using it to assist them in the process. 51 was made to close some of the gaps, but it still leaves some room for interpretation.
Geotechnical	There is room for developers and designers to take a flexible approach to their design. I have seen on many occasions developers stretch the boundaries of the guidance to meet their own requirements. Not necessarily to the benefit of the best outcome for the project itself. Driven by commercial considerations.
Insurer	Guidance is at an adequate level. However, there's no recourse for developers not following rules (unless something goes extremely wrong). There's a problem with having the right information at the right time. Government does not provide information early enough in the process, which is of no consequence to the developers except that there may be a delay later down the line. Devising points of verification is important.
Geotechnical Specialist	-
Developer	The mitigation measures are open to interpretation and are not very prescriptive. It might be a precautionary approach to put in gas protection measures, but then they are put in very badly. If a site is deemed as high risk, that should trigger there being an extra building control and the gas membranes

	being further verified. A lot of councils require robust risk assessments and request precautionary measures, but it is not clear what membranes should look like.
Developer	BS8485 is comprehensive, robust conservative assessment. A certain amount of points has to be achieved to balance the risk with the points system, and sometimes developers will limit protection for cost. Improvements in longevity and in the application of the mitigation measures could be made.
Consultant	The points-based system does not address specifics. It is a generic solution for a generic problem. GS3 doesn't take into account pathways. Pilings are a risk and they are tested to see if they will work. Why can't you apply the same principals to gas migration? Verification is hard to do. Mitigation should be sufficiently rigorous so that the added development of post-installation verification is unnecessary.
Developer	The risk assessment is carried out by experienced consultants, OUR COMPANY tend to use the same pool of consultants for this work over a long time scale. Attempting to influence the outcome of a risk assessment would entail significant financial risk. Modern management structures in for developers have technical directors at same level as land directors and therefore technical issues and risks are taken into consideration more in the land acquisition process. Building Control will require verification of the membrane and the inspection is carried out by experienced consultants. This verification included a range from visual inspection to tests. OUR COMPANY requires photographic records and a certificate from the consultants. The certificate will be included in the habitation certificate for a dwelling. OUR COMPANY use third party review to get around quality issues. Membranes are not popular with groundworks contractors as they add to the complexity of completing a project.
5) Sub-question/ discussion points	**B) Are consultants/ developers interpreting the standards appropriately?**
Geotechnical	The standards are broad, which is the point. It leaves room to interpret based on the specifics of a site. There are some problems due to a lack of understanding. Also, generalist engineers or consultants may not encounter ground gas issues often, so they lack experience. It's the policing and the maintenance of the standards that should be improved.
Geotechnical	In fully understanding the how the membrane is installed onsite, one needs to understand the difficulties the installers have to overcome. The local authority's capability to critically review design is based on

	their own personal experience. Those doing verification need the technical knowledge in building and construction methods.
Insurer	There is a problem with consultants with a contaminated land background not being appropriately experienced or qualified to assess mine gas risk
Geotechnical Specialist	There needs to be more awareness/ training.
Developer	The problem is that ground gas is often part of the contaminated land assessment. Developers tend to rely on consultants and consultancies are generalists that do heavy metals, water assessment and then ground gas.
Developer	-
Consultant	-
Developer	See 5A
5) Sub-question/ discussion points	**C) To what extent are limitations in knowledge e.g. of building design from land quality professionals a constraint?**
Geotechnical	The person doing the ground gas assessment should have a concept of what's being built. Each expert has to have a knowledge of the other areas. CLR11 is less rigorously enforced, which is an excellent approach on contaminated land not just the proportionality of the risk, but also the flow chart. We need to invest more in the experience of the checker and the provider.
Geotechnical	Contaminated land professionals not necessarily trained in ground gas mitigation measure installation. Need more training on construction methods.
Insurer	There is a lack of experience amongst consultant and architects. They may not understand amber 1 and 2.
Geotechnical Specialist	-
Developer	Implications of design not fully considered. In an environmental investigation, you don't go into much foundation discussion. We should be focusing on geomonitoring of foundations. Vibrostone columns might not be considered by consultants as leading to contamination.
Developer	-
Consultant	-
Developer	See 5A

5) Sub-question/ discussion points	D) To what extent are poor installation/ inadequate verification factors?
Geotechnical	Currently, gas membranes performance is in excess of the construction industry's ability to install them.
Geotechnical	Ventilated void is always the first level of protection.
Insurer	NVQ for installers has raised standards of installation but will take time to work through system to fully improve standards. Verification is very variable. Over the years it has generally improved. There is little push back on developers to improve practice.
Geotechnical Specialist	-
Developer	-
Developer	After installation, gas membranes should undergo integrity testing to ensure they are working.
Consultant	How do you do a gas risk assessment without understanding the receptor (the building)? There is a training gap. You can now get SoBRA qualifications for human health, and r ground gas risk assessment.
Developer	Work is carried out by ground works contractors who now use sub-contractors to install membranes, previously ground works contractors used to install membranes themselves. The use of specialist companies that use bespoke seals and membrane pieces around the foundation has resulted in improved practice. Two to three years ago quality was more mixed e.g. the use of tapes to provide sealing was not effective compared to the plastic weld which is used now.

Question 6: Are construction methods that do not involve creating a ventilated solum beneath the ground floor of a property, inherently more liable to permit the transmission of mine gases to the inside of these properties compared to a traditional ventilated solum construction type?	
6) Sub-question/ discussion points	**What factors are driving the reduced use of a ventilated solum beneath domestic properties?**
Geotechnical Specialist	Liability of certain construction methods is up to interpretation. But, unequivocally the case that a fully ventilated solum is a very good mechanism for reducing the potential impact of ground gases to the building above. The best method of gas protection is up for debate. Ventilation is variable over time whereas a barrier is either there or it's not so is more reliable. Ventilation is dependent on things like wind speed.

Geotechnical Supplier	Beam and Block floor with ventilated void is the first line of defence. In England, most houses built on a beam and block floor. This design incorporates ventilation - 1500 mm sq open vented capacity per linear meter of wall. Any gas mitigation measures required for a site would need to be incorporated into that system. Construction methods in the rest of the UK by default have a ventilated void. The industry should be looking to change the method of construction to incorporate a ventilated void which provides a very good level of defence against any gasses which may get into the building to start with.
Insurer	Ventilation is the first line of defence; unventilated voids are a risk. In England 90% houses modernized. In Scotland it is very rare that you have ventilators because it is more cost effective to put in a ventilated void rather than a slab.
Geotechnical Specialist	Sub floor ventilation important, granular fill and perforated pipe can reduce sub floor ventilation.
Developer	Most dwellings in England use a ventilated void, and major housebuilders follow standard designs where possible, e.g. Redrow has 3 types of houses. Timber framed construction used in Scotland. The use of a wooden frame facilitates use of concrete slab. 'Modern Methods of Construction' have been adopted more widely in Scotland than England.
Developer	Ventilated solums have been constructed in mining areas for hundreds of years. Yet it is rare to get mine gas within constructed property in the UK. Houses from the 1920s, 30s, 40s are not impacted by ground gas because they had a ventilated sub floor, air control and were not as tightly sealed.
Consultant	Ventilated solum reliability depends on floor type. If there is a ventilated sub floor with a structural slab that’s not cracking, and is sealed properly on the outside, then a ventilated solum wouldn't change things. Basements also offer a lot of protection. The ventilated sub-floor void is a first line of protection, and by taking that away it places more emphasis on adequate construction maintenance of gas protection measures, including a membrane, service entries, etc. It all comes back to having a good conceptual site model. It's adequately covered in the guidance and standards. It’s all related to having a gas protection system, as opposed to one gas protection measure and building in an appropriate level of redundancy. Sometimes the RA will be done, then the design progresses, and the foundation method might change or ground improvements that will be used, by a third party. And then that gas RA isn’t re-assessed.

	There is definitely a gap between people at the investigation stage and the development stage (the developer, structural engineers and architects). The more information that moves between organisations, the higher the potential for recommendation to get lost.
Building sciences consultant	Yes, a solum reduces risk. Risk will depend on construction technique. Gas migration through slabs will be slow/ non-existent so migration not through slab itself but from around the perimeter and from services entries.
6) Sub-question/ discussion points	To what extent is the issue addressed in existing standards and guidance e.g. BS8485?
Geotechnical Specialist	The revision of BS8485 in 2015 put far more detail about foundation design and risks with different slab constructions than the 2007 document. The 2007 document didn't discuss any of that, it advised to find structural engineering knowledge elsewhere. Changes in building standards in the last 5-10 years to provide more disabled access has placed more reliance on gas mitigation design and moved away from ventilated solum. There needs to be more research on resistivity of concrete slabs to the passage of gas. The guidance doesn't tell you about that.
Geotechnical Supplier	Guidance from CIRIA etc. has certainly made a difference because there is a lot more verification and validation being done on site. But the person doing the validation must have the knowledge and understanding of ground gas issues. Everyone needs to know what they are doing and why to get a solution that is fit for purpose. Ackroyd going through Assessor Qualification process just now. That qualification has just been released by the British verification council. Verifiers should be standardised and validation without a qualification should not be accepted.
Insurer	-
Geotechnical Specialist	-
Developer	-
Developer	-
Consultant	See comments above
Building sciences consultant	-

Question 7: Is the drive to improve the energy efficiency of modern properties by increasing the levels of insulation and ensuring they are less prone to uncontrolled air movement (draughts) and are consequently more air tight, a potential factor contributing to the retention of mine gas emissions that manage to penetrate a property?	
7) Sub-question/ discussion points	**To what extent is the assumption correct that the drive towards air tightness and improved insulation contributing to the retention of mine gases within a property?**
Geotechnical Specialist	It's overwhelming. If the gas kept out, it's a positive. If gas gets in and can't get out, it's a negative. The most research that has been done about this has been about radon because radon is a gas that only causes a risk in increasing concentrations over extended periods of time. In research by Melansis back in 2014 medical professionals said that the improvements we are making for thermal energy efficiency is potentially creating an increased number of deaths per year for radon by about 15-20%.
Consultant	No evidence of whether it is or not, there may be an NHBC report on air quality in housing to be commissioned
Insurer	Biggest driver for gas entry to a house is the heat exiting the property. If increased insulation and little temperature variation in a house, that should reduce the suction effect.
Consultant	Yes, if you have a draughty building, the gas getting into it is going to escape out. If you have a building that is airtight, any gas getting into it is going to escape. You've got to make sure your gas protection system works. If it works, then gas can't get into the building.
Building sciences consultant	Measurement of CO2 increasing indoors due to lack of ventilation in the whole house. Houses in Scandinavia typically have whole house heat recovery system which provides high air quality. • Air quality is a big issue in residential properties because of more efficient energy use and sealing of windows. (Air tightness on dwelling, Trickle vents – 3 m3/hr per m2 at 50 pascals, Assumes at 3m3/h/m2) • Numbers for air quality are distributed throughout the whole house equally, but living rooms and bedrooms are especially under-ventilated • There was a study in Finland on the impact on human health that is still being evaluated. Further research to consider impact of ventilation on human health would be useful.
7) Sub-question/ discussion points	**To what extent is this considered in the standards and guidance e.g. BS8485?**

Geotechnical Specialist	The guidance has been written by people who are experts on the topic and didn't foresee people interpreting the guidance differently or actively seeking loopholes.
Consultant	-
Insurer	-
Consultant	See comments above
Building sciences consultant	See comments above
7) Sub-question/ discussion points	**Are ambient levels of CO2 from household sources understood as a 'baseline' to which mine gas emissions may increase?**
Geotechnical Specialist	Gas ovens and heaters create background levels of CO2 is a problem. Also creating sealed homes and then creating slots for service entries for utilities is a source of risk. Sources should come in through the side.
Consultant	-
Insurer	-
Consultant	-
Building sciences consultant	See comments above

Question 8: Would the simplest and most appropriately precautionary solution to the problems highlighted by the Gorebridge incident be to require mandatory gas risk mitigation measures in all new residential and similar developments in areas of Scotland defined by the Coal Authority as former coalfields?	
8) Sub-question/ discussion points	**If you agree with this proposed approach, how should "mandatory gas risk mitigation measures" be interpreted in accordance with BS845? If you disagree with the approach, please explain why.**
Geotechnical Specialist	No. It's very tempting to take a blanket approach to a problem. The problem is that every single site will have a different level of risk according to geology, gas potential, etc. If you standardise the risk, you standardise the solution. Every single site that is defined by the CA as a former coal field, or that is sitting near a landfill site or has any other reasonable cause for ground gas contamination should have an appropriate risk assessment.

	CIRIA C659 and the NHBC traffic light system to me is saying, if it's a really risky site, you install gas mitigation measures properly, and if it's a less risky site, you don't do it properly.
Geotechnical Supplier	Ideally, yes. However, the construction industry would not be very happy with the cost implications of doing that. Problems will be stopped with proper risk assessment and mitigation design. Blanket requirements of gas mitigation for every site is unnecessary, only some will need it. It should come down to having a robust gas risk assessment which should consider constructability. Design practices and risk assessments can be robust, but construction methodology is not taken seriously enough.
Insurer	It needs to be clarified further. Ventilated void is preferred over a membrane in coal mining areas. Mandatory gas protection may lead to complacency in construction techniques. You have to make sure that the membrane is working and that it has been verified.
Geotechnical Specialist	Can be over precautionary; however, sometimes mitigation is cheaper than understanding the source.
Developer	What would a mandatory gas protection measure look like? May not be straightforward to implement.
Developer	The current Coal Authority guidance on construction of dwellings on former coalfields is that gas mitigation measures should be used or at least strongly considered, that was in about 2016. A Wardell Armstrong report mentioned that when doing an investigation of a site in a former mining area, pathways may become opened to deeper coal and mines and increase risk. Placing blanket ground gas mitigation measures where they are not required is a problem. There needs to be consistency in application. A blanket mitigation measure shouldn't remove the need for a proper risk assessment and geotechnical investigation. Compliance from consultants might diminish if robust mitigation was required where it was not needed. Developers will not want to spend money mitigation.
Consultant	No, mandatory measures are generic and don't necessarily resolve the problem. They are overly precautionary for some sites, and insufficiently precautionary at the high-risk sites. They will also will cost a lot of money.
Consultant	Mitigation measures must be site specific, considering the conceptual site model, the gas regime, and the RA, which all determine the necessary ground gas mitigation measures, which must then be installed properly.
Building sciences consultant	Yes, mandatory gas mitigation is the most sensible solution moving forward.

8) Sub-question/ discussion points	**How should such an approach be applied e.g. limited to CA defined high risk development areas?**
Geotechnical Specialist	See comments above
Geotechnical Supplier	See comments above
Insurer	-
Geotechnical Specialist	Could require ventilated sub-floor voids in in areas underlain by old coal workings.
Developer	-
Developer	See comments above
Consultant	-
Consultant	-
Building sciences consultant	-

Question 9: Can retrofitting be carried out effectively for existing properties affected by mine gas as an alternative to demolition?	
Geotechnical Specialist	Retrofitting is very difficult and very expensive. The major pathway will be cracks in the screed. You can retroactively put a membrane in, seal up the walls, and put a screed down. Another potential pathway is up through the cavities. You can try cavity filling using close cell foam, or you can jack the building up and try to put a continuous DPC across the whole thing which is massively expensive. Another way of doing it is to actually use positive pressurization, ground negative, ventilation system. There's a real reticence towards using managed activated systems on private residential buildings because the householder has to keep them going.
Geotechnical supplier	Retrofitting is doable and definitely has advantages over demolition. Techniques are to either put membrane on top of slab or remove the slab and incorporate the new membrane under the new slab.
Insurer	Retrofitting can be done successfully provided there is a good design, and experienced personnel carry it out. Retrofits also need verification.
Geotechnical Specialist	Not difficult to do but leaves a duty of care and difficult to maintain in long term. E.g. retrofitting at Western Quarried Runcorn where elevated mine gas present.
Developer	Retrofitting is feasible e.g. Northwich where retrofitting was cheaper than demolition and rebuilding. However, retrofitting can get very disruptive.?
Developer	Geoff Card, who has offered lots of guidance, has the approach is that in a high-risk area, retrofitting cannot be relied on. Traditional retrofitting usually involves adding a membrane and a floating floor, and the membrane would be taped and lapped behind the plaster boards and ventilation. Installing retrofitting can be really intrusive ad require removing stairwells and bathrooms.
Consultant	Yes, retrofitting can work.
Consultant	Retrofitting can work – example where we retrofitted gas protection into a housing estate and the risks were mitigated. Retrofitting can work but is disrupting to the residents. When you do anything to an existing property, it requires lots of communication with residents. The guidance says and it's the practice, that your gas protection system is designed so that it is effective and lasts for the lifetime of the development and does not therefore require ongoing monitoring. How would you do ongoing monitoring inside someone's home?

Building sciences consultant	Sealing of penetrations into a void can be carried out, and top hats used for pipes can be fully sealed. No reason why retrofitting shouldn't work, except for variability of workmanship in the house building sector. Retrofitting can be done easily. Pressurize the house to find leakage pathways and use tracers to get pathways out of building. It is worth attempting to seal a house and assess impact.
Developer	Retrofitting is expensive, and gaining access to private properties is particularly problematic e.g. the cost of retrofit might be £10k, but the overall cost might be much greater because of 'distress' to occupants etc. As an example of the cost benefit assessment, you mentioned the Penicuik development of 450 units where it was considered quicker and less of a risk to put in place membranes rather than risk a retrospective fix. Installing a gas membrane costs £1500 to £1800 per unit, but the cost of retrofit would dwarf this.

This publication is available at **www.gov.scot**

Any enquiries regarding this publication should be sent to us at
The Scottish Government
St Andrew's House
Edinburgh
EH1 3DG

ISBN: 978-1-83960-130-9 (web only)

Published by The Scottish Government, September 2019

Produced for The Scottish Government by APS Group Scotland, 21 Tennant Street, Edinburgh EH6 5NA
PPDAS619010 (09/19)